Crowned Ridge Wind, LLC Response to Staff Data Request 5-2

5-2 Please identify if an ice detector and/or ice detection system will be used for the wind turbines. If an ice detection system will be used, please explain what turbine parameters will be monitored and how the turbine's control system will know when ice is accumulating on the blades.

Response: Yes, an ice detector and ice detection system will be used for all Crowned Ridge Wind wind turbines. More specifically, the turbine is capable of detecting ice buildup on the blades by activating sensors that compare wind speed, ambient temperature and rotor (blade) rpm to the power output of the turbine. If the ice buildup is at a level that causes the turbine output to be outside expected limits set by GE, the turbine will automatically shut down. In addition, ice buildup can be detected through higher than normal vibration, in which case the turbines will shut down automatically.

Technical Documentation
Wind Turbine Generator Systems
All Onshore Turbine Types

General Description

Setback Considerations for Wind Turbine Siting

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Table of Contents

1 Introduction

This document provides setback guidance for the siting of wind turbines. This guidance considers potential safety risks associated with wind turbines such as objects (maintenance tools, ice, etc.) directly falling from the wind turbine, unlikely occurrences such as tower collapse and blade failure, and environmental / operational risks such as ice throw. The guidance is general in nature, and is based on the published advice of recognized industry associations. Local codes and other factors may dictate setbacks greater than the guidance in this document. The owner and the developer bear ultimate responsibility to determine whether a wind turbine should be installed at a particular location, and they are encouraged to seek the advice of qualified professionals for siting decisions. It is strongly suggested that wind developers site turbines so that they do not endanger the public.

2 Falling Objects

There is the potential for objects to directly fall from the turbine. The objects may be parts dislodged from the turbine, or dropped objects such as tools. Falling objects create a potential safety risk for anyone who is within close proximity to the turbine, i.e., within approximately a blade length from the turbine.

3 Tower Collapse

In very rare circumstances a tower may collapse due to unstable ground, a violent storm, an extreme earthquake, unpredictable structural fatigue, or other catastrophic events. Tower collapse presents a possible risk to anyone who is within the distance equal to the turbine tip height (hub height plus ½ rotor diameter) from the turbine.

4 Ice Shedding and Ice Throw

As with any structure, wind turbines can accumulate ice under certain atmospheric conditions. A wind turbine may shed accumulated ice due to gravity, and mechanical forces of the rotating blades. Accumulated ice on stationary components such as the tower and nacelle will typically fall directly below the turbine. Ice that has accumulated on the blades will likewise typically fall directly below the turbine, especially during start-up. However, during turbine operation under icing conditions, the mechanical forces of the blades have the potential to throw the ice beyond the immediate area of the turbine.

5 Blade Failure

During operation, there is the remote possibility of turbine blade failure due to fatigue, severe weather, or other events not related to the turbine itself. If one of these events should occur, pieces of the blade may be thrown from the turbine. The pieces may or may not break up in flight, and are expected to behave similarly to ice thrown from the blade. Blade failure presents a possible risk for anyone beyond the immediate area of the turbine.

6 Industry Best Practices

Recognized industry practices suggest the following actions be considered when siting turbines in order to mitigate risk resulting from the hazards listed above:

- Place physical and visual warnings such as fences and warning signs as appropriate for the protection of site personnel and the public.
- Remotely stop the turbine when ice accumulation is detected by site personnel or other means. Additionally, the wind turbine controller may have the capability to shut down or curtail an individual turbine based on the detection of certain atmospheric conditions or turbine operating characteristics.
- Restrict site personnel access to a wind turbine if ice is present on any turbine surface such as the tower, nacelle or blades. If site personnel absolutely must access a turbine with ice accumulation, safety precautions should include but are not limited to remotely shutting down the turbine, yawing the turbine to position the rotor on the side opposite from the tower door, parking vehicles at a safe distance from the turbine, and restarting the turbine remotely when the site is clear. As always, appropriate personnel protective gear must be worn.

7 Setback Considerations

Setback considerations include adjoining population density, usage frequency of adjoining roads, land availability, and proximity to other publicly accessed areas and buildings. Table 1 provides setback guidance for wind turbines given these considerations. GE recommends using the generally accepted guidelines listed in Table 1, in addition to any requirements from local codes or specific direction of the local authorities, when siting wind turbines.

Setback Distance from center of turbine tower	Objects of concern within the setback distance
All turbine sites (blade failure/ice throw): 1.1 x tip height[1], with a minimum setback distance of 170 meters	- Public use areas - Residences - Office buildings - Public buildings - Parking lots - Public roads - Moderately or heavily traveled roads if icing is likely - Heavily traveled multi-lane freeways and motorways if icing is not likely - Passenger railroads
All turbine sites (tower collapse): 1.1 x tip height[1]	- Public use areas - Residences - Office buildings - Public buildings - Parking lots - Heavily traveled multi-lane freeways and motorways - Sensitive above ground services[2]
All turbine sites (rotor sweep/falling objects): 1.1 x blade length[3]	- Property not owned by wind farm participants[4] - Buildings - Non-building structures - Public and private roads - Railroads - Sensitive above ground services

Table 1: Setback recommendations

The wind turbine buyer should perform a safety review of the proposed turbine location(s). Note that there may be objects of concern within the recommended setback distances that may not create a significant safety risk, but may warrant further analysis. If the location of a particular wind turbine does not meet the Table 1 recommended guidelines, contact GE for guidance, and include the information listed in Table 2 as applicable.

1 The maximum height of any blade tip when the blade is straight up (hub height + ½ rotor diameter).

2 Services that if damaged could result in significant hazard to people or the environment or extended loss of services to a significant population. Examples include pipelines or electrical transmission lines.

3 Use ½ rotor diameter to approximate blade length for this calculation.

4 Property boundaries to vacant areas where there is a remote chance of future development or inhabitancy during the life of the wind farm.

Condition/object within setback circle	Data Required
If icing is likely at the wind turbine site	- Annual number of icing days
Residences	- Number of residences within recommended setback distance - Any abandoned residences within setback distance
For industrial buildings (warehouse/shop)	- Average number of persons-hours in area during shift - Number of work shifts per week - Any abandoned buildings within setback distance
For open industrial areas (storage/parking lot)	- Average number of persons-hours in area during shift - Number of shifts per week. - Any abandoned buildings within setback distance
For sports/assembly areas	- Average number of persons in area per day - Average number of hours occupied per day - Number of days area occupied per week - If area covered, what type of cover
For roads/waterways	- Plot of road/waterway vs. turbine(s) - Average number of vehicles per day - Type of road and speed limit (residential, country, # of lanes, etc.)
For paths/trails (walk, hike, run, bike, ski)	- Plot of paths/trails vs. turbine(s) - Average number # of persons per day by type of presence (walk, hike, etc.) - Flat or uneven/hilly terrain

Table 2: Setback recommendations

BEFORE THE PUBLIC UTILITIES COMMISSION
OF THE STATE OF SOUTH DAKOTA

IN THE MATTER OF THE APPLICATION OF
CROWNED RIDGE, LLC FOR A FACILITIES PERMIT TO
CONSTRUCTION 300 MEGAWATT WIND FACILITY

Docket No. EL19-003

REBUTTAL TESTIMONY AND EXHIBITS

OF CHRIS OLLSON

May 24, 2019

INTRODUCTION

Q. PLEASE STATE YOUR NAME AND BUSINESS ADDRESS.

A. My name is Chris Ollson. My business address is 37 Hepworth Crescent, Ancaster, Ontario, Canada.

Q. **BY WHOM ARE YOU EMPLOYED AND IN WHAT CAPACITY?**

A. I am the sole proprietor of Ollson Environmental Health Management. This consultancy provides expertise on environmental health challenges related to siting of energy projects (e.g., oil and gas, pipelines, gas plants, wind turbines, solar, transmission lines, and energy-from-waste). Clients include a mix of private sector companies and governments at all levels.

Q. **WHAT ARE YOUR RESPONSIBILITIES?**

A. I am a consultant to Crowned Ridge Wind, LLC ("CRW") on the scientific literature related to sound and shadow/flicker and proper siting of wind turbines to ensure the protection of health of residents.

Q. **ARE YOU THE SAME CHRIS OLLSON WHO SUBMITTED SUPPLEMENTAL TESTIMONY ON APRIL 10, 2019?**

A. Yes.

Q. HAS THIS TESTIMONY BEEN PREPARED BY YOU OR UNDER YOUR DIRECT SUPERVISION?

A. Yes.

Q. PLEASE DESCRIBE THE PURPOSE OF YOUR REBUTTAL TESTIMONY.

A. The purpose of my testimony is to respond to the direct testimony of Staff witness David Hessler and Intervenors' proposed conditions as set forth in Staff witness Darren Kearney's Direct Testimony, Exhibit DK-8.

Staff Witness Hessler's Testimony

Q. STAFF WITNESS HESSLER (TESTIMONY AT PAGE 5, LINES 4-7) ASSERTS THAT ANYTIME WIND TURBINES SOUND LEVELS ARE HIGHER THAN 40 DBA, RESIDENTS WILL COMPLAIN, AND THE SEVERITY OF THE COMPLAINTS WILL INCREASE EXPONENTIALLY AS THE SOUND LEVEL APPROACHES 50 DBA. ALSO, INTERVENORS HAVE PROPOSED CONDITIONS 19, 20, 21 (KEARNEY EXHIBIT DK-8) THAT WOULD LIMIT SOUND AT 40 DBA AT THE PROPERTY LINE OF A NON-PARTICIPATING PROPERTY OWNER. DOES THE SCIENTIFIC PEER REVIEWED LITERATURE OR GOVERNMENT REPORTS SUPPORT A 40 DBA SOUND LIMIT FOR NON-PARTICIPANTS?

A. No. The scientific literature published over the past decade from Europe and Canada showS that as wind turbine sound levels of sound increase over 40 dBA that there may be an increase in annoyance (not complaints) for some living around wind turbines. The level of annoyance certainly is higher for those non-participating homes at greater than 45 dBA.

To elaborate, noise-related annoyance from common sound sources is prevalent in many communities. For instance, results of national surveys in Canada and the U.K. by Michaud et al. (2005) and Grimwood et al. (2002) attached as Exhibit CO-R-1 and -2, respectively, suggested that annoyance from noise (predominantly traffic noise) might impact approximately 8% of the general population. Even in small communities in Canada (i.e., <5000 residents) where traffic is relatively light compared to traffic in urban centers, Michaud et al. (2005) reported that 11% of respondents were moderately to extremely annoyed by traffic noise. Importantly, annoyance is not a medical condition. It is not a recognized medical disease and it is not classified in the World Health Organization's International Statistical Classification of Disease and Related Health Problems 11th revision – ICD 11.

There have been a number of studies that have found that annoyance levels specific to wind turbine noise vary considerably upon whether one economically benefits. For example, Tables 3 and 4 from Bakker et al., 2012 (provided in my Supplemental Testimony as Exhibit CO-3) clearly indicate that the percentage of people that were rather/very annoyed of outdoor wind turbine noise (up to 54 dBA) that did not economically benefit was 12%, while it was only 3% for those who did economically benefit. In addition, no one who economically benefited from the wind project was rather/very annoyed with resulting indoor noise levels. This study, therefore, further supports that it is not the wind turbine noise itself that drives the annoyance state; rather, subjective factors such as visual cues and attitude are important.

Annoyance Levels in the Bakker et al., 2012 Study.

Table 3
Response to outdoor wind turbine sound among economically benefitting and non-benefitting respondents.

	Response											
	Do not notice		Notice, nor annoyed		Slightly annoyed		Rather annoyed		Very annoyed		Total	
	n	%	n	%	n	%	n	%	n	%	n	%
No economical benefit	255	44	184	31	78	13	41	7	28	5	586	100
Economical benefit	15	15	68	69	13	13	2	2	1	1	99	100

Table 4
Response to indoor wind turbine sound among economically benefitting and non-benefitting respondents.

	Response											
	Do not notice		Notice, not annoyed		Slightly annoyed		Rather annoyed		Very annoyed		Total	
	n	%	n	%	n	%	n	%	n	%	n	%
No economical benefit	394	68	98	17	46	8	21	4	20	4	579	100
Economical benefit	53	54	39	39	7	7	0	0	0	0	99	100

Furthermore, Michaud et al. (2018) (Exhibit CO-R-3) go on to state "Aggregate annoyance was effectively 0 (i.e., least squares mean − 0.11) among the 110 participants who reported to receive personal benefit from having wind turbines in the area, compared to an average of 1.93 among those who did not report such benefits." It is for these reasons I believe it is appropriate to set a 50 dBA limit for participating homes, because statistically landowners who economically benefit do not report annoyance from the wind turbines at levels over 50 dBA.

Further, a Canadian study (CO-Exhibit 11 in my Supplemental Testimony) concluded that:

> The results provide no evidence that self-reported or objectively measured stress reactions are significantly influenced by exposure to increasing levels of WTN up to 46 dB. There is an added level of confidence in the findings as this is the first study to date to investigate the potential stress impacts associated with WTN exposure using a combination of self-reported and objectively measured endpoints.

Therefore, at sound levels of 46 dBA wind turbine noise annoyance should not be considered a health impact and the level of annoyance falls within levels that we accept in our daily lives. Accordingly, Staff witness Hessler and the Intervenors advancement of a 40 dBA design standard is not supported by the weight of scientific evidence, because, regardless of the sound level being low in the Project area, it will result in some potential increase in annoyance in local populations. However, the annoyance level would be considered acceptable given:

- the annoyance level is similar to that of other forms of noise sources and approximately (e.g., road, rail, airplane);
- it is being influenced by other factors, including attitudes and visual cues with respect to the turbines themselves, and that it is not the noise itself that is driving this annoyance; and,
- that in the largest of its kind study by Health Canada (supported by past research) living with wind turbine noise <46 dBA was not associated with self-reported or physical measures of health or well-being.

Thus, the scientific literature does not support Intervenors' proposed conditions imposing a 40 dBA sound limit for non-participants nor Staff witness Hessler's position that the project should be viewed from the perspective of whether it is meeting 40 dBA for non-participants.

Q. EVEN IF WIND TURBINE ANNOYANCE DOES NOT LEAD TO HEALTH EFFECTS AT 45 dBA CAN IT ADVERSELY AFFECT QUALITY OF LIFE FOR THOSE LIVING NEAR WIND TURBINES?

A. The science shows that noise at 45 dBA poses no impact to quality of life. Determining if annoyance or any other perceived health effects for those living around wind projects has also been examined by determining if there has been a diminishment in their overall quality of life ("QOL"). This relates directly to whether annoyance leads to a deterioration of QOL.

Feder et al. (2015) conducted an assessment of quality of life using the WHOQOL-BREF among participants living in the vicinity of wind turbines Journal of Environmental Research. (Health Canada) (Exhibit CO-R-4), a World Health Organization Quality of Life – BREF (WHOQOL-BREF) administered a questionnaire to 1238 participants that lived between 820 feet to 7 miles away from wind turbines. This questionnaire evaluates self-reported physical health, psychological, social relationships, and environment in relation to QOL. Regardless of sound level at people's homes wind turbine noise did not influence QOL. The authors stated:

> The present study findings do not support an association between exposure to WTN up to 46 dBA [820 ft] and any of the WHOQOL-BREF domains (Physical Health, Psychological, Social Relationships and Environment) or the two stand-alone questions pertaining to rated QOL and Satisfaction with Health. Participants who were exposed to higher WTN levels did not rate their QOL or Satisfaction with Health significantly worse than those who were exposed to lower WTN levels, nor did they report having significantly worse outcomes in terms of factors that comprise the 4 domains.

Overall, the recent work by Health Canada suggests that quality of life should not be diminished for non-participating residents around the CRW project.

Q. STAFF WITNESS HESSLER'S TESTIMONY AT PAGE 5 LINES 17 TO PAGE 6 LINE 5 CLAIMS THAT CRW SHOULD MOVE 16 PRIMARY TURBINE LOCATIONS TO ALTERNATIVE LOCATIONS TO REDUCE THE DBA FOR NON-PARTICIPANTS FROM A RANGE OF 43-45 DBA TO 41 OR 42 DBA.

DOES THE SCIENTIFIC PEER REVIEWED LITERATURE OR GOVERNMENT REPORTS SUPPORT THE NEED TO REDUCE THE DBA AS HE PROPOSES?

A. There is no evidence in the scientific literature that a minor shift in noise levels from wind turbines from 43-45 to 41-42 dBA would change annoyance levels or complaint numbers. Such fine-tuning has not been reported in any of the literature. Knowing that the human ear can barely perceive a change in sound at 3 dBA it is unlikely that such a change would even be perceptible.

Most importantly, as stated above the bulk of the peer-reviewed scientific literature has demonstrated that the sound level itself does not contributing to the annoyance (or potentially complaints), rather it is visual cue and attitude that play a larger role. Therefore, such an arbitrary minor modification to sound levels is not supported by the scientific literature.

Intervenors' Proposed Conditions

Q. THE INTERVENORS' PROPOSED CONDITION 1 (KEARNEY EXHIBIT DK-8) WOULD REQUIRE THAT THERE BE A 2 MILE SETBACK FROM ALL NON-PARTICIPATING LANDOWNERS. IS SUCH A CONDITION SUPPORTED BY THE SCIENTIFIC PEER REVIEWED LITERATURE OR GOVERNMENT REPORTS?

A. No. As previously described in my Supplemental Testimony the appropriate manner in which wind turbine setbacks should governed is by sound limits at the exterior of the homes. To achieve the 45 dBA limit at non-participating homes it effectively requires a minimum setback distance of approximately 2000 feet. There is no peer reviewed scientific literature that supports the need for a 2 mile set back.

Q. THE INTERVENORS' PROPOSED CONDITION 2 (KEARNEY EXHIBIT DK-8) REQUIRES THAT THERE BE A 2 MILE SETBACK FROM THE WAVERLY SCHOOL TO PROTECT CHILDREN FROM DISTURBANCES FROM THE PROJECT WHILE IN THEIR LEARNING ENVIRONMENT. IS SUCH A CONDITION SUPPORTED BY THE SCIENTIFIC PEER REVIEWED LITERATURE OR GOVERNMENT REPORTS?

A. No. In 2008, Shield & Dockrell (Exhibit CO-R-5) published a paper in the Journal of the Acoustical Society of America (<u>The effects of environmental and classroom noise on the academic attainments of primary school children</u>.) In this paper, they describe the typical level of noise a child would experience in a primary school classroom:

> For much of the day in a primary school classroom, young children are exposed to the noise of other children producing "classroom babble" at levels typically of around 65 dBA LAeq, while the typical overall exposure level of a child at primary school has been estimated at around 72 dBA LAeq.

The modeled sound level at Waverly School was 39 dBA and the closest turbine is 6,207 feet away. At this setback distance, the sound level at the exterior of the school would be well below typical sound levels already experienced in the classroom. Given that the average sound level in a primary classroom (without external noise) is 65 dBA, and that the modeled sound level is 39.1 dBA at the exterior of the school the resulting sound would not be audible inside the classroom, even with windows open. Accordingly, there would be no additional benefit to setting wind turbines back two miles from the school.

Q. A NUMBER OF THE INTERVENORS' PROPOSED CONDITIONS (KEARNEY EXHIBIT DK-8) REQUIRE THE MEASUREMENT AND MONITORING OF INFRASOUND. ARE THESE CONDITIONS SUPPORTED BY THE SCIENTIFIC PEER REVIEWED LITERATURE OR GOVERNMENT REPORTS?

A. No. As previously described in my Supplemental Testimony, although infrasound is emitted from wind turbines it is at a level well below the perception threshold and the limited number of international general standards for infrasound (not specific to wind turbines). Although infrasound is not modeled for wind turbine projects the level of infrasound at varying distances from wind turbines can be predicted based on previous measurements in the scientific literature. These levels have been demonstrated to be well below any international infrasound standards at even 1000 feet from wind turbines. As stated by the Ministry for the Environment, Climate and Energy of the Federal State of Bade Wuerttemberg in Germany (Exhibit CO-R-6) "adverse effects relating to infrasound from wind turbines cannot be expected on the basis of the evidence at hand." Therefore, there would be no need to measure or monitor infrasound levels from the Crowned Ridge Wind project to ensure the protection of health.

Q. A NUMBER OF THE INTERVENORS' CONDITIONS (KEARNEY EXHIBIT DK-8) ARE PREMISED ON PEOPLE COMPLAINING ABOUT PHYSICAL CONDITIONS OR HEALTH ISSUES THEY BELIEVE ARE BROUGHT ON BY THE CRW WIND PROJECT. DOES THE SCIENTIFIC PEER REVIEWED LITERATURE OR GOVERNMENT REPORTS SUPPORT IMPOSING

CONDITIONS BECAUSE PEOPLE MAY ATTRIBUTE A PHYSICAL OR HEALTH ISSUE TO THE CRW WIND PROJECT?

A. As stated in my Supplemental Testimony an exterior sound limit of 45 dBA at non-participating homes is sufficient to ensure the protection of health of the residents. The scientific studies, including those published by Health Canada (the Michaud papers) indicate that both objective and subjective measures of health are not impacted by wind turbine sound at 45 dBA at the exterior of non-participating homes.

In addition, the phenomenon of complaints associated with those who previously opposed wind projects has been studied in Australia. In 2013, Chapman et al., published (Exhibit CO-R-7; The Pattern of Complaints about Australian Wind Farms Does Not Match the Establishment and Distribution of Turbines: Support for the Psychogenic, 'Communicated Disease' Hypothesis.) This paper demonstrated that the majority of wind projects generated no complaints from surrounding landowners. However, they reported:

> The large majority 116/129(90%) of complainants made their first complaint after 2009 when anti wind farm groups began to add health concerns to their wider opposition. In the preceding years, health or noise complaints were rare despite large and small-turbine wind farms having operated for many years.

Professor Chapman and his colleagues concluded:

> The reported historical and geographical variations in complaints are consistent with psychogenic hypotheses that expressed health problems are "communicated diseases" with nocebo effects likely to play an important role in the aetiology of complaints.

In other words, those who opposed the wind farms prior to their construction and were concerned about health impacts are far more likely to file complaints and mistakenly attribute symptoms to the operation of the wind project.

Q. THE INTERVENORS' PROPOSED CONDITION 19 (KEARNEY EXHIBIT DK-8) WOULD REQUIRETHAT "NO FLICKER SHALL BE ALLOWED TO CROSS NON-PARTICIPATING LANDOWNER'S PROPERTY LINE." IS SUCH A CONDITION SUPPORTED BY THE SCIENTIFIC PEER REVIEWED LITERATURE OR GOVERNMENT REPORTS?

A. No. As previously described in my Supplemental Testimony shadow flicker does not impact health. Shadow flicker limits at homes have been developed to reduce any undue nuisance effect for residents. Shadows cast by wind turbines on open spaces or fields does not result in a "flicker effect", similar to that which can be experienced in enclosed rooms in a home. Instead it can be observed as an intermittent shadow on the ground (e.g., in a field) that does not cause annoyance. There have been no scientific reports that such shadows produce an annoyance for neighboring properties.

Q. DOES THIS CONCLUDE YOUR REBUTTAL TESTIMONY?

A. Yes, it does.

Noise Annoyance in Canada

D.S. Michaud[1], S.E. Keith[1] and D. McMurchy[2]

[1]*Consumer and Clinical Radiation Protection Bureau, Health Canada, Ottawa, Ontario, Canada*
[2]*Dale McMurchy Consulting, Box 252, Norland, Ontario, Canada*

The present paper provides the results from two nation-wide telephone surveys conducted in Canada on a representative sample of 5,232 individuals, 15 years of age and older. The goals of this study were to gauge Canadians' annoyance towards environmental noise, identify the source of noise that is viewed as most annoying and quantify annoyance toward this principal noise source according to internationally accepted specifications. The first survey revealed that nearly 8% of Canadians in this age group were either very or extremely bothered, disturbed or annoyed by noise in general and traffic noise was identified as being the most annoying source. A follow-up survey was conducted to further assess Canadians' annoyance towards traffic noise using both a five-item verbal scale and a ten-point numerical scale. It was shown that 6.7% of respondents indicated they were either very or extremely annoyed by traffic noise on the verbal scale. On the numerical scale, where 10 was equivalent to "extremely annoyed" and 0 was equivalent to "not at all annoyed", 5.0% and 9.1% of respondents rated traffic noise as 8 and above and 7 and above, respectively. The national margin of error for these findings is plus or minus 1.9 percentage points, 19 times out of 20. The results are consistent with an approximate value of 7% for the percentage of Canadians, in the age group studied, highly annoyed by road traffic noise (i.e. about 1.8 million people). We found that age, education level and community size had a statistically significant association with noise annoyance ratings in general and annoyance specifically attributed to traffic noise. The use of the International Organization for Standardization/Technical Specification (ISO/TS)-15666 questions for assessing noise annoyance makes it possible to compare our results to other national surveys that have used the same questions.

Keywords: telephone survey, annoyance, noise, traffic, Canada, ISO/TS-15666

Introduction

Noise can be defined as unwanted sound and is commonly associated with annoyance reactions. Environmental noise is ubiquitous and annoyance is one of the most widely studied adverse reactions to noise. According to the World Health Organization (WHO), health should be regarded as "a state of complete physical, mental and social wellbeing and not merely the absence of disease or infirmity" (World Health Organization 2001). Under this broad definition, noise-induced annoyance is an adverse health effect. As with any psychological reaction, annoyance has a wide range of individual variability, which is influenced by multiple personal and situational factors (Fields 1993, Broadbent 1972). On a community scale, however, annoyance is more uniform so that estimating community annoyance is possible through the use of established dose-response curves. The relationship between day-night sound level (Ldn) and the percentage of an exposed population highly annoyed by any transportation noise source was first given by Schultz as a single curve (Schultz 1978)[1]. The term "highly annoyed" refers to a response to a social survey question on noise annoyance with a response in the top 27 to 29% on an anchored numerical scale or in the top two categories on an adjectival, five point verbal scale (Schultz 1978). The Schultz curve has been updated

[1] *%Highly annoyed=0.8553Ldn - 0.0401Ldn^2 + 0.00047Ldn^3*

(Finegold and Finegold 2002)[2] (Fidell et al. 1991)[3] and separate relationships are also available for aircraft, road traffic and electric rail (Miedema and Oudshoorn 2001)[4] (ISO 2003)[5]. In the ISO standard for assessment procedures for environmental noise the percent highly annoyed is obtained from the rating level (RL) using equation:

%highly annoyed = 100/[1+exp(10.4-0.132*RL)]

where, RL is typically an adjusted Ldn[6], with adjustments made depending on the type of noise source. In the ISO standard, the relationship for road traffic noise is obtained when RL equals Ldn. The resulting curve nearly coincides with Schultz's original curve.

International estimates of exposure to road traffic noise have been made for Europe, Australia and the U.S. In 1996, it was estimated that, in Europe, 40% of the population was exposed to traffic sound levels between 45-65dBA (Ldn) and 20% (nearly 80 million people) were exposed to levels over 65dBA (Commission of the European Communities 1996). In Australia, approximately 8% of the population was exposed to outdoor road traffic noise levels greater than 65dBA during daytime hours (OECD 1991). In 1986, the Organization for Economic Co-operation and Development (OECD) estimated that 30% of the U.S. population was exposed to a 24 hr time-averaged (Leq24) traffic noise level between 55-65dBA and 7% was exposed to traffic levels above 65 dBA (Leq24) (OECD 1986). Eldred (1990) estimated that 138 million Americans were exposed to outdoor day-night sound levels above 55dBA, with more than 25 million U.S. citizens exposed to levels above 65dBA (Eldred 1990).

International estimates of road traffic noise annoyance from social surveys have also been made for several European countries. Estimations of road traffic noise annoyance from Austria and France (annoyed), Germany (severely affected) and the Netherlands (highly annoyed) range from 20% to 25% of the respective populations (Commission of the European Communities 1996, INRETS 1994). A recent national survey in the United Kingdom (UK) found that between 7-9% of the population was either very or extremely bothered, annoyed or disturbed by traffic noise (Department for Environment, Food and Rural Affairs 2002).

There has been a gap in our knowledge as to how Canada compares to international estimates of annoyance and noise exposure. Only by comparison to Australian data (OECD 1991) has it recently been estimated that about 2 million Canadians live in areas where road traffic noise exceeds Leq24 outdoor levels of 65 dBA (Health Canada 2001).

Comparing results from different surveys on annoyance is difficult because of differences in methodology, which include variability in reporting high annoyance (Finegold and Finegold 2002). As an attempt to circumvent this problem, the ISO/TS-15666 proposed that socio-acoustic surveys incorporate two standardized questions aimed at assessing annoyance (ISO 2001). Our objectives for the present study were to use these standardized questions in order to assess noise annoyance in Canada and characterize the source that was most annoying.

Methods

Subject sampling

The two surveys each entailed a probability

---

2 *%Highly annoyed=100/[1+exp(11.13 - 0.141Ldn)]*

3 *%Highly annoyed= 78.9181 - 3.2645Ldn + 0.0360Ldn²*

4 *%Highly annoyed (aircraft) = -1.395*10 $^{-4}$(Ldn-42)^3 + 4.081*10 $^{-2}$(Ldn-42) + 0.342(Ldn-42)*

5 *%Highly annoyed (road traffic) = 9.994*10 $^{-4}$(Ldn-42)^3 - 1.523*10 $^{-2}$(Ldn-42)^2 + 0.538(Ldn-42)*

*%Highly annoyed (rail) = 7.158*10 $^{-4}$(Ldn-42)^3 - 7.774*10 $^{-3}$(Ldn-42)^2 + 0.163(Ldn-42)*

%Highly annoyed= 100/[1 + exp(10.4 - 0.132Ldn)]

6 *The number of daylight hours is 15, defined as the hours from 07:00-22:00 (ISO 2003)*

sample of approximately 2,600 Canadians 15 years and older, using the Waksberg-Mitofsky technique for random digit phone number selection. Most provinces were allocated a sample size reflecting a 5% margin of error and a 95% confidence interval; the Atlantic Provinces had smaller sample sizes and were grouped together for the purposes of analysis. For each region, the sample was then distributed among community strata according to their relative contributions to the overall provincial population. The five community strata used were as follows: i) less than 5,000; ii) 5,000-9,999; iii) 10,000-29,999; iv) 30,000-99,999; and v) 100,000-999,999. A sixth stratum was added for cities with a population over 1 million residents (Montreal, Toronto and Vancouver). Each respondent indicated the population of their community. Random digit dialing was used to generate potential telephone numbers and one subject within each household was selected using the Troldahl-Carter technique. This technique ensures that the sample accurately represents the eligible population according to its age and sex structures (Troldahl and Carter 1964). Once a potential respondent was chosen using this technique, no other person in the household could be substituted as a respondent. Upon completion of the survey, data were also weighted within provinces by age, sex and community size. Additionally, they were weighted nationally to reflect each province's relative contribution to the overall Canadian population. The national margin of error for this study is plus or minus 1.9 percentage points in 19 samples out of 20.

Telephone Survey #1

In the spring of 2002, PricewaterhouseCoopers Consulting™ performed a telephone survey for Health Canada wherein a randomized sample of 2,565 Canadians, age 15 and older, responded to a questionnaire on health, their experience with the health care system and health policy. The response rate to this survey was 33%. The questionnaire, that required 20-25 minutes to complete, contained the two following noise-related questions: *Over the past 12 months or so, when you are at home, how much are you bothered, disturbed, or annoyed by noise from outside your home?* Subjects were given the following response options: *Extremely, Very, Moderately, Slightly or Not at all.* The following open-ended question was asked to identify which source Canadians were most annoyed with: *What type of noise from outside your home bothers disturbs or annoys you the most?*

Telephone Survey #2

A follow-up telephone survey was conducted for Health Canada in December of 2002 by IBM Business Consulting Services™. This survey employed the same methodology as the first survey and the questionnaire was similar in content and length as the first and the response rate was 32%. However, the noise questions in this case specifically probed attitudes towards traffic noise, since this was the source identified as most annoying in the first survey. In accordance with the recommendations provided by ISO/TS-15666 the following two questions were asked to the randomized sample of 2,667 Canadians 15 years of age and older: *Thinking about the last 12 months or so, when you are at home, how much does noise from road traffic bother, disturb, or annoy you?* Again, subjects were asked to respond with one of the following options: *Extremely, Very, Moderately, Slightly or Not at all*. An important methodological shortcoming to the verbal scale is that the response categories do not necessarily engender the same meaning between individuals. As a way of checking this possibility the ISO/TS-15666 suggests that a second question with a numerical scale be used to validate the response obtained to the first question. Thus, in this survey the verbal question was followed by the following question: *Thinking about the last 12 months or so, what number from zero to ten best shows how much you are bothered, disturbed or annoyed by road traffic noise?* Prior to asking this question, the interviewer indicated to the respondent that *zero* is equivalent to "not at all bothered" and *ten* is equivalent to "extremely bothered".

Statistics

Univariate and bi-variate (cross-tabulations and t-tests) analyses were employed using statistical data management software, SPSS® version 11.5.

Table 1. Demographic characteristics of responses to the following question: Over the past 12 months or so, when you are at home, how much are you bothered, disturbed, or annoyed by noise from outside your home?

		Extremely (n)	Very (n)	Moderately (n)	Slightly (n)	Not at all (n)
Number of respondents (percentage of total N=2573)		108 (4.2)[7]	95 (3.7)	407 (15.8)	700 (27.3)	1257 (49.0)
Sex	male	52	30	192	364	662
	female	55	65	215	336	595
Age (years)	15-24	38	35	120	280	404
	25-44	38	38	155	234	362
	45-64	20	17	98	127	292
	65+	12	5	33	59	199
Gross salary (x1000/yr)	<20	22	24	94	153	229
	20-50	36	32	150	201	378
	>50	33	20	119	230	407
Education Level	<secondary	8	3	21	9	92
	secondary	57	25	151	335	565
	>secondary	41	67	230	355	594
Employment Status	not working	48	37	131	300	517
	working	59	59	275	399	739
Community Size (estimated by respondent)	<5,000	10	3	35	55	241
	5,000-99,999	6	8	91	125	249
	100,000+	92	84	281	520	768
Self-reported health status	poor-fair	25	11	66	118	176
	excellent-good	82	85	341	573	1080

7 Cells for each variable may not always add to the corresponding sample size because respondents could choose to not answer questions.

Results reported were statistically significant at the 0.05 level. Where multiple variables were significant and deemed relevant, logistic regression was employed to identify those factors most predictive of the various outcomes.

Results

Table 1 shows that about 8% of the sample indicated that they were either very or extremely bothered, disturbed or annoyed by noise outside their home, whereas nearly half of the respondents (49%) were not at all bothered. The major findings presented in Table 1 indicate that there was a statistically significant relationship between age, community size, education and sex with the level of annoyance. People 65 and over were the least likely to be annoyed by noise and the larger the respondent's community size, the more likely he or she was to be very or extremely disturbed by noise. Females were more likely to respond that they were slightly to extremely annoyed by noise compared to males. Finally, respondents with greater than secondary education were the least likely to respond that they were slightly or not at all annoyed by noise compared to those with a secondary or less then secondary education.

Table 2 shows the breakdown of the sources that respondents identified as being most annoying.

Table 2. The percentage of people annoyed the most by a particular type(s) of noise as a function of the extent to which they were bothered by noise in general.

Type of noise [8]	extremely (n=108)	very (n=95)	moderately (n=407)	slightly (n=700)	not at all (n=1257)
Road traffic	39.9	37.6	51.8	44.9	17.9
Animals outside	25.8	3.5	10.0	11.1	6.6
Other people outside	16.2	23.0	12.4	9.8	2.2
Off road traffic	7.0	13.2	4.2	7.6	2.5
Children outside	5.9	13.8	9.7	5.0	2.2
Trains	4.4	0.8	7.2	6.9	1.5
Neighbor's Music/TV (in/outside their home)	10.1	15.1	6.9	2.9	2.0
Construction work	7.3	11.0	3.5	4.1	2.6
Social events	6.6	9.3	5.0	5.3	0.7
People/animals from inside another dwelling	12.3	8.6	3.9	2.7	1.6
Aircraft	7.2	1.7	1.9	3.9	1.7
Snow removal	0.4	3.3	3.9	3.1	1.2
Alarms	1.9	3.9	2.3	0.6	2.7
Factories/machinery	5.6	0.2	2.5	3.4	0.8
Garden equipment	0.0	5.1	1.0	1.8	1.4
Farming machinery	8.9	0.1	0.3	0.0	0.3
Power tools	0.6	1.7	0.2	0.5	0.5
Subways	0.0	1.7	0.3	0.0	0.3
Other	7.7	17.1	5.9	5.8	12.0

[8] *Columns may not add to 100% because respondents were free to identify more than one source of noise.*

It is apparent that traffic noise is the most significant source of noise annoyance in Canada.

Results from the December survey were intended to further probe Canadians' annoyance towards traffic noise. The major findings were that, while nearly 7% of the respondents indicated that they were either very or extremely bothered by traffic noise, almost 63% were not at all bothered. Figure 1, panel A, shows the distribution of annoyance towards traffic noise. In this survey, respondents also had the opportunity to indicate how annoyed they were with traffic noise on a ten-point numerical scale, where zero represented "not at all annoyed" and ten represented "extremely annoyed". These results are presented in Figure 1, panel B. Panel C, in Figure 1 presents the results from the numerical scale collapsed according to the following breakpoints (0+1=not at all; 2+3=slightly; 4+5+6=moderately; 7+8=very and 9+10=extremely). Collapsing the numerical scale in this way yielded a correlation coefficient of 0.765 ($p<0.001$) between panel A and panel C.

Table 3 shows how annoyance ratings varied as a function of community size. Not surprisingly, annoyance towards traffic noise increased as function of community size so that almost 78% of the respondents from communities with less than 5,000 people were not at all annoyed by traffic noise, compared to only 58% of the respondents in communities with more than 100,000 residents. In communities with more

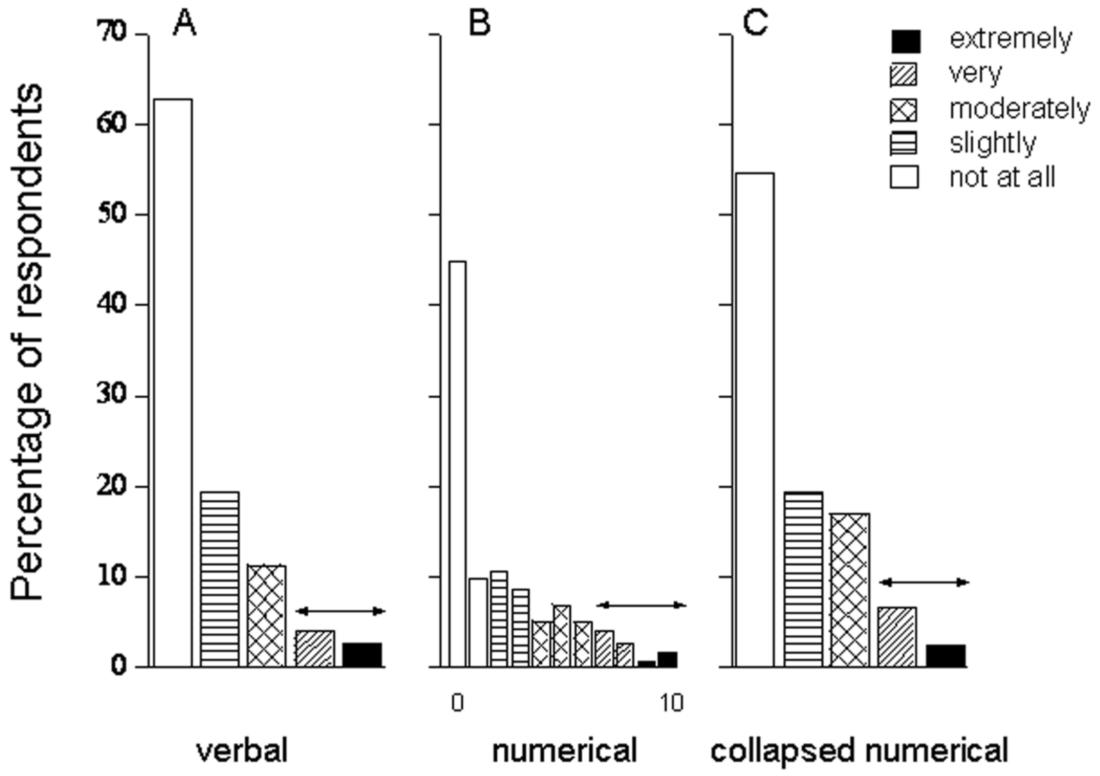

Figure 1. The distribution of self-reported annoyance towards traffic noise among respondents interviewed in the 2nd telephone survey using the ISO/TS 15666 recommended questions for assessing community annoyance. Panel A, shows the response on the verbal scale, Panel B shows the range of annoyance on the ten-point numerical scale and Panel C presents the results from the numerical scale collapsed according to the following breakpoints (0+1=not at all; 2+3=slightly; 4+5+6=moderately; 7+8=very and 9+10=extremely). Collapsing the numerical scale in this manner yielded a correlation coefficient of 0.765 ($p<0.001$) between panel A and panel C. Bars with arrowheads on each panel delineate the range of respondents considered "highly annoyed".

than 100,000 people, approximately 20% of respondents were moderately to extremely annoyed by traffic noise, compared to only 11% in communities with less than 5,000 residents.

Females were not only more annoyed by noise than males in general, but were 1.5 times more likely to be annoyed by traffic noise in particular. The average response from females on the numerical scale was 2.37 compared to 1.93 for males. Age and income had a statistically significant influence on respondent's annoyance ratings towards traffic noise. Individuals 65 and over were more likely to respond "not at all" annoyed and individuals between 25 and 44, were least likely to respond this way. Those in the middle-income bracket ($20,000-$49,999) were significantly more likely to be annoyed by traffic noise than respondents with incomes below and above this level. While almost three-quarters of those with less than a secondary education were not at all bothered by traffic

Table 3. The extent to which Canadians are bothered, annoyed or disturbed by road traffic noise as a function of community size.

		% Not at all	% Slightly	% Moderately	% Very	% Extremely
< 5,000	N=344	77.6	11.6	7.6	2.3	0.9
5,000-99,000	N=510	70.6	13.3	10.4	3.9	1.8
100,000+	N=1836	57.7	22.5	12.1	4.2	3.3

noise compared to 60% of those with a post-secondary education, no significant difference was found among education levels when those responding "slightly" and "not at all" were considered together. Another interesting observation was that individuals who rated their health as only fair or poor had a significantly higher mean rating on the numerical scale compared to those who said their health was good or excellent indicating that for traffic noise they had a greater level of annoyance (2.47 versus 2.09, respectively).

Discussion

There is no doubt that transportation noise can represent a significant source of annoyance. Efforts to reduce annoyance towards environmental noise should be greatly improved by an understanding of the pervasiveness of the annoyance. To our knowledge, the present study represents the first attempt to estimate noise annoyance in Canada using a national survey. Statistics Canada estimates that the Canadian population 15 years of age and over in 2003 was approximately 26 million (Statistics Canada 2004). Thus, our results suggest that nearly 2.1 million Canadians 15 years of age and over (+/- approximately 400,000) are either very or extremely annoyed by noise in general, and that 1.8 million Canadians 15 years of age and over (+/- 350,000) are similarly annoyed by traffic noise. It follows that the greatest reduction, nationally, in annoyance can be expected from efforts aimed towards reducing traffic noise in Canada. Our results are comparable to that obtained in the national survey conducted in the UK where it was found that 8% of the population was either very or extremely annoyed by traffic noise (BRE Environment 2002). This is an interesting comparison because the population of the UK in mid-2000 was about double that of Canada (Office for National Statistics 2003).

Our results indicate that traffic noise annoyance was greater among women and individuals with a higher income, and is lower among those 65 and over. In this study, education was no longer statistically associated with the level of traffic noise annoyance when the categories "slightly" and "not at all" were collapsed. However, these results were not entirely consistent with those of Fields (1993) in his review of the personal and situational factors contributing to noise annoyance. He found that education, income and age had no influence on annoyance ratings (Fields 1993). Our results are similar to a community study conducted in Canada 25 years ago that showed annoyance towards traffic noise was greater among residents classified as having a higher socioeconomic status (Bradley 1979). A higher socioeconomic status may be correlated with annoyance inasmuch as higher social status may be associated with a greater expectation of quiet, but this remains to be confirmed.

A recent study by (Ohrstrom 2004) showed the effectiveness of reducing annoyance by reducing traffic volume in a community in Sweden. In her longitudinal study, 58% of the exposed community was very annoyed by traffic noise caused by 25,000-30,000 vehicles per day (Leq-24hr = 67 dBA) and the average numerical rating on the 10-point annoyance scale was 8.9[9]. When traffic volume was reduced to 2,400 vehicles per day (Leq-24hr = 55dBA) the percentage highly annoyed dropped to 6.7% and the average numerical rating fell to 1.4. Not surprisingly, the reduction in traffic noise annoyance corresponded to an overall improvement in self-assessed general well-being. It is notable that it has been estimated that about 2 million Canadians are exposed to traffic noise levels in the range reported in Ohrstrom's study, before traffic volume was reduced (i.e. Leq24 > 65dBA). Based on the ISO curve (ISO 2003) though, it would not be expected that as many as 58% of these 2 million Canadians are very or extremely annoyed with traffic noise; non-acoustic variables likely contributed to annoyance in Ohrstrom's study sample (2001).

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9 *Using the dose-response curve recommended by ISO 1996-1: 2003, an Leq(24) of 67dBA would be associated with high annoyance in approximately 21% of the exposed community.*

Our findings provide a basis for establishing a full-scale national socio-acoustic survey similar to the UK study (BRE Environment 2002). This could further identify Canadian's concerns towards noise and, in turn, help devise strategies targeted at reducing annoyance. For instance, it was revealed in the UK survey that what specifically annoyed people the most about traffic was accelerating or speeding vehicles (BRE Environment 2002). In our initial survey we attempted to identify the sources which annoyed people the most, but among the 7.9% of respondents that were either very or extremely annoyed by noise in general, nearly 25% of them identified a type of source that was not one of the 18 sources listed in Table 2. More research could also help identify these unknown sources and target them to reduce annoyance among those highly annoyed.

Since acoustic variables may account for one third of the variance in annoyance, (Guski 1999) the present study would be improved if estimating respondent's noise exposure were possible. Future questions could specifically ask subjects how close they are to traffic and how often they are exposed. This would enable an estimate of the extent to which the noise levels correlate with annoyance scores.

The first survey was initiated as a pilot study to gauge Canadian's annoyance toward noise in general. It is of interest that among the 1257 respondents that indicated they were not at all annoyed by noise, 225 of them identified traffic as one of the sources that bothers, disturbs or annoys them the most. At first this finding seems paradoxical. It should be noted, however, that although everyone was asked both questions, most respondents that were not at all annoyed by noise in general did *not* provide a source that annoyed them the most. Thus, it is possible that one identifies traffic as the most annoying source of noise after indicating they are not at all annoyed by noise because 1) they have an expectation of the noise source that people would indicate as most annoying and they conform to this or 2) they find traffic so annoying that they effectively eliminate annoyance by avoiding the source that is most annoying.

Some caution should be made in comparing the results we obtained in the December survey to those conducted during warmer months since indoor noise exposure levels may be reduced in December with closed windows and people are more likely to be indoors during colder months. Although respondents are specifically instructed to respond based on their experience over the last 12 months or so, this may not fully account for seasonal effects. Seasonal effects on noise annoyance have been shown to account for as much as 10% of the variability in annoyance (Fields *et al.* 2000). Still, our results remain comparable to those obtained in the UK study since it was conducted in December/January.

For both surveys, the response rate was around 33%. Although this is common for public opinion research that utilizes random digit dialing (O'Rourke *et al.* 1998), we cannot rule out the possibility that selection bias may have had an impact on our results. It is important to note, though that a respondent's decision to participate or refuse to participate in the telephone survey was made without any knowledge that the survey would contain questions related to environmental noise. Furthermore, follow-up calls were made to individuals with soft refusals and numbers with no initial response.

The results of this study provide a basis for a more elaborate socio-acoustic survey that contains questions designed to estimate the respondent's level of noise exposure to transportation noise and to understand what non-auditory factors contribute to environmental noise annoyance. An ideal study would be supplemented with environmental noise mapping to better calculate how noise levels correlate with annoyance.

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The UK National Noise Attitude Survey 1999/2000

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The UK National Noise Attitude Survey 1999/2000

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Summary

A survey of community response to environmental noise involving over 5,000 respondents has recently been completed and has established a year 2000 benchmark for community response to noise in the UK. This paper presents some of the key findings. The survey was undertaken for the Department for Environment, Food and Rural Affairs and the Devolved Administrations. The survey design involved two parallel population samples and two different noise attitude questionnaires. One of the questionnaires had been used previously in England and Wales during 1991, allowing us to investigate changes in attitudes to noise over the last 10 years.

The key findings from this research should be considered in the following context:
- 69% of respondents reported general satisfaction with their noise environment.
- 57% of respondents reported that noise did not at all spoil their home life.
- noise was ranked 9th in a list of 12 environmental problems.

Nevertheless:
- 21% of respondents reported that noise spoilt their home life to some extent, with 8% reporting that their home life was spoilt either '*quite a lot*' or '*totally*'.
- 84% of respondents heard road traffic noise and 40% were bothered, annoyed or disturbed to some extent.
- 28% of respondents reported that road traffic noise at their homes had got worse in the last five years; this should be considered alongside the trends in noise level and noise exposure found in the National Noise Incidence Study 00/01.
- 81% of respondents heard noise from neighbours and/or other people nearby and 37% were bothered, annoyed or disturbed to some extent.
- the proportion of respondents who reported being adversely affected by noise from neighbours has increased over the last 10 years, whilst for all other categories of environmental noise the proportion adversely affected has remained unchanged.
- only a small proportion of respondents who were bothered by noise from neighbours complained to the environmental health department of the local authority, which means that noise complaint statistics will greatly underestimate the extent of community dissatisfaction.

1 Introduction

The Department for Environment, Food and Rural Affairs commissioned BRE to carry out a research project with the following main objectives:
- to track changes in community attitude to environmental noise in England & Wales between 1991[1] and 1999.
- to obtain the best possible estimate of attitudes to environmental noise in the UK for 1999/2000.

- to investigate the importance of questionnaire design in noise attitude surveys.

Between November 1999 and February 2000, two sample groups, each approximately equivalent in size to that used in 1991, were interviewed in England and Wales; the first with the 1991 questionnaire, and the second with a new modular questionnaire. During October and November 2000, the survey using the new modular questionnaire was extended to include Scotland and Northern Ireland in order to estimate UK attitudes to environmental noise.

The sample used was a multi-stage clustered sample generated with probability of selection proportional to population at each stage, in order to obtain a sample representative of the national population. All respondents were adult householders, pre-selected from the electoral role, and all interviews were conducted face to face in their homes.

This paper presents some interesting findings from the National Noise Attitude Survey (NAS). Section 2 gives examples of the UK results using the new questionnaire. Section 3 gives examples of trends in community attitude to noise for England and Wales between 1991 and 2000. Further information on the studies is available in the full project reports, which are being made available on the web[2,3,4,5,6].

Throughout this paper, NAS91 refers to the 1991 questionnaire as used in 1991; NAS91_99 refers to the 1991 questionnaire being used in 1999 and NAS99 refers to use of the new 1999 modular questionnaire. Where appropriate, the survey results given in Annex A and B are shown with 95% confidence intervals.

2 Community attitude to noise in the UK

A new questionnaire, NAS99, was designed for the UK wide survey with a modular structure that is intended to allow the six supplementary sections dealing with various categories of environmental noise to be used independently of each other in the future. Numerous specific sources of environmental noise are embraced in the design through the use of showcards. Filter and ranking techniques are used to manage the overall length of interview and the size of subsamples. Supplementary sections on road traffic noise and neighbour noise were made mandatory for all respondents. A total of 2876 interviews were achieved, with an overall response rate of 63%. Some key findings from the UK survey are listed below.

- 18% of respondents reported noise as one of the top five from a list of environmental problems that personally affected them. Overall, noise was ranked ninth in this list of 12 environmental problems.
- 69% of respondents reported general satisfaction with their noise environment (i.e. liking the amount (or absence) of noise around them at home to some extent).
- 21% of respondents reported that noise spoilt their home life to some extent, with 8% reporting that their home life was spoilt either '*quite a lot*' or '*totally*'.
- 84% of respondents heard road traffic noise; 40% were bothered, annoyed or disturbed to some extent; 28% said it had got worse and 10% that it had got better over the past five years.

- 81% of respondents heard noise from neighbours and/or other people nearby; 37% were bothered, annoyed or disturbed to some extent; 14% said it had got worse and 15% that it had got better over the past five years.
- 71% of respondents heard noise from aircraft; 20% were bothered, annoyed or disturbed to some extent.
- 49% of respondents heard noise from building, construction, demolition, renovation or road works; 15% were bothered, annoyed or disturbed to some extent.
- the most commonly selected word (from a list of 21) used to describe the effects of noise was *irritated*; 30% of respondents selected this for road traffic noise and 25% for noise from neighbours.
- the evening (1900 – 2300) and night-time (2300 – 0700) periods are the times when the greatest proportion of respondents reported being particularly bothered, annoyed or disturbed by most types of noise from neighbours and/or other people nearby.
- only a small proportion of respondents who were bothered by the various specific sources of noise from neighbours complained to the environmental health department of the local authority. The most common action taken was to complain directly to the person responsible. In general, only a small proportion (usually less than 10%, although this depends on source) of respondents who were bothered contacted any department of the local authority. For all sources of noise from neighbours a greater proportion of respondents complained to the police rather than the environmental health department.

More details of these findings are illustrated in Annex A of this paper. The full reports should be consulted if further information, or a more detailed understanding, is required.

3 Trends in attitude to noise in England & Wales

The survey using the NAS91_99 questionnaire was designed to be as similar as possible to the survey first undertaken in England and Wales during 1991, hence enabling a direct assessment of changes in attitude to be made. The questionnaire used in 1999/2000 was identical to that previously used in 1991; the first part of the questionnaire gathered information on the noises heard whilst a second part asked further questions on up to 49 specific sources of environmental noise. The questionnaire design was intended to increase the likelihood of accurate response data for each specific noise source but has disadvantages in terms of the length of interview and the creation of small subsamples for certain noise sources. A total of 2534 interviews were achieved, with a response rate of 64%. Examples of the trends found for the most commonly heard sources of environmental noise are presented in the subsections below. Unless otherwise stated all trends are statistically significant at the 95% confidence level.

Respondents were asked if they heard a number of general categories and specific sources of environmental noise whilst at home. The main findings are:

- An increase in the proportion of respondents reporting hearing road traffic (from 48 to 54%).
- An increase in the number of respondents reporting hearing the following specific road traffic noise sources: *private cars/vans* (24 to 32%), *residential/estate roads* (10 to 14%), *police/other sirens* (10 to 14%), *vehicles starting/stopping/ticking over* (5 to 7%), *motorways* (1 to 6%).

- An increase in the proportions of respondents reporting hearing *neighbours* (19 to 25%) and *other people nearby* (15 to 21%).
- An increase in the number of respondents reporting hearing the following specific neighbour noise sources: *people's voices* (11 to 17%), *children* (9 to 16%), *radio/TV/hi-fi* (9 to 12%), *cars or motorcycles starting up/leaving/repairs* (6 to 10%), *doors banging* (5 to 7%) and *lawnmowers* (5 to 10%).
- No statistically significant change in the proportion of people reporting hearing aircraft (41 to 43%).
- An increase in the proportion of people reporting hearing the following specific aircraft noise source: *private / commercial helicopters* (10 to 16%).

Respondents were asked a number of questions about the various effects of noise. In this paper the term 'adversely affected' means that the respondent reported one or more effects from the list of six adverse effects in the question reproduced below.

Q13 NAS91 & NAS91_99 Section A

I would now like you to think about the noise that you hear from…. Please answer yes or no to the following:

A. Do you personally object to this noise?
B. Does the noise irritate you?
C. Does the noise sometimes disturb you?
D. Are you personally concerned about the noise?
E. Do you find the noise annoys or upsets you at times?
F. Do you consider the noise a nuisance to you personally?

The main findings are:

- No statistically significant change in the proportion of people reporting being adversely affected by noise from road traffic (29 to 30%).
- An increase in the proportion of people reporting being adversely affected by the following specific road traffic noise sources: *private cars/vans* (11 to 13%), *motorways* (1 to 3%).
- An increase in the proportion of people reporting being adversely affected by noise from neighbours and/or other people nearby (21 to 26%).
- An increase in the proportion of people reporting being adversely affected by the following specific sources of noise from neighbours and/or other people nearby: *people's voices* (7 to 11%), *children* (5 to 8%), *radio/TV/hi-fi* (6 to 9%), *lawnmowers* (1 to 3%).
- An increase in the proportion of people reporting the following activities being disturbed by noise from neighbours and/or other people nearby: *sleeping or resting* (12 to 16%), *listening to TV/radio/music* (11 to 14%), *reading or writing* (7 to 10%), *can't open windows* (6 to 8%), *telephone conversations* (5 to 9%), *use of garden* (4 to 6%).
- An increase in the proportion of people reporting the following reactions to noise from neighbours and/or other people nearby: *annoys me* (12 to 16%), *resent loss of peace and quiet* (11 to 14%), *makes me fed up* (6 to 8%), *makes me stressed* (3 to 5%), *makes me tired* (3 to 5 %), *makes me depressed* (2 to 7%).
- No statistically significant change in the proportion of people reporting being adversely affected by noise from aircraft (17 to 17%).
- An increase in the proportion of people reporting being adversely affected by the following specific aircraft noise sources: *private/commercial helicopters* (3 to 7%), *microlight aircraft/powered gliders* (0 to 1%).

More details of these findings are illustrated in Annex B of this paper. The full reports should be consulted if further information, or a more detailed understanding, is required.

4 The importance of questionnaire design

The sampling basis of the two studies was essentially identical and no statistically significant differences were found between the demographics of the two separate survey samples for England and Wales. Therefore this project affords a unique opportunity to compare the results obtained from two different noise attitude questionnaires (NAS91_99 and NAS99) applied to a similar population at a similar time. For the purpose of this paper we have simply chosen a question dealing with the general adverse effects of environmental noise and presented the corresponding results from the two questionnaires in Figures 1 and 2. The two questions being compared in Figures 1 and 2 are shown below.

Q13 NAS91_99 Section A

I would now like you to think about the noise that you hear from…. Please answer yes or no to the following:

A. Do you personally object to this noise?
B. Does the noise irritate you?
C. Does the noise sometimes disturb you?
D. Are you personally concerned about the noise?
E. Do you find the noise annoys or upsets you at times?
F. Do you consider the noise a nuisance to you personally?

NAS99 Main / NAS99 Road Traffic Noise / NAS99 Noise from Neighbours & Other People Nearby

When you are at home, to what extent are you personally bothered, annoyed or disturbed by noise from…?

Not at all – A little – Moderately – Very – Extremely – (Don't Hear)

Figure 1 shows the relationship between these two questions when using general categories of noise such as road traffic noise, aircraft noise, noise from neighbours and/or other people nearby. Figure 2 shows the relationship when using specific source descriptors of road traffic noise such as heavy lorries, motorbikes, motorways, and specific source descriptors of neighbour noise such as banging doors, footsteps, radio/TV/music.

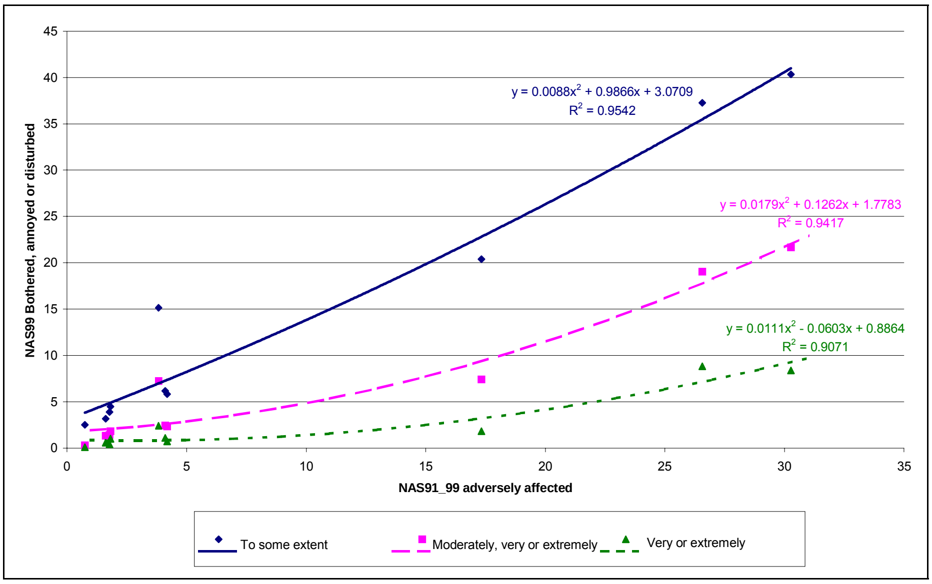

Figure 1. Proportion reporting annoyance from general categories of noise sources – relationship between two questionnaires

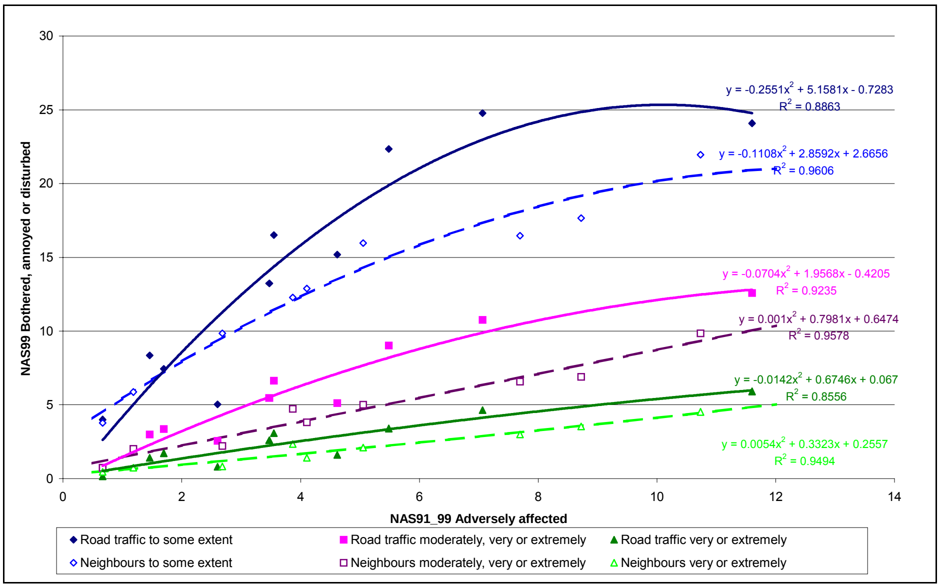

Figure 2. Proportion reporting annoyance from specific sources of road traffic noise and neighbour noise – relationship between two questionnaires

This is one example of a number of similar findings from the study[6] which demonstrate that great care must be taken when making comparisons between different noise attitude surveys using different questionnaires. Indeed, even where it appears that two questions are identical, the responses obtained may differ significantly owing to a variety of other factors within the questionnaire and its administration. A number of differences between the results obtained from the two questionnaire designs have been found in the study which can be attributed to a number of factors, including the following: (i) routing within the questionnaires and the use of filter questions, (ii) question wording and the options given for responses, (iii) interviewer coding instructions, (iv) use of showcards, (v) focus of questions on specific noise sources or general categories of noise, (vi) interviewers themselves, (vii) questionnaire structure and the order of questions within the questionnaires.

The direction of the effect of each of these factors may be relatively easily predicted but the overall result of the combination of several factors, and determining which will dominate in a given situation, is much less predictable and contributes to the observed lack of correspondence between the results obtained from the two different questionnaires.

However, as shown above in Figures 1 and 2, we have found that whilst there may be a lack of *correspondence* there is nevertheless a strong *correlation* between the results from the two questionnaires. This between-questionnaire correlation is particularly strong for the questions dealing with the adverse effects from general categories of noise. This, in turn, suggests that it may be possible to estimate the response to certain questions using the responses from another questionnaire but it seems to us that this relationship would need to be determined empirically for the particular studies under consideration. This finding has implications for those involved in the combined analysis of results from several different studies and for those making noise policy decisions on the basis of the results of social surveys.

5 Acknowledgements

This study was funded by the UK Department for Environment, Food and Rural Affairs (DEFRA), on behalf of DEFRA and the Devolved Administrations for Wales, Scotland and Northern Ireland. All interviews were carried out on behalf of BRE by Beaufort Research and PAS (now part of the NFO Group).

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Annex A – United Kingdom results (NAS99 questionnaire)

Environmental problems

Q21 NAS99 Main

Please look at this list of environmental problems. Which FIVE would you say you are personally most affected by?

- Chemicals put into the rivers and/or seas
- Sewage on beaches or in bathing water
- Loss of plant life and/or animal life
- Quality of drinking water
- Use of insecticides and/or fertilisers
- Losing green belt land
- Litter & rubbish
- Traffic exhaust fumes & urban smog
- Fouling by dogs
- Using up of natural resources
- Not enough recycling
- Noise

Environmental problems affecting respondents	**Proportion ranking problem in top five (%) (n=2876)**
Fouling by dogs	50 ± 3
Litter and rubbish	48 ± 3
Traffic exhaust fumes & urban smog	31 ± 4
Losing green belt land	27 ± 4
Quality of drinking water	26 ± 3
Chemicals put into the sea and/or rivers	24 ± 3
Sewage on beaches or in bathing water	24 ± 4
Not enough recycling	20 ± 3
Noise	18 ± 3
Use of insecticides and/or fertilisers	18 ± 3
Loss of plant life and/or animal life	16 ± 2
Using up of natural resources	9 ± 1

Attitudes to noise environment

Q22 NAS99 Main

In general, how do you feel about the amount of noise (or the absence of noise) around here?

	Proportion (%) (n=2876)
1 – Definitely like	32 ± 3
2	22 ± 2
3	15 ± 2
4	13 ± 1
5	7 ± 1
6	4 ± 1
7 – Definitely don't like	5 ± 1
Don't know	1 ± 0

Extent bothered, annoyed or disturbed by categories of environmental noise and specific sources of noise from neighbours and/or other people nearby

Q24 NAS99 Main
When you are at home, to what extent are you personally bothered, annoyed or disturbed by noise from …?

Not at all – A little – Moderately – Very – Extremely

Noise Category (n=2876)	Hear (%)	Bothered, annoyed or disturbed (%) To some extent	Moderately, very or extremely	Very or extremely
Road traffic	84 ± 3	40 ± 3	22 ± 2	8 ± 1
Neighbours (inside their homes)	58 ± 4	18 ± 2	9 ± 1	4 ± 1
Neighbours (outside their homes)	71 ± 4	22 ± 2	10 ± 1	4 ± 1
Other people nearby	68 ± 4	20 ± 3	8 ± 1	3 ± 1
Neighbours and/or other people nearby (combined category)	*81 ± 3*	*37 ± 3*	*19 ± 2*	*9 ± 1*
Aircraft/airports/airfields	71 ± 4	20 ± 4	7 ± 2	2 ± 1
Building, construction, demolition, renovation or road works	49 ± 5	15 ± 2	7 ± 2	2 ± 1
Trains or railway stations	36 ± 4	6 ± 1	2 ± 1	1 ± 0
Sports events	34 ± 4	4 ± 1	1 ± 0	0 ± 0
Other entertainment or leisure	31 ± 4	6 ± 1	2 ± 1	1 ± 0
Community buildings	30 ± 3	4 ± 1	1 ± 0	0 ± 0
Forestry, farming or agriculture	26 ± 4	3 ± 1	0 ± 0	0 ± 0
Factories or works	23 ± 3	4 ± 1	2 ± 0	1 ± 0
Other commercial premises	23 ± 4	3 ± 1	1 ± 0	1 ± 0
Sea, river or canal traffic	16 ± 3	0 ± 0	0 ± 0	0 ± 0
Any other noise[a]	15 ± 3	4 ± 1	3 ± 1	1 ± 0

[a] The additional specific sources of noise given by respondents under the category *any other noise* included: birds / pigeons, church bells, crackling of overhead power lines, electric substations, military establishments

NN1 NAS99 Neighbour Noise
When you are at home, to what extent are you personally bothered, annoyed or disturbed by noise from …?

Not at all – A little – Moderately – Very – Extremely

Specific source of noise from neighbours and/or other people nearby (n=2782)	Hear (%)	Bothered, annoyed or disturbed (%) To some extent	Moderately, very or extremely	Very or extremely
Teenagers' or adults' voices	70 ± 4	22 ± 3	10 ± 2	5 ± 1
Radio, TV, music	55 ± 4	18 ± 2	7 ± 1	4 ± 1
Dogs	65 ± 4	17 ± 2	7 ± 1	3 ± 1
Children	67 ± 4	16 ± 2	7 ± 1	3 ± 1
Cars/motorcycles starting up/leaving, repairs etc.	67 ± 4	15 ± 2	5 ± 1	2 ± 1
Burglar alarms	53 ± 4	15 ± 2	5 ± 1	2 ± 1
DIY (hammering, drilling, etc.)	62 ± 4	13 ± 2	4 ± 1	1 ± 0
Doors banging	46 ± 4	12 ± 2	5 ± 1	2 ± 1
Lawnmowers or other garden equipment	74 ± 4	10 ± 2	2 ± 1	1 ± 0
Parties (when held outdoors)	50 ± 4	8 ± 1	3 ± 1	1 ± 0
Parties (when held indoors)	44 ± 4	7 ± 1	3 ± 1	1 ± 0
Footsteps	41 ± 4	6 ± 1	2 ± 1	1 ± 0
Domestic equipment	36 ± 4	4 ± 1	1 ± 0	0 ± 0
Other animals	31 ± 4	3 ± 1	1 ± 1	1 ± 0
Electric Switches	20 ± 4	1 ± 0	0 ± 0	0 ± 0
Any other kind of noise[b]	24 ± 4	5 ± 1	3 ± 1	2 ± 0

[b] The additional specific sources of noise from neighbours given by respondents under the category *any other kind of noise* included: mobile phones, telephones, fireworks, toilets flushing and plumbing noises

Times when bothered by noise from neighbours and/or other people nearby

DNN1 NAS99 Detailed Neighbour Noise

Does the noise from … particularly bother, annoy or disturb you, at each of the times listed on the card…
a) during the week (Monday to Friday)?
b) during the weekend (Saturday and Sunday)?

- Day (0700-1900)
- Evening (1900-2300)
- Night(2300-0700)

Specific source of noise from neighbours and/or other people nearby	n	Weekdays (%) Day	Evening	Night	Weekends (%) Day	Evening	Night
Other animals	28	32	25	61	32	25	64
Footsteps	55	27	51	55	36	45	53
Parties (when held indoors)	81	1	35	54	6	57	79
Doors banging	141	33	55	46	41	49	45
Burglar alarms	150	19	27	35	19	23	36
Cars, motorcycles starting up/leaving, repairs etc.	137	41	42	34	45	41	33
Radio, TV, music	201	26	54	34	41	54	40
Teenagers' or adults' voices	295	24	64	33	34	62	43
Dogs	201	43	35	32	44	32	29
Parties (when held outdoors)	74	9	34	30	20	65	59
Electric switches	6	0	33	17	33	50	17
DIY (hammering, drilling etc)	110	32	50	15	65	47	17
Children	189	45	63	12	62	59	14
Domestic equipment (vacuum cleaners etc)	27	22	37	7	48	41	4
Lawnmowers and other garden equipment	64	44	20	2	73	23	2
Other noises	75	35	53	44	37	55	47

View on whether noise from road traffic and noise from neighbours is getting worse

NAS99 Road Traffic Noise RT7

Would you say the road traffic noise here, at your home, has been getting better or worse over the past five years?

	Proportion (%) England (n=2356)	Wales (n=147)	Scotland (n=247)	Northern Ireland (n=99)	UK (n=2849)
1 - Definitely better	4	3	5	0	4
2	5	4	14	8	6
3	42	48	40	57	43
4	13	10	15	16	13
5 - Definitely worse	16	16	6	13	15
Have not liver here for 5 years	13	8	16	3	13

NAS99 Noise from Neighbours & Other People Nearby NN8

Would you say that the noise from neighbours and/or other people around here, at your home, has been getting better or worse over the part five years?

	Proportion (%) England (n=2296)	Wales (n=140)	Scotland (n=247)	Northern Ireland (n=99)	UK (n=2782)
1- Definitely better	7	12	7	3	7
2	7	5	15	10	8
3	51	53	43	62	50
4	7	7	9	10	7
5 - Definitely worse	8	4	4	11	7
Have not lived here 5 years	16	9	17	3	15

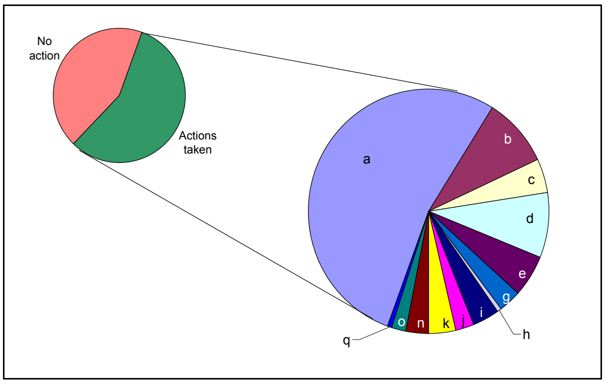
Actions taken in response to noise from neighbours and/or other people nearby

DNN5a NAS99 Detailed Neighbour Noise

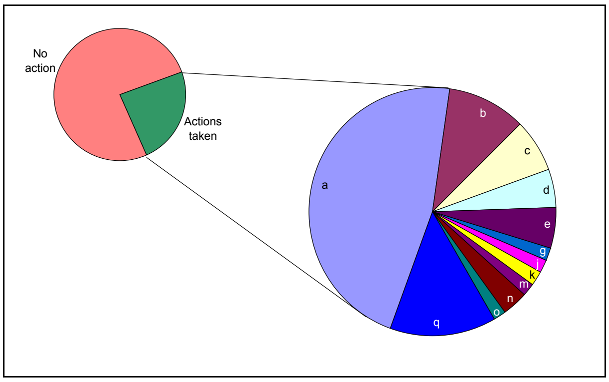
Have you ever done any of the things listed on the card to try to deal with the noise from … that you hear?

a) Complained to the person / people / organisation that is making the noise
b) Complained to the police
c) Complained to the Environmental Health Department
d) Complained to another Local Authority (Council) Department
e) Complained to the Landlord / Housing Department / Housing Association / Other landlord
f) Complained to a Government Department
g) Complained to an MP or councillor
h) Started / signed / joined a campaign or petition
i) Installed double glazing
j) Did something else to keep the noise out
k) Did something to help you sleep (e.g. earplugs, sleeping pills)
l) Talked to the Citizens Advice Bureau
m) Took legal advice / action
n) Did something else
o) Asked someone else to do one of the above
p) No action taken
q) Same action as for another neighbour noise type

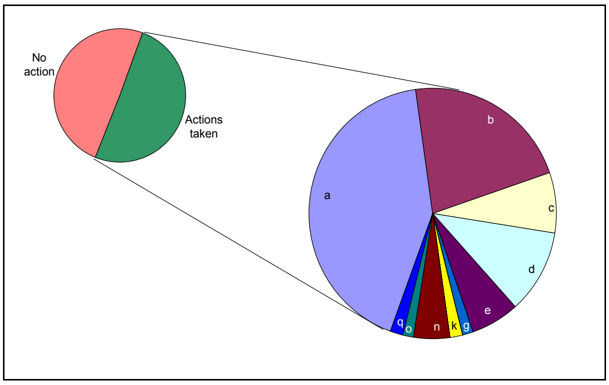
The results from this question are presented in the pie charts opposite for several specific types of noise from neighbours and/or other people nearby. The results are presented as proportions of the subsample that completed a Detailed Neighbour Noise (DNN) questionnaire for that noise type. It should be noted that the DNN questionnaire was only completed by respondents who reported being *moderately*, *very* or *extremely* bothered, annoyed or disturbed by noise from that source.



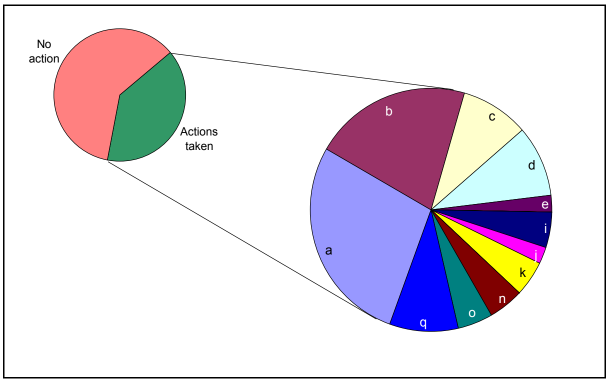
Actions taken for noise from radio, TV, music (n=201)



Actions taken for noise from dogs (n=162)



Actions taken for noise from parties (when held indoors (n=81)



Actions taken for noise from parties (when held outdoors) (n=74)

Annex B – England & Wales – changes from 1991 to 1999

Noise sources heard

Q6 Main NAS91 & NAS91_99

When you are at home do you, personally, hear any of the following noises? You may mention as many or as few as you like.

Category of environmental noise	1991 (%) (n=2373)	1999 (%) (n=2534)	Significant changes (95% confidence level)
Road traffic	48	54	Increase
Aircraft	41	43	-
Neighbours	19	25	Increase
Other people nearby	15	21	Increase
Neighbours and/or other people nearby (combined category)	*28*	*38*	*Increase*
Trains or railways	13	17	-
Building construction or road works	6	7	-
Sports events	6	7	-
Entertainment or leisure	5	6	-
Farming or agriculture	4	5	-
Factories or works	2	4	-
Commercial premises	2	3	-
None of these	22	17	Decrease

Q10 Main NAS91 & NAS91_99
Which of these kinds of road traffic noise do you hear while you are at home?

Specific noise source	1991 (%) (n=2373)	1999 (%) (n=2534)	Significant changes (95% confidence level)
Private cars/vans	24	32	Increase
Heavy lorries	20	20	-
Other main roads	19	22	-
Smaller lorries/buses	16	16	-
Motor bikes/scooters	13	13	-
Minor roads	12	12	-
Residential/estate roads	10	14	Increase
Police/other sirens	10	14	Increase
Brake squeal	7	6	-
Vehicles starting/stopping/ticking over (at traffic lights, crossings etc.)	5	7	Increase
Air brakes	3	3	-
Noise caused by irregularities in road surface	3	3	-
Milk floats	3	2	-
Motorways	1	6	Increase
None of these other special noise types	29	24	Decrease
None of these road types	12	6	Decrease
None of these vehicle types	9	7	-

Q11 Main NAS91 & NAS91_99

Which of these kinds of noise do you hear from neighbours or from other people nearby?

Specific noise source heard	1991 (%) (n=2373)	1999 (%) (n=2534)	Significant changes (95% confidence level)
People's voices	11	17	Increase
Children	9	16	Increase
Radio/TV/hi-fi	9	12	Increase
Barking dogs or other animals	9	12	-
Cars, motorcycles starting up/leaving, repairs etc.	6	10	Increase
DIY – drilling, hammering etc.	5	7	-
Doors banging	5	7	Increase
Lawnmowers	5	10	Increase
Vacuum cleaners, washing machines etc.	2	3	-
Footsteps	3	4	-
Other neighbour noises	1	2	-

Proportion adversely affected

The proportions of the whole sample who reported hearing and being adversely affected are presented for general categories of environmental noise and specific sources of noise from neighbours and/or other people nearby in the tables below.

A separate Section A supplementary questionnaire was completed for each specific noise source that respondents reported hearing in the Main Questionnaire. Question 13 from Section A has been used to assess the proportion of respondents who reported being adversely affected by each specific noise source.

Environmental noise categories

Category of environmental noise	**Proportion adversely affected**		**Significant changes (95% confidence level)**
	1991 (%) (n=2373)	**1999 (%) (n=2534)**	
Road Traffic (one or more specific sources)	29	30	-
Neighbours and/or other people nearby (one or more specific sources)	*21*	*26*	*Increase*
Aircraft (one or more specific sources)	17	17	-
Trains or railways (one or more specific sources)	4	4	-
Building construction or road works	3	4	-
Entertainment or leisure	3	4	-
Factories or works	2	2	-
Commercial premises	1	2	-
Sports events	1	2	-
Farming of agriculture	1	1	-

Specific sources of noise from neighbours and/or other people nearby

Specific source of noise from neighbours and/or other people nearby	**Proportion adversely affected**		**Significant changes (95% confidence level)**
	1991 (%) (n=2373)	**1999 (%) (n=2534)**	
People's voices	7	11	Increase
Children	5	8	Increase
Radio/TV/hi-fi	6	9	Increase
Barking dogs or other animals	6	7	-
Cars, motorcycles starting up/leaving, repairs etc.	4	5	-
DIY – drilling, hammering etc.	3	4	-
Doors banging	4	4	-
Lawnmowers	1	3	Increase
Footsteps	1	1	-
Vacuum cleaners, washing machines etc.	1	1	-

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Exhibit A38-3

QUANTITATIVE RESEARCH

The association between self-reported and objective measures of health and aggregate annoyance scores toward wind turbine installations

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Abstract

Objective An aggregate annoyance construct has been developed to account for annoyance that ranges from *not at all annoyed* to *extremely annoyed*, toward multiple wind turbine features. The practical value associated with aggregate annoyance would be strengthened if it was related to health. The objective of the current paper was to assess the association between aggregate annoyance and multiple measures of health.

Methods The analysis was based on data originally collected as part of Health Canada's Community Noise and Health Study (CNHS). One adult participant per dwelling (18–79 years), randomly selected from Ontario (ON) ($n = 1011$) and Prince Edward Island (PEI) ($n = 227$), completed an in-person questionnaire.

Results The average aggregate annoyance score for participants who indicated they had a health condition (e.g., chronic pain, Pittsburgh Sleep Quality Index (PSQI) > 5, tinnitus, migraines/headaches, dizziness, highly sensitive to noise, and reported a high sleep disturbance) ranged from 2.53 to 3.72; the mean score for those who did not report these same conditions ranged between 0.96 and 1.41. Household complaints about wind turbine noise had the highest average aggregate annoyance (8.02), compared to an average of 1.39 among those who did not complain.

Conclusion A mean aggregate annoyance score that could reliably distinguish participants who self-report health effects (or noise complaints) from those who do not could be one of several factors considered by jurisdictions responsible for decisions regarding wind turbine developments. However, the threshold value for acceptable changes and/or levels in aggregate annoyance has not yet been established and could be the focus of future research efforts.

Résumé

Objectif Un indice de gêne global, de *pas du tout gênant* à *extrêmement gênant*, a été élaboré pour tenir compte de la gêne causée par de nombreuses caractéristiques des éoliennes. La valeur pratique associée à la gêne globale serait renforcée si celle-ci était liée à la santé. L'objectif était d'évaluer l'association entre la gêne globale et divers indicateurs de santé.

Méthode Cette analyse est fondée sur des données recueillies à l'origine dans le cadre de l'Étude sur le bruit ambiant et la santé (ÉBAS) de Santé Canada. Des participants adultes (18 à 79 ans), un par ménage, sélectionnés au hasard en Ontario ($n = 1011$) et à l'Île-du-Prince-Édouard ($n = 227$), ont rempli un questionnaire en personne.

Résultats En moyenne, l'indice de gêne global des participants ayant fait état d'une affection de santé (p. ex. douleur chronique, indice de qualité du sommeil de Pittsburgh [PSQI] >5, acouphène, migraines/maux de tête, étourdissements, forte sensibilité au

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bruit et perturbation élevée du sommeil) se situait entre 2,53 et 3,72; l'indice moyen des participants n'ayant pas déclaré ces mêmes affections se situait entre 0,96 et 1,41. Les plaintes des ménages au sujet du bruit des éoliennes ont été associées en moyenne à l'indice de gêne global le plus élevé, soit 8,02, contre 1,39 en moyenne chez les participants qui ne se plaignaient pas du bruit des éoliennes.

Conclusion Un indice de gêne global moyen permettant de façon fiable de distinguer les participants qui font état d'effets sur leur santé (ou qui se plaignent du bruit) de ceux qui ne déclarent pas de tels effets pourrait être l'un de plusieurs facteurs à considérer par les administrations qui prennent des décisions sur le développement éolien. Toutefois, le seuil de gêne globale acceptable (son niveau et/ou son changement) reste à définir et pourrait faire l'objet d'études futures.

Keywords Noise · Principal component analysis · Community survey · Renewable energy · Canada

Mots-clés Bruit · Analyse en composantes principales · Enquête communautaire · Énergie renouvelable · Canada

Introduction

An aggregate annoyance construct has been developed to account for magnitudes of annoyance that range from *not at all annoyed* to *extremely annoyed* toward five wind turbine features (Michaud et al. 2018). These features included noise, shadow flickers, blinking lights, visual impacts, and vibrations. The construct was developed in recognition of the observation that wind turbine noise (WTN) was not the only, nor the most prevalent, wind turbine feature associated with community annoyance in the Community Noise and Health Study (CNHS). An aggregate annoyance score provides a more comprehensive assessment of annoyance than can be gleaned from any individual feature in isolation. The setback distance that corresponds with a statistically significant change in an aggregate annoyance score can inform jurisdictions that set policy. Although the point of departure from the curve is informative, there may be added value in knowing if there is, on average, an aggregate annoyance score that can reliably distinguish groups reporting health effects from those that do not.

As discussed elsewhere (Michaud et al. 2018), principal component analysis (PCA) weights each annoyance response in terms of how much it contributes to the aggregate annoyance construct. However, the authors acknowledge that the validity of the construct as one that has relevance to health or well-being is based on the tacit assumption that the valuation of significance placed on the items that constitute aggregate annoyance is reflected in the magnitude of rated annoyance assigned to each by study participants. The science base available to date does not refute this assumption; however, as outlined in the "Discussion" section, evaluating an untested assumption of equivalence could be a focus of future research in this area.

Previous research has demonstrated a statistical association between *high* noise annoyance and several measures of reported and measured health outcomes (Basner et al. 2014; WHO 2011; Niemann et al. 2006), including several objectively measured outcomes in Health Canada's CNHS (Michaud et al. 2016a). While statistical associations between high noise annoyance and some indicators of health are clearly insufficient to conclude a causal relation between annoyance and health, they may provide support for efforts that aim to mitigate long-term high noise annoyance. The same analysis has not yet been conducted for a measure that is based on several variables related to annoyance (i.e., aggregate annoyance).

Aggregate annoyance represents a novel approach to evaluating community annoyance. The adoption of this approach over conventional methods requires that there is a predictable change in aggregate annoyance as a function of proximity to wind turbines similar to that reported elsewhere (Michaud et al. 2018). Moreover, the pragmatic application of presenting an aggregate annoyance score as representing a community's magnitude of total annoyance toward wind turbines would be more defensible if the aggregate annoyance score was shown to be statistically related to measures of health and/or well-being. To this end, the primary purpose of the current analysis was to assess the mean aggregate annoyance scores among participants' health outcomes measured in the CNHS. The specific health measures assessed were based on their claimed attribution to WTN exposure (e.g., dizziness, tinnitus, migraines, sleep disturbance, depression) or the idea that they may be altered if annoyance represents or influences a stress response. Multiple measures of stress were reported and objectively measured in the CNHS, including but not limited to hair cortisol, blood pressure, heart rate, and perceived stress.(Michaud et al. 2016a)

Methods

Study characteristics

The current study is a secondary analysis of the data collected as part of Health Canada's CNHS. Any duplication of the methods already presented is intentional and considered the minimum necessary for the current analysis to stand on its own. The study characteristics have been described in another publication (Michaud et al. 2016b). Briefly, dwellings were identified from two Canadian provinces. The ON and PEI sampling regions included 315 and 84 wind turbines and 1011 and 227 dwellings, respectively. The wind turbine electrical power outputs ranged between 660 kW and 3 MW (average 2.0 ± 0.4 MW). Turbine hub heights were predominantly 80 m. To maximize sampling in areas where potential impacts from WTN exposure would be most likely to occur, a "take-all" sampling strategy was employed for all identified dwellings within approximately 600 m of a wind turbine. The remaining dwellings were selected randomly up to approximately 11 km. From each dwelling, one participant between the ages of 18 and 79 years was randomly chosen to participate. No substitution was permitted under any circumstances, and participants were not compensated for their participation.

Data collection

The full study questionnaire is available in the supplementary materials elsewhere (Michaud et al. 2016b). Statistics Canada-trained interviewers (16) conducted in-person home interviews between May 2013 and September 2013. In addition to basic demographic variables and previously validated content, the questionnaire's *perception module* included several questions on annoyance to multiple wind turbine features. In addition to noise, participants were also asked to indicate their magnitude of annoyance toward turbine blinking lights, shadows or flickers of light, visual impacts, and vibration or rattles noticed indoors which coincided with a participant's recollection of wind turbine operations. Annoyance response categories included *not at all*, *slightly*, *moderately*, *very*, and *extremely*. Pertinent to the current analysis, the questionnaire also included several health-related measures, including but not limited to, chronic pain, stress, blood pressure, tinnitus, migraines, dizziness, quality of life, and sleep disturbance. For brevity, methodological procedures for measured blood pressure, heart rate, and hair cortisol levels are presented elsewhere (Michaud et al. 2016c). In an attempt to mask the study's focus on wind turbines, potential participants were informed that the purpose of the survey was to investigate the potential impact on health from community noise.

Statistical methodology

Derivation of an aggregate annoyance construct

The method for deriving the aggregate annoyance construct has been reported elsewhere (Michaud et al. 2018). Briefly, a PCA was conducted in order to discover and summarize the pattern of intercorrelations among the five evaluated wind turbine features (i.e., "annoyance features"). The information derived from this preliminary investigation was then used to predict a single criterion variable for annoyance based on the five wind turbine features. Aggregate annoyance was based on all magnitudes of annoyance from not at all annoyed to extremely annoyed (0: not at all, 1: slightly annoyed, 2: moderately annoyed, 3: very annoyed, 4: extremely annoyed) and therefore reflects the combined annoyance toward multiple wind turbine features. The possible range in aggregate annoyance was 0 to 20. A score of 0 reflects no perception/annoyance toward any wind turbine feature and a score of 20 reflects extreme annoyance toward all 5 features.

Relationship between aggregate annoyance and health conditions

An ANOVA was performed based on the constructs derived from the PCA to compare aggregate annoyance levels with the presence or absence of self-reported health conditions. The variability due to distance and province were accounted for in the ANOVA models. The analysis was reanalyzed using A-weighted WTN categories in place of distance categories (see supplemental material). This was not repeated with C-weighted WTN levels as the results would essentially mirror A-weighted findings due to the high correlation between dBA and dBC values (i.e., Pearson's linear correlation coefficient $r > 0.8$) (Keith et al. 2016). The assumptions of the ANOVA were verified using the Anderson-Darling test for normality and Levene's test for equal variance of the residuals. When the assumptions were not satisfied, non-parametric methods were applied (i.e., the data were ranked, and the analysis was conducted on the ranks of the data). Self-reported variables of interest included chronic pain, high blood pressure, heart disease, quality of sleep, quality of life, satisfaction with one's health, tinnitus, migraines/headaches, dizziness, medication for anxiety/depression, noise sensitivity, sleep disturbance, lodging a complaint about wind turbines, and reporting to receive personal benefits from having wind turbines in the area. Quality of sleep was based on the Pittsburgh Sleep Quality Index (PSQI) where values greater than 5 are considered to indicate "poor" sleep (Buysse et al. 1989). Quality of life and satisfaction with one's health are based on the two stand-alone questions from the WHOQOL-BREF questionnaire (WHOQOL Group 1998). As reported elsewhere (Feder et al. 2015), participants were considered to have a poor quality of life if they responded either "poor" or "very poor" to *In the past month, how would you rate your quality of life?* All other responses ("neither poor nor good," "good," "very good") were considered to indicate participants have a good quality of life. Similarly, participants were considered to be "dissatisfied" with their health if they responded either "dissatisfied" or "very dissatisfied" to *In the past month, how satisfied were you with your health?* All other responses (“neither dissatisfied nor satisfied”, “satisfied”, very satisfied) were considered to indicate participants were satisfied with their health (Feder et al. 2015). ANOVA models relating self-reported health conditions and aggregate annoyance were further adjusted for age and sex, in addition to distance to the nearest turbine and province. Spearman correlation coefficient and linear regression models were used to investigate the relationship between the overall annoyance construct and the following continuous variables: systolic blood pressure, diastolic blood pressure, heart rate, hair cortisol levels, perceived stress scale (PSS), PSQI, and the four WHOQOL-BREF domains (physical health, psychological well-being, social relationships, and environmental factors). Again, these linear regression models were adjusted for distance to nearest turbine and province, and then refit adjusting for age and sex in addition to distance to nearest turbine and province.

The data analysis for this paper was generated using SAS/STAT software, version 9.2 of the SAS System for Windows 7. Unless otherwise indicated, a 5% significance level ($\alpha = 0.05$) was implemented throughout.

This study was approved by the Health Canada and Public Health Agency of Canada Review Ethics Board in accordance with the Tri-Council Policy Statement Ethical Conduct For Research Involving Humans (TCPS) (Protocol no. 2012-0065 and no. 2012-0072).

Results

Relationship between aggregate annoyance and health conditions

The association between aggregate annoyance (which reflects all levels of annoyance, from *not at all annoyed* to *extremely annoyed*) and self-reported health outcomes or other negative reactions to noise (e.g., complaints) was investigated. Table 1 presents the results when relating aggregate annoyance to various health conditions originally reported in Health Canada’s CNHS (Michaud et al. 2016b). Self-reported variables of interest in the current analysis included chronic pain, high blood pressure, heart disease, quality of sleep, quality of life, satisfaction with one’s health, tinnitus, migraines/headaches, dizziness, medication for anxiety/depression, noise sensitivity, and sleep disturbance. In addition, lodging a complaint about noise from wind turbines and reporting to receive personal benefit from having wind turbines in the area were assessed.

All health conditions were equally distributed between distance groups and dBA WTN groups (results not shown). Least squares means and confidence intervals were based on the mean of the total five annoyance features for each participant; *p* values of the models were based on non-parametric statistics of the first construct from PCA for the overall annoyance. A significant increase in average aggregate annoyance was observed among participants who self-reported to have chronic pain, scores on the PSQI above 5 (i.e., poor sleep), tinnitus, migraines/headaches, dizziness, reported very or extreme (i.e., high) sensitivity to noise, and reported very or extreme (i.e., high) sleep disturbance at home over the last year, for any reason.

An increase in average aggregate annoyance was also observed among those who lodged a complaint as well as among those who did not receive personal benefits. Age and sex were also related to aggregate annoyance; participants between the ages of 45 and 64 years had higher aggregate annoyance scores when compared to other age categories, as did males compared to females. Further adjusting the models for age and sex differences did not affect the results (see Table 1). For the self-reported health variables considered, the average aggregate annoyance score for those participants who indicated they had a health condition (e.g., chronic pain, PSQI > 5, tinnitus, migraines/headaches, dizziness, highly sensitive to noise, and reported a high sleep disturbance) ranged from 2.53 to 3.72; the mean aggregate annoyance for those who did not exhibit these same health conditions ranged between 0.96 and 1.41. Participants who reported that someone in their household lodged a formal complaint (34 participants) had the highest average aggregate annoyance (i.e., 8.02), compared to an average of 1.39 among those who did not lodge a formal complaint. Aggregate annoyance was effectively 0 (i.e., least squares mean − 0.11) among the 110 participants who reported to receive personal benefit from having wind turbines in the area, compared to an average of 1.93 among those who did not report such benefits.

Similar results were detected when the analysis was conducted with A-weighted WTN levels (see supplemental material). For example when A-weighted WTN levels were used in place of proximity to turbines, a significant increase in average aggregate annoyance was also observed among participants who self-reported to have chronic pain, scores on the PSQI above 5 (i.e., poor sleep), tinnitus, migraines/headaches, dizziness, reported very or extreme (i.e., high) sensitivity to noise, and reported very or extreme (i.e., high) sleep disturbance at home over the last year, for any reason. Again, the average aggregate annoyance score for those participants who reported these health effects ranged from 2.38–3.50; the mean aggregate annoyance for those who did not report these same health conditions ranged from 0.78 to 1.27.

Finally, linear regression models, after adjustments were made for age and sex, revealed that diastolic blood pressure, PSS, and PSQI scores were positively associated with increased values of aggregate annoyance (see Table 2). For example, for every unit increase in the log-transformed diastolic blood pressure (log mmHg), aggregate annoyance would increase by 2.28 (SE 0.86, $p = 0.0084$). Aggregate annoyance would increase by 0.07 (SE 0.02, $p < 0.0001$) for every unit increase in PSS and by 0.21 (SE 0.03, $p < 0.0001$) for every

Table 1 Aggregated annoyance related to specific outcome assessed

Variable	Number	ANOVA model adjusted for distance and province[a]		ANOVA model adjusted for distance, province, age, and sex[b]	
		Least squares means (95% CI)[c]	p value[d]	Least squares means (95% CI)[e]	p value[d]
Sex					
Male	600	1.89 (1.47, 2.31)	0.0345		
Female	626	1.46 (1.05, 1.87)			
Age group (years)					
≤24	72	0.63 (−0.29, 1.54)	0.0089		
25–44	327	1.65 (1.16, 2.14)			
45–64	543	1.94 (1.51, 2.37)			
65+	284	1.38 (0.85, 1.91)			
Chronic pain					
Yes	285	2.69 (2.16, 3.22)	0.0001	2.47 (1.89, 3.05)	0.0002
No	939	1.41 (1.04, 1.78)		1.20 (0.80, 1.61)	
High blood pressure					
Yes	368	1.52 (1.04, 2.01)	0.3909	1.20 (0.65, 1.76)	0.1962
No	854	1.72 (1.34, 2.10)		1.48 (1.06, 1.90)	
Heart disease					
Yes	94	1.45 (0.63, 2.26)	0.3341	1.15 (0.31, 2.00)	0.2533
No	1131	1.68 (1.32, 2.04)		1.42 (1.02, 1.83)	
Reported “poor” sleep					
PSQI > 5	549	2.53 (2.11, 2.96)	< 0.0001	2.31 (1.84, 2.77)	< 0.0001
PSQI ≤ 5	650	0.96 (0.54, 1.37)		0.75 (0.31, 1.19)	
Rated QOL, previous month[f]					
Poor	80	2.41 (1.54, 3.28)	0.1187	2.14 (1.25, 3.02)	0.1372
Good	1144	1.61 (1.25, 1.98)		1.36 (0.95, 1.76)	
Rated satisfaction with health, previous month[g]					
Dissatisfied	173	2.32 (1.69, 2.95)	0.1086	2.04 (1.38, 2.70)	0.1392
Satisfied	1053	1.56 (1.19, 1.93)		1.31 (0.91, 1.72)	
Tinnitus					
Yes	290	2.89 (2.38, 3.40)	< 0.0001	2.63 (2.09, 3.17)	< 0.0001
No	935	1.28 (0.91, 1.65)		1.02 (0.61, 1.43)	
Migraines[h]					
Yes	287	3.49 (2.98, 4.01)	< 0.0001	3.37 (2.83, 3.92)	< 0.0001
No	938	1.21 (0.85, 1.57)		0.90 (0.50, 1.29)	
Dizziness					
Yes	270	3.00 (2.48, 3.53)	< 0.0001	2.82 (2.26, 3.37)	< 0.0001
No	956	1.30 (0.94, 1.67)		1.04 (0.63, 1.45)	
Medication for anxiety or depression					
Yes	141	1.51 (0.83, 2.20)	0.2415	1.30 (0.59, 2.02)	0.3293
No	1085	1.68 (1.31, 2.05)		1.41 (1.01, 1.82)	
Noise sensitivity[i]					
High	171	3.72 (3.10, 4.34)	< 0.0001	3.52 (2.87, 4.18)	< 0.0001
Less than high	1051	1.36 (1.00, 1.72)		1.14 (0.74, 1.54)	
Long-term sleep disturbance[j]					
High	162	3.48 (2.84, 4.12)	< 0.0001	3.25 (2.58, 3.93)	< 0.0001
Less than high	1061	1.41 (1.05, 1.77)		1.19 (0.79, 1.59)	
Household complaint lodged regarding WTN					
Yes	34	8.02 (6.79, 9.24)	< 0.0001	7.73 (6.48, 8.97)	< 0.0001

Table 1 (continued)

Variable	Number	ANOVA model adjusted for distance and province[a]		ANOVA model adjusted for distance, province, age, and sex[b]	
		Least squares means (95% CI)[c]	p value[d]	Least squares means (95% CI)[e]	p value[d]
No	1189	1.39 (1.04, 1.74)		1.18 (0.79, 1.56)	
Personal benefit[k]					
Yes	110	− 0.11 (− 0.88, 0.66)	< 0.0001	− 0.36 (− 1.15, 0.43)	< 0.0001
No	1064	1.93 (1.54, 2.31)		1.68 (1.25, 2.11)	

[a] Analysis of variance (ANOVA) model of aggregate annoyance related to variable, model adjusted for province and distance to turbines

[b] ANOVA model of aggregate annoyance related to variable, model adjusted for province, distance to turbines, age, and sex

[c] Least squares means of aggregate annoyance and corresponding 95% confidence interval (CI) after adjusting for province and distance to turbines

[d] p values are based on the ranks of the data (non-parametric statistics)

[e] Least squares means of aggregate annoyance and corresponding 95% confidence interval (CI) after adjusting for province, distance to turbines, age, and sex

[f] Poor includes ratings of "poor" and "very poor"; good includes ratings "neither poor nor good," "good," and "very good"

[g] Dissatisfied includes the ratings "dissatisfied" and "very dissatisfied"; satisfied includes the ratings "neither satisfied or dissatisfied," "satisfied," and "very satisfied"

[h] Frequent migraines or headaches (includes nausea, vomiting, sensitivity to light and sound)

[i] Noise sensitivity was defined as "high" for participants who reported to be very or extremely sensitive and "less than high" for participants who reported to be not at all, slightly, or moderately sensitive

[j] The magnitude of reported sleep disturbance over the previous year while at home for any reason was defined as "high" for participants who reported to be very or extremely sleep disturbed and "less than high" for participants who reported to be not at all, slightly or moderately sleep disturbed

[k] Includes benefit through rent, payments, or other indirect benefits such as a hall or community centre for having wind turbines in their area

unit increase in PSQI. From the WHOQOL-BREF, physical health, psychological well-being, and environmental factors domains were negatively associated with increased values of aggregate annoyance (see Table 2). Larger domain values indicate a healthier QOL for the respective domain. For example, as physical health domain increased, aggregate annoyance decreased by − 0.23 (SE 0.04, $p < 0.0001$); as the psychological well-being index increased, aggregate annoyance decreased by − 0.12 (SE 0.04, $p = 0.0085$); as the environmental factors index increased, aggregate annoyance decreased by − 0.25 (SE 0.05, $p < 0.0001$). All model-adjusted R^2 ranged between 7% and 12%. Results were similar when A-weighted WTN levels were used in the linear regression model (see supplemental material).

Discussion

The current analysis investigated the potential statistical association between aggregate annoyance and health outcomes that were either subjectively reported or objectively measured in the CNHS. Although the associations observed were not as widespread as they were when the analysis was limited to high WTN annoyance (Michaud et al. 2016a), higher aggregate annoyance scores were found to correlate with an increase in diastolic blood pressure, perceived stress (i.e., PSS), rated sleep quality over the previous 30 days (i.e., PSQI scores), physical health, psychological well-being, and environmental factors as measured by the WHOQOL-BREF domains. Annoyance was also higher among participants reporting chronic pain, tinnitus, migraines/headaches, dizziness, and high sleep disturbance at home for any reason over the previous year. When considered collectively, an aggregate annoyance level around 2.5 appeared to separate the group reporting these conditions from those that did not. Average aggregate annoyance dropped below 2.5 in the distance ranges (0.550–1) km in PEI and (1–2) km in ON, from wind turbines.(Michaud et al. 2018) Conditions not related to aggregate annoyance included hair cortisol concentrations, systolic blood pressure, and rated quality of life when assessed with the single standalone question. It should be underscored that the observed associations between aggregate annoyance and health outcomes should not be mistakenly interpreted to mean that annoyance causes adverse health effects (or vice

Table 2 Aggregated annoyance related to specific health condition, continuous variables

Variable (minimum, maximum)	Number	Spearman correlation coefficient (p value)	Adjusted R^2 of the linear regression model[a]	Linear regression of aggregate annoyance relative to the variable[a]		Adjusted R^2 of the linear regression model[c]	Linear regression of aggregate annoyance relative to the variable[c]	
				Slope (SE)[b]	p value		Slope(SE)[b]	p value
Systolic blood pressure (83, 186)	1066	0.06 (0.0580)	0.07	0.01 (0.01)	0.0911	0.07	0.01 (0.01)	0.1356
log(systolic blood pressure) (4.42, 5.23)	1066	0.06 (0.0580)	0.07	1.54 (0.84)	0.0682	0.07	1.48 (0.91)	0.1041
Diastolic blood pressure (50, 114)	1066	0.12 (0.0001)	0.08	0.03 (0.01)	0.0066	0.08	0.03 (0.01)	0.0118
log(diastolic blood pressure) (3.91, 4.74)	1066	0.12 (0.0001)	0.08	2.41 (0.85)	0.0047	0.08	2.28 (0.86)	0.0084
Heart rate (41, 125)	1066	0.02 (0.4222)	0.07	0.00 (0.01)	0.7764	0.07	0.00 (0.01)	0.8553
log(heart rate) (3.71, 4.83)	1066	0.02 (0.4222)	0.07	− 0.15 (0.70)	0.8301	0.07	− 0.07 (0.71)	0.9180
Cortisol (18.12, 7139.34)	670	0.03 (0.4021)	0.07	0.00 (0.00)	0.2896	0.07	0.00 (0.00)	0.3026
log(cortisol) (2.90, 8.87)	670	0.03 (0.4021)	0.08	0.25 (0.14)	0.0871	0.07	0.22 (0.15)	0.1274
PSS (0, 37)	1220	0.13 (< 0.0001)	0.08	0.06 (0.02)	< 0.0001	0.09	0.07 (0.02)	< 0.0001
PSQI (0, 21)	1199	0.19 (< 0.0001)	0.12	0.20 (0.03)	< 0.0001	0.12	0.21 (0.03)	< 0.0001
DOM1 (4–20)	1225	− 0.17 (<0.0001)	0.10	− 0.22 (0.03)	< 0.0001	0.10	− 0.23 (0.04)	< 0.0001
DOM2 (4–20)	1224	− 0.06 (0.0404)	0.08	− 0.11 (0.04)	0.0104	0.08	− 0.12 (0.04)	0.0085
DOM3 (4–20)	1222	− 0.04 (0.1689)	0.07	− 0.05 (0.04)	0.2342	0.07	− 0.04 (0.04)	0.2916
DOM4 (7–20)	1225	− 0.14 (<0.0001)	0.09	− 0.25 (0.05)	< 0.0001	0.09	− 0.25 (0.05)	< 0.0001

PSS perceived stress scale, *PSQI* Pittsburgh Sleep Quality Index, *DOM1* the physical health domain of the WHOQOL-BREF, *DOM2* the psychological well-being domain of the WHOQOL-BREF, *DOM3* the social relationships domain of the WHOQOL-BREF, *DOM4* the environmental factors domain of the WHOQOL-BREF

[a] Linear regression model is adjusted for distance and province

[b] The slope (SE) standard error corresponds to that of the variable listed in column 1 of the table

[c] Linear regression model is adjusted for distance, province, age, and sex

versa). These are statistical observations made from data collected at one point in time with no documented historical records for any of the evaluated outcomes or control for other factors that may impact annoyance or health.

Part of the widespread adoption of *high noise annoyance* as a targeted outcome for community noise in general is that the WHO has quantified the burden of disease associated with it (WHO 2011). No equivalent measure is available to calculate the impact associated with lower magnitudes of annoyance, or when annoyance is directed toward non-noise exposures. High noise annoyance has repeatedly been shown to have a statistical association with elevated long-term average sound levels and other health measures (Niemann et al. 2006; Michaud et al. 2016a). The relationship between elevated sound levels and high noise annoyance may be adequate for transportation noise sources and certain resource activities (e.g., mining) where high noise levels are the principal factor driving community annoyance. A change in high noise annoyance by an equivalent of 6.5% has been suggested as one of the potential measures of a significant noise impact in environmental assessments that are subject to Canadian federal government review (Michaud et al. 2008; Health Canada 2016). However, in situations where multiple variables are driving community annoyance, as appears to be the case with utility scale wind turbines, consideration of only high noise annoyance may undermine other emissions that contribute to overall community annoyance.

As data in this area accumulates, there is no reason why an alternative approach, based upon aggregate annoyance, could not eventually be adopted for situations where multiple source features are known to underscore community annoyance reactions. A mean aggregate annoyance score that could reliably distinguish participants who self-report health effects (or noise complaints) from those who do not could be one of several factors considered by jurisdictions responsible for decisions regarding wind turbine developments. Decisions would have even more support if aggregate annoyance scores could be reliably associated with objectively measured health outcomes. However, the threshold value for acceptable changes and/or levels in aggregate annoyance has not yet been established and some insight may be gained in this regard from future research. Additional research in this area could also assess the perceived valuation attributed to various wind turbine features. For example, aggregate annoyance as an outcome that has some relevance to land-use planning assumes that rated measures of annoyance toward noise, shadow flickers, blinking lights, vibrations, or overall visual impacts represent the attributed impact that people assign to each of these wind turbine features. The assumption is that instructing respondents to recall their exposure *over the previous year* before reporting their annoyance level balances differences between wind turbine features, be that in exposure and/or the level of effort one invests in coping with each.

It should also be underscored that in response to concerns raised during the external peer review of this paper, the association between the non-noise annoyance variables and self-reported and measured health outcomes was evaluated. With the exception of vibration annoyance, which could not be evaluated due to the small sample size, blinking lights, shadow flicker, and visual annoyance were found to be statistically associated with several measures of health, including, but not limited to, migraines, dizziness, tinnitus, chronic pain, sleep disturbance, perceived stress, quality of life measures, lodging a WTN-related complaint, and measured diastolic blood pressure. Although these annoyance-specific associations with various health measures lend support to actions that may rely on an aggregate annoyance measure, it would be of interest to compare findings from stated choice experiments to results based on rated annoyance. Stated choice studies can estimate the value assigned to each wind turbine feature using a willingness to pay/accept model similar to that presented by Thanos Wardman and Bristow for aircraft noise valuation (Thanos et al. 2011). Finally, although aggregate annoyance has been presented as a construct that reflects a more complete measure of community annoyance toward wind turbines (Michaud et al. 2018), additional research could investigate indirect factors for their potential contribution to community annoyance (e.g., perceived impacts on property value, electricity costs, and wildlife). Similarly, perceived benefits to the environment could be evaluated as nullifying rated annoyance toward any given wind turbine feature.

As this area of research matures, new findings may identify an aggregate annoyance value that corresponds to a threshold for community acceptability. Although individual exposure response relationships with a clear point of departure in the curve can inform policy decisions, their interpretation can be complicated when separate exposure response functions differ in the overall prevalence of annoyance or when their pattern of change is inconsistent across multiple exposure categories. These issues can be addressed, in part, with an exposure response based upon an aggregate annoyance construct.

Compliance with Ethical Standards

Conflict of Interest The authors declare that they have no conflict of interest.

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An assessment of quality of life using the WHOQOL-BREF among participants living in the vicinity of wind turbines ☆

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ABSTRACT

Living within the vicinity of wind turbines may have adverse impacts on health measures associated with quality of life (QOL). There are few studies in this area and inconsistent findings preclude definitive conclusions regarding the impact that exposure to wind turbine noise (WTN) may have on QOL. In the current study (officially titled the *Community Noise and Health Study or CNHS*), the World Health Organization QOL-BREF (WHOQOL-BREF) questionnaire provided an evaluation of QOL in relation to WTN levels among randomly selected participants aged 18–79 (606 males, 632 females) living between 0.25 and 11.22 km from wind turbines (response rate 78.9%). In the multiple regression analyses, WTN levels were not found to be related to scores on the Physical, Psychological, Social or Environment domains, or to rated QOL and Satisfaction with Health questions. However, some wind turbine-related variables were associated with scores on the WHOQOL-BREF, irrespective of WTN levels. Hearing wind turbines for less than one year (compared to not at all and greater than one year) was associated with improved (i.e. higher) scores on the Psychological domain ($p=0.0108$). Lower scores on both the Physical and Environment domains ($p=0.0218$ and $p=0.0372$, respectively), were observed among participants reporting high visual annoyance toward wind turbines. Personal benefit from having wind turbines in the area was related to higher scores on the Physical domain ($p=0.0417$). Other variables significantly related to one or more domains, included sex, age, marital status, employment, education, income, alcohol consumption, smoking status, chronic diseases and sleep disorders. Collectively, results do not support an association between exposure to WTN up to 46 dBA and QOL assessed using the WHOQOL-BREF questionnaire.

Abbreviations: ANOVA, Analysis of Variance; CNHS, Community Noise and Health Study; dBA, A-weighted decibel; dBC, C-weighted decibel; MW, megawatt; ON, Ontario; PEI, Prince Edward Island; QOL, quality of life; SAS, Statistical Analysis System; SF-36®, Short Form Health Survey; WHO, World Health Organization; WHOQOL, World Health Organization Quality Of Life; WHOQOL-BREF, World Health Organization Quality Of Life—abbreviated version of the WHOQOL 100; WTN, wind turbine noise

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1. Introduction

Quality of life (QOL) evaluation in health research emerged in the 1970s in order to supplement traditional morbidity and mortality outcomes. The meaning of the concept of QOL and how it can be reliably evaluated has been studied for many years. The World Health Organization (WHO) defines QOL as "*an individual's perception of their position in life in the context of the culture and value systems in which they live, and in relation to their goals, expectations, standards and concerns*" (WHOQOL Group, 1994). Quality of life is a global measure, broader than health status, inherently subjective and pertains to all aspects of life important to the person (Harrison et al., 1996; Molzahn and Pagé, 2006). There is evidence that dissatisfaction with environment, psychological and/or social domains may impact physical health and well-being in individuals (Guite et al., 2006; Silva et al., 2012).

The methodologies and tools used in environmental noise studies are wide-ranging and have included participant diaries, observational checklists, specialized questionnaires, validated health measures scales and/or QOL scales. The use of a validated measure can be advantageous in that psychometric evaluation such as validity and reliability testing has been completed. In addition, the use of a standardized measure facilitates comparisons across studies enabling trends in research to be more easily examined.

Many QOL studies have used the World Health Organization QOL (WHOQOL)-100, a questionnaire consisting of 100 items divided into multiple domains, which has demonstrated discrimination between healthy and ill populations (WHOQOL Group, 1998). An abbreviated 26-item version (i.e. WHOQOL-BREF) has also been used in numerous studies to evaluate perceptions of health. This questionnaire, developed using data from 30 international field centres, has been found to be an effective cross-cultural assessment of QOL with good to excellent psychometric properties of reliability and validity (Kalfoss et al., 2008; Skevington et al., 2004). The WHOQOL-BREF consists of 4 domains, Physical Health, Psychological, Social Relationships, and Environment. Each domain is comprised of multiple questions that are considered together in the derivation of each domain score. In addition to the 4 domains, the WHOQOL-BREF includes two standalone questions to assess rated QOL and Satisfaction with Health (WHOQOL Group, 1994).

Some environmental noise studies have utilized QOL measures to quantify and compare community response to different noise sources (Shepherd et al., 2010; Welch et al., 2013), with the general observation that increasing exposure to noise is associated with decreased QOL. As reliance on wind power as a source of energy increases, the introduction of wind farms into communities is sometimes resisted or negatively received based, at least in part, on the perception that exposure to wind turbine noise (WTN) has adverse impacts on health and QOL. In a review of literature related to the health effects of WTN, the Council of Canadian Academies (2015) concluded that the only health effect with sufficient evidence for a causal association with exposure to WTN was long term annoyance. Among the Council's key findings was an acknowledgement that there was a paucity of epidemiological studies to draw upon and those that did exist suffered from methodological problems that included, but were not limited to weak statistical power, bias, and lack of controls. Other reviews by researchers and government agencies have reached similar conclusions (Chief Medical Officer of Health Ontario, 2010; Knopper et al., 2014; MassDEP and MDPH, 2012; Merlin et al., 2014; Oregon Health Authority, 2013; Schmidt and Klokker, 2014).

In comparison to the large body of scientific literature examining the response to transportation noise, there are few original epidemiological studies that have investigated the possible impact on QOL among communities living within the vicinity of wind turbines and among those studies, only a limited number of them have utilized validated instruments to examine QOL (Onakpoya et al., 2014). Shepherd et al. (2011) reported that individuals who lived near a wind farm scored worse on general QOL and on the Physical and Environment domains of the WHOQOL-BREF compared to a geographically and socioeconomically matched group living at least 8 km from any wind farms. Conflicting results were found in two other wind turbine studies (Mroczek et al., 2012; Nissenbaum et al., 2012), where QOL was evaluated using a Short Form Health Survey (SF-36®) to examine health outcomes in individuals who lived close to wind turbines and those who lived further away. Nissenbaum et al. (2012) reported lower scores on the mental, but not physical component of the SF-36®, among 38 participants living between 375 m and 1400 m of a wind turbine when compared to 41 participants living between 3.3 km and 6.6 km from a wind turbine. This is in contrast to the findings from a much larger study by Mroczek et al. (2012) where *improved* QOL for all SF-36® domains was found among those living at the closest distance to a wind farm (i.e. <700 m), in comparison to those living beyond 1500 m. In an extended analysis, Mroczek et al. (2015) reaffirmed a higher reported QOL among participants living closer to wind turbines, relative to those living further away and reported that the stage of the wind farm development was an important factor in this regard. These incongruent results, in addition to their methodological issues, small sample sizes and low response rates underscored the need for more research.

Where wind turbines are concerned, it has also been shown that there can be adverse community reactions to features that go beyond WTN emissions. In particular, self-reported health effects have been attributed to features such as shadow flicker. Wind turbine shadow flicker is a phenomenon caused by the flickering effect of rotating blades periodically casting shadows over some but not all neighbouring properties and through windows (Bolton, 2007; Department of Energy and Climate Change (DECC), 2011; Saidur et al., 2011). With their blade length accounted for, utility-scale wind turbines can reach 130 m and wind farms can include dozens of wind turbines. Their height necessitates aircraft warning signals (e.g. blinking lights on the turbine nacelle) and the visual intrusion of wind turbines on the landscape, in addition to WTN, are features that are known to underlie the response to wind turbines (Harding et al., 2008; Pedersen and Larsman, 2008; Pohl et al., 1999; Smedley et al., 2010; van den Berg et al., 2008). While the annoyance response to shadow flicker and/or blinking lights on top of wind turbines has been investigated (Katsaprakakis, 2012; Pohl et al., 2000, 2012), the only field study to assess QOL measures as a function of shadow flicker exposure was published in German by Pohl et al. (1999). In this study, exposure to shadow flicker was related to decreased QOL and elevated annoyance (Pohl et al., 1999).

In assessing the potential contribution that exposure to wind turbines may have on health and QOL, it is important to consider personal and situational factors that may influence reported QOL. For instance, expectations of negative reactions and worry about perceived risk may play a role in self-reported health impacts related to wind turbines (Crichton et al., 2014; Henningsen and Priebe, 2003). Others have found attitudinal factors, personality traits and personal benefit from wind turbines influenced the magnitude of the annoyance to wind turbines; which in turn may be responsible for reported health effects (Chapman et al., 2013; Rubin et al., 2014; Taylor et al., 2013; Pedersen et al., 2009). Regardless of the mechanisms, it is well known that self-reported health is highly correlated with QOL (Bowling, 1995; Hutchinson et al., 2004).

The objective of the present paper was to assess self-reported QOL among individuals living in areas with varying levels of WTN exposure. To this end, the WHOQOL-BREF was administered as part of Health Canada's CNHS. The underlying hypothesis in the current study is that if QOL is adversely impacted by WTN exposure, participants living in areas with higher exposures to WTN would yield lower scores on the WHOQOL-BREF.

2. Methods

2.1. Sample design

2.1.1. Target population, sample size and sampling frame strategy

A detailed description of the study design and methodology, the target population, final sample size and allocation of participants, as well as the strategy used to develop the sampling frame has been described by Michaud et al. (2013) and Michaud (2015). Briefly, the study locations were drawn from areas in southwestern Ontario (ON) and Prince Edward Island (PEI) where there were a sufficient number of dwellings within the vicinity of wind turbine installations. There were 2004 potential dwellings identified from the ON and PEI sampling regions, which included 12 and 6 wind farms, representing a total of 315 and 84 wind turbines respectively. The wind turbine electrical power outputs ranged between 660 kW and 3 MW (average 2.0 $\pm$ 0.4 MW). All turbines were modern monopole design with 3 pitch controlled rotor blades (~80 m diameter) upwind of the tower and most had 80 m hub heights. All dwellings within approximately 600 m from a wind turbine and a random selection of dwellings between 0.60 and 11.22 km were selected from which one person per household between the ages of 18 and 79 years was randomly chosen to participate. Several factors influenced the determination of the final sample size, including having adequate statistical power to assess the study objectives, and the time required for collection of data (Michaud et al., 2013). Taken together, it was determined that a sample size of approximately 1100 would be required to meet study objectives. It was likely that this sample size would be sufficient to detect statistically significant impacts on QOL in the current study given that Shepherd et al. (2011) reported a statistically significant impact on QOL using the WHOQOL-BREF among 39 participants living near wind turbines when compared to 158 participants living further away.

2.1.2. Wind turbine sound pressure levels at dwellings

Outdoor wind turbine sound pressure levels were estimated at each dwelling using both ISO 9613-1 and ISO 9613-2 (ISO 1993, 1996) as incorporated in the commercial software CadnaA version 4.4 (DataKustik GmbH®, 2014). The calculations included all wind turbines within a radius of 10 km, and were based on manufacturers' octave band sound power spectra at 8 m/s, standardized wind speed and favourable sound propagation conditions. Favourable conditions assume the dwelling is located downwind of the noise source, or a stable atmosphere and a moderate ground based temperature inversion. Although different wind speeds and temperature difference could not be considered in the model calculations due to a lack of relevant data, 8 m/s was considered a reasonable estimate of the highest noise exposure conditions. The manufacturers' data were verified for consistency using on-site measurements of wind turbine sound power. The standard deviation in sound levels was estimated to be 4 dB up to 1 km, and at 10 km the uncertainty was estimated to be between 10 dB and 26 dB. While calculations based on predictions of WTN levels reduces the risk of misclassification compared to direct measurements, the risk remains to some extent.

Outdoor WTN levels were also modeled in C-weighted values (dBC), however due to the similarity of the sound power spectra, dBC levels were highly correlated with dBA levels such that there was no additional benefit in using dBC in the current study. Unless otherwise stated, all dB references are A-weighted. A-weighting filters out high and low frequencies in a sound that the human auditory system is less sensitive to at low sound pressure levels.

2.2. Data collection

2.2.1. Questionnaire development, administration and refusal conversion strategies

The questionnaire instrument included the following modules: noise annoyance, health effects, sleep quality, perceived stress, lifestyle behaviours and prevalent chronic disease. QOL was assessed using the WHOQOL-BREF. This 26 item QOL instrument has shown good to excellent psychometric properties and is cross culturally sensitive (WHOQOL Group, 1998). The WHOQOL-BREF generates a profile and score for each of the 4 QOL domains; questions are centered around the meaning respondents attribute to each aspect of life and how problematic or satisfactory they perceive them to be (Skevington et al., 2004). The Physical Health domain includes questions pertaining to sleep, energy, mobility, the extent to which pain prevents performance of necessary tasks, the need for medical treatment to function in daily life, level of satisfaction with their capacity for work. The Psychological domain focuses on the ability to concentrate, self-esteem, body image, spirituality i.e. the extent to which they feel their life is meaningful, the frequency of positive or negative feelings i.e. blue mood, despair, anxiety, depression. The Social Relationships domain includes questions pertaining to satisfaction with personal relationships, social support systems and sexual satisfaction. The fourth domain, the Environment, includes questions related to safety and security, home and physical environment satisfaction, finance i.e. does the respondent have enough money to meet their needs, health/social care availability, information and leisure activity accessibility and transportation satisfaction (Skevington et al., 2004). In addition to the 4 domains, the WHOQOL-BREF includes two stand-alone questions, one pertaining to the respondents' rated QOL, and one related to their Satisfaction with Health. The WHOQOL-BREF instructions specify that this questionnaire is to be used without modification (WHOQOL-BREF, 1996).

Throughout data collection, the Health Canada study was officially referred to as the "*Community Noise and Health Study*" in an attempt to mask the true intent of the study, which was to investigate the association between health and WTN exposure. This approach is commonly used in epidemiological studies to avoid a disproportionate contribution from any group that may have distinct views regarding a study subject, such as wind turbines. Data collection took place through in-person interviews between May 2013 and September 2013 in southwestern ON and PEI. Once a roster of all adults, 18–79 years, living in the dwelling was compiled, a computerized method was used to randomly select one adult per household. No substitution was permitted; therefore, if the targeted individual was not at home or unavailable, alternate arrangements were made to encourage participation at a later time.

All 16 interviewers were instructed to make every reasonable attempt to obtain interviews, which included visiting the dwelling at various times of the day on multiple occasions and making contact by telephone when necessary. If the individual refused to participate, they were then contacted a second time by either the senior interviewer or another interviewer. If, after a second contact, respondents refused to participate, the case was coded as a final refusal.

2.2.2. Statistical analysis

The 4 domains are factors based on the 26 questions which make up the WHOQOL-BREF. As such they are treated as continuous outcomes with each domain score converted to scores ranging between 4 and 20, in accordance with the first transformation method outlined in the WHOQOL-BREF scoring instructions (WHOQOL-BREF 1996). The two stand-alone questions related to QOL rating and Satisfaction with Health were analysed separately, as recommended by WHOQOL-BREF (1996). These two questions include five point response categories for QOL: "*very poor*", "*poor*", "*neither poor nor good*", "*good*" and "*very good*" and for Satisfaction with Health: "*very dissatisfied*", "*dissatisfied*", "*neither satisfied nor dissatisfied*", "*satisfied*" and "*very satisfied*". Analysis was performed after collapsing the bottom two categories (i.e., for QOL "*very poor*" and "*poor*"; for Satisfaction with Health "*very dissatisfied*" and "*dissatisfied*") and comparing them to the top three. This approach produced the following derived variables: "*poor QOL*" vs. "*good QOL*" and "*dissatisfied with own health*" vs. "*satisfied with own health*". Therefore, unlike the 4 domains, these two questions are treated as binary outcomes.

The relationship between sensitivity to noise, QOL and WTN exposure was also considered. Sensitivity to noise was scored on the following five-point response scale: "*not at all*", "*slightly*", "*moderately*", "*very*" and "*extremely*". The response scale for this variable was dichotomized with "*high sensitivity*" including the "*very*" and "*extremely*" categories; and "*low sensitivity*" including "*not at all*", "*slightly*" and "*moderately*" categories. A sensitivity analysis was conducted to investigate the advantage of keeping the noise sensitivity as a 3 scale parameter ("*highly*", "*moderately*", "*low*"). Conclusions in the analysis were similar whether noise sensitivity was included as a dichotomized scale or a 3 scale parameter (i.e. there was no statistical difference in QOL domains between those having moderate noise sensitivity and low noise sensitivity). No additional information was gained by including the 3 scale parameter (results not shown).

The analysis for continuous and categorical outcomes follows the description outlined in Michaud et al. (2013). Final WTN categories (dBA) were defined as follows: {<25; 25–<30; 30–<35; 35–<40; and 40–46}. Univariate analyses of WHOQOL-BREF domains, rated QOL and Satisfaction with Health questions were carried out in relation to a number of variables which could conceivably be expected to influence QOL. The analysis of each variable only adjusts for WTN exposure category and province, and interpretation of any individual relationship must therefore be made with caution. Multiple linear regression models for the domains (continuous outcomes) and multiple logistic regression models for the two stand-alone questions (binary outcomes) were developed using the stepwise method with a 20% significance entry criterion (determined from the univariate analyses, see Supplemental material). A 10% significance criterion was applied to retain variables in the model. The stepwise regression was carried out in three different ways: (1) the base model included exposure to WTN categories and province; (2) the base model included exposure to WTN categories, province and an adjustment for participants who received personal benefit; and (3) the base model included exposure to WTN categories and province, conditional for those who received no personal benefit. In cases when cell frequencies were small (i.e. <5) in the contingency tables or logistic regression models, exact tests were used as described in Agresti (2002) and Stokes et al. (2000). Since this latter technique is very computationally intensive, the WTN level categories had to be treated as a continuous variable. All models were adjusted for provincial differences with province initially considered as an effect modifier. Since the interaction was not statistically significant, province was treated as a confounder in the linear and logistic regression models. Statistical analysis was performed using Statistical Analysis System (SAS) version 9.2. A 5% statistical significance level was implemented throughout unless otherwise stated. Pairwise tests or multiple comparisons were only conducted when the overall significance of the variable was less than 0.05. In addition, Tukey (for continuous outcomes) and Bonferroni (for binary outcomes) corrections were carried out to account for all pairwise comparisons to ensure that the overall Type I (false positive) error rate was less than 0.05. Only variables which are conceptually, and/or have been previously found to be related to QOL were included in the analysis.

3. Results

3.1. Wind turbine sound pressure levels at dwellings, response rates and sample characteristics

Calculated outdoor sound pressure levels reached levels as high as 46 dB. Calculations are representative of typical worst case long term (1 year) average WTN levels. Initially, 2000 addresses were targeted, with 4 additional addresses added during field investigations. Of the 2004, 1570 addresses were considered to be valid dwellings, from which 1238 occupants agreed to participate in the study (606 males, 632 females). This produced a final calculated response rate of 78.9%. The 434 dwellings that were found to be out-of-scope was anticipated based on previous surveys carried out in rural Canadian areas and on Census data forecasting a higher out-of-scope dwelling rate in PEI compared to ON. A characterisation of the out-of-scope locations is provided in Michaud (2015).

Factors that might be expected to influence QOL, such as self-reported prevalence of chronic disease, health conditions, noise sensitivity and reporting to be highly sleep disturbed in any way, for any reason, were all found to be equally distributed across WTN categories (Michaud, 2015).

3.2. Internal consistency of the WHOQOL-BREF domains

Table 1 presents the summary statistics and Cronbach's alpha for the WHO domains. Cronbach's alpha, a measure of the internal consistency of the facets/domains, was above the recommended 70% for all domains except Social Relationships (Cronbach's alpha=66%). This indicates that the correlation within the data for the three items used to determine the Social Relationships domain was found to be questionable within the current study. Caution is therefore advised when interpreting the results within this domain. In the case of a Cronbach's alpha of <0.70, it is recommended that the item(s) least correlated with the construct be dropped one at a time. However, this approach would yield a Social domain that consists of only two questions. Furthermore, analysis of individual items is not recommended as there is a risk of considerable random measurement error (McIver and Carmines, 1981; Nunnally and Bernstein, 1994; Spector, 1992).

3.3. Univariate analysis of variables related to the WHOQOL-BREF

Univariate analyses of WHOQOL-BREF domains and rated QOL and Satisfaction with Health questions were carried out in relation to a number of variables including, but not limited to, chronic

Table 1
Summary of the WHOQOL-BREF domains.

Domain	Mean (SD)	Range	Cronbach's alpha	Standardized Cronbach's alpha	*n*
Physical Health	16.06 (3.03)	(4, 20)	0.86	0.86	1236
Psychological	15.99 (2.43)	(4, 20)	0.79	0.80	1236
Social Relationships	16.46 (2.83)	(4, 20)	0.64	0.66	1233
Environment	16.47 (2.20)	(7, 20)	0.72	0.73	1237

SD, standard deviation.

Table 2a
Multiple linear regression model: Physical Health domain.

Variable	Groups in Variable[a]	LSM (95%CI)[b] (R^2=0.45, n=945)[e]	PWC[c]	p-Value[d]
WTN levels (dB)	< 25 (n=84)	13.11 (12.32, 13.90)		0.1689
	25– < 30 (n=95)	13.35 (12.55, 14.15)		
	30– < 35 (n=304)	13.31 (12.65, 13.98)		
	35– < 40 (n=521)	13.71 (13.08, 14.34)		
	40–46 (n=234)	13.45 (12.81, 14.10)		
Province	PEI (n=227)	13.49 (12.79, 14.19)		0.3415
	ON (n=1011)	13.28 (12.72, 13.84)		
Personal benefit	Yes (n=110)	13.68 (12.91, 14.45)	A	0.0415
	No (n=1075)	13.10 (12.57, 13.62)	B	
Employed	Yes (n=722)	13.85 (13.22, 14.49)	A	< 0.0001
	No (n=515)	12.92 (12.31, 13.53)	B	
Marital status	Married/common-law (n=848)	13.47 (12.89, 14.05)	AB	0.0141
	Widowed/separated/divorced (n=215)	13.76 (13.10, 14.43)	A	
	Single, never been married (n=172)	12.92 (12.20, 13.65)	B	
Audible rail noise	Yes (n=227)	13.58 (12.91, 14.26)		0.0568
	No (n=1011)	13.19 (12.61, 13.77)		
Visual annoyance to turbines	High (n=159)	13.11 (12.41, 13.81)	A	0.0193
	Low (n=1075)	13.67 (13.09, 14.24)	B	
Alcohol use	Do not drink alcohol (n=274)	13.16 (12.52, 13.80)	AB	0.0069
	≤ 3 Times per month (n=474)	13.06 (12.44, 13.68)	A	
	1–3 Times/week (n=325)	13.61 (12.96, 14.26)	B	
	≥ 4 Times/week (n=164)	13.72 (13.00, 14.44)	B	
Smoking status	Current (n=284)	13.12 (12.48, 13.76)	A	0.0273
	Former (n=423)	13.38 (12.74, 14.02)	AB	
	Never (n=531)	13.66 (13.02, 14.29)	B	
Migraines[f]	Yes (n=289)	12.99 (12.34, 13.63)	A	0.0001
	No (n=948)	13.79 (13.17, 14.40)	B	
Dizziness	Yes (n=273)	12.85 (12.21, 13.50)	A	< 0.0001
	No (n=965)	13.92 (13.31, 14.54)	B	
Tinnitus	Yes (n=293)	13.16 (12.53, 13.80)	A	0.0237
	No (n=944)	13.61 (12.99, 14.22)	B	
Chronic pain	Yes (n=293)	12.21 (11.58, 12.84)	A	< 0.0001
	No (n=943)	14.56 (13.93, 15.19)	B	
Arthritis	Yes (n=402)	13.12 (12.50, 13.74)	A	0.0043
	No (n=835)	13.66 (13.03, 14.29)	B	
Diabetes	Yes (n=113)	13.06 (12.33, 13.79)	A	0.0197
	No (n=1123)	13.72 (13.14, 14.29)	B	
Medication for high blood pressure, past month	Yes (n=370)	13.14 (12.51, 13.77)	A	0.0093
	No (n=866)	13.63 (13.01, 14.25)	B	
Chronic bronchitis/emphysema/COPD	Yes (n=71)	12.87 (12.07, 13.67)	A	0.0027
	No (n=1165)	13.90 (13.36, 14.45)	B	
Diagnosed sleep disorder	Yes (n=119)	12.84 (12.14, 13.54)	A	< 0.0001
	No (n=1119)	13.93 (13.33, 14.53)	B	

COPD, chronic obstructive pulmonary disease, LSM, least square mean; ON, Ontario; PEI, Prince Edward Island; PWC, pairwise comparison; WTN, wind turbine noise. Table footnotes are applicable for Tables 2a–2d.

[a] The sample size for each variable does not always sum to the study sample size (n=1238) as not all participants responded to each question.

[b] Based on the multiple linear regression model adjusted for all other variables in the model and 95% Tukey adjusted confidence interval.

[c] Where overall p-value is < 0.05, pairwise comparisons were conducted. After adjusting for multiple comparisons, groups with the same letter are statistically similar, groups with different letters are statistically different.

[d] Overall p-value from multiple linear regression model testing the significance of the variable.

[e] Only participants with complete records were considered in the final model.

[f] Migraines or headaches (including nausea, vomiting, sensitivity to light and sound).

diseases, self-reported health conditions, socio-demographic characteristics, audibility of wind turbines, WTN annoyance, annoyance with the visual aspect of wind turbines and other variables related to the perception of wind turbines, which could conceivably be expected to influence QOL. Included among these variables was personal benefit. In this study, personal benefit refers to those who reported to benefit in any way from having a wind turbine in their area, including receiving rent, payments or other indirect benefits from community improvements. The primary objective in the current analysis was to use multiple regression models to identify the variables that have the strongest statistical association with the WHOQOL-BREF domains and rated QOL and Satisfaction with Health questions. All explanatory variables significant at the 20% level in the univariate analysis were considered in the multiple regression models. The univariate analyses are available in Supplemental material.

3.4. Multiple linear regression models for WHOQOL-BREF domains

Multiple linear regression models to describe the variability in the WHOQOL-BREF domains were developed using stepwise regression with 20% significance entry criteria for predictors and a 10% significance criteria to remain in the model. A complete list of these variables has been made available in Supplemental material. The final models for the three approaches to stepwise regression as listed in the statistical methods section produced nearly

Table 2b
Multiple linear regression model: Psychological domain.

Variable	Groups in Variable	LSM (95%CI) (R^2=0.25, n=949)	PWC	p-Value
WTN levels (dB)	<25 (n=84)	15.13 (14.38, 15.88)		0.6002
	25–<30 (n=95)	14.98 (14.19, 15.76)		
	30–<35 (n=304)	14.79 (14.17, 15.40)		
	35–<40 (n=521)	15.02 (14.45, 15.58)		
	40–46 (n=234)	14.81 (14.23, 15.39)		
Province	PEI (n=227)	14.63 (14.00, 15.27)	A	0.0018
	ON (n=1011)	15.26 (14.72, 15.79)	B	
Personal benefit from having wind turbines in the area	Yes (n=110)	15.13 (14.43, 15.84)		0.1512
	No (n=1075)	14.76 (14.26, 15.26)		
Age group	≤24 (n=72)	15.33 (14.42, 16.25)	AB	0.0230
	25-44 (n=331)	14.71 (14.12, 15.30)	AB	
	45-64 (n=547)	14.60 (14.07, 15.13)	A	
	65+ (n=288)	15.14 (14.53, 15.74)	B	
Marital status	Married/common-law (n=848)	15.33 (14.77, 15.89)	A	0.0013
	Widowed/separated/divorced (n=215)	14.71 (14.07, 15.36)	B	
	Single, never been married (n=172)	14.80 (14.15, 15.45)	AB	
Employed	Yes (n=722)	15.14 (14.56, 15.72)	A	0.0265
	No (n=515)	14.75 (14.17, 15.33)	B	
Level of education	≤High school (n=678)	14.62 (14.06, 15.18)	A	0.0109
	Trade/certificate/college (n=469)	14.76 (14.18, 15.34)	A	
	University (n=90)	15.45 (14.75, 16.15)	B	
Sensitivity to noise	High (n=175)	15.12 (14.49, 15.75)		0.0947
	Low (n=1059)	14.77 (14.22, 15.32)		
Alcohol use	Do not drink alcohol (n=274)	14.92 (14.33, 15.51)		0.0565
	≤3 Times per month (n=474)	14.67 (14.10, 15.25)		
	1–3 Times/week (n=325)	15.16 (14.55, 15.77)		
	≥4 times/week (n=164)	15.03 (14.35, 15.70)		
Number of years hearing the wind turbines	Do not hear wind turbines (n=651)	14.54 (14.02, 15.05)	A	0.0108
	Less than 1 year (n=61)	15.54 (14.72, 16.36)	B	
	1 year or more (n=522)	14.76 (14.19, 15.32)	A	
Migraines	Yes (n=289)	14.74 (14.15, 15.34)	A	0.0364
	No (n=948)	15.14 (14.57, 15.72)	B	

Table 2b (*continued*)

Variable	Groups in Variable	LSM (95%CI) (R^2=0.25, n=949)	PWC	p-Value
Dizziness	Yes (n=273)	14.32 (13.72, 14.92)	A	<0.0001
	No (n=965)	15.57 (15.00, 16.14)	B	
Tinnitus	Yes (n=293)	14.72 (14.12, 15.31)	A	0.0138
	No (n=944)	15.17 (14.60, 15.74)	B	
Chronic pain	Yes (n=293)	14.45 (13.85, 15.05)	A	<0.0001
	No (n=943)	15.44 (14.87, 16.00)	B	
Diabetes	Yes (n=113)	14.72 (14.03, 15.40)		0.0721
	No (n=1123)	15.17 (14.66, 15.69)		
Diagnosed sleep disorder	Yes (n=119)	14.25 (13.59, 14.91)	A	<0.0001
	No (n=1119)	15.64 (15.10, 16.18)	B	

identical results to one another. Therefore, results are only presented for the regression method where the variables WTN, province and personal benefit were forced into the model.

Tables 2a–2d present a detailed account of the demographic, wind-turbine related, personal and health-related variables found to be most strongly associated with the WHOQOL-BREF domains. The final multiple linear regression models accounted for 16%, 24%, 25% and 45% of the variance in the Social Relationships, Environment, Psychological and Physical Health domains, respectively. As shown in Tables 2a–2d, WTN exposure was not found to be significant in any domain, even after adjusting for the other factors. Also, no differences between provinces were observed among domains with the exception of the Psychological domain, where ON had higher domain values than PEI (p=0.0018). A notable observation was that high visual annoyance with wind turbines was associated with lower scores on the Physical Health (Table 2a) and Environment (Table 2d) domains, p=0.01931 and p=0.0096, respectively.

3.5. *Multiple logistic regression models, QOL, Satisfaction with Health*

Multiple logistic regression models to describe the variability in the two stand-alone questions of the WHOQOL-BREF (QOL and Satisfaction with Health) were also developed using stepwise regression with 20% significance entry criteria for predictors and a 10% significance criteria to remain in the model. A complete list of these variables has been made available in the Supplemental Material. The stepwise regression was carried out in a similar fashion as for the 4 domains i.e., (1) the base model included exposure to WTN categories and province; (2) the base model included exposure to WTN categories, province and an adjustment for participants who received personal benefit; and (3) the base model included exposure to WTN categories and province, conditional for those who received no personal benefit. The final models for the three approaches to stepwise regression listed above produced nearly identical results to one another. Therefore, results are only presented for the regression method where the variables WTN, province and personal benefit were forced into the model.

Multiple logistic regression models for prevalence of those who rated their QOL to be "*poor*" (includes the ratings "*very poor*" and "*poor*") and reported to be "*dissatisfied*" with their health (includes ratings "*very dissatisfied*" and "*dissatisfied*") are presented in

Table 2c
Multiple linear regression model: Social Relationships domain.

Variable	Groups in variable	LSM (95%CI)	PWC	*p*-Value
		(R^2=0.16, *n*=987)		
WTN levels (dB)	<25 (*n*=84)	14.57 (13.73, 15.42)		0.7298
	25–<30 (*n*=95)	14.95 (14.07, 15.83)		
	30–<35 (*n*=304)	14.42 (13.72, 15.13)		
	35–<40 (*n*=521)	14.60 (13.92, 15.27)		
	40–46 (*n*=234)	14.59 (13.88, 15.29)		
Province	PEI (*n*=227)	14.43 (13.67, 15.19)		0.1225
	ON (*n*=1011)	14.82 (14.25, 15.40)		
Personal benefit from having wind turbines in the area	Yes (*n*=110)	14.58 (13.76, 15.39)		0.7560
	No (*n*=1075)	14.68 (14.12, 15.23)		
Sex	Male (*n*=606)	14.41 (13.75, 15.07)	A	0.0154
	Female (*n*=632)	14.84 (14.20, 15.49)	B	
Age group	≤24 (*n*=72)	15.27 (14.25, 16.29)	A	0.0029
	25-44 (*n*=331)	14.65 (13.96, 15.34)	A	
	45-64 (*n*=547)	14.04 (13.41, 14.67)	B	
	65+ (*n*=288)	14.55 (13.85, 15.26)	AB	
Marital status	Married/common-law (*n*=848)	15.52 (14.88, 16.17)	A	<0.0001
	Widowed/separated/divorced (*n*=215)	13.95 (13.22, 14.68)	B	
	Single, never been married (*n*=172)	14.41 (13.65, 15.16)	B	
Employed	Yes (*n*=722)	14.84 (14.19, 15.50)	A	0.0368
	No (*n*=515)	14.41 (13.75, 15.07)	B	
Façade type	Fully bricked (*n*=340)	15.13 (14.46, 15.80)	A	0.0012
	Partially bricked (*n*=218)	14.19 (13.44, 14.95)	B	
	No brick/other (*n*=680)	14.55 (13.92, 15.18)	B	
Audible rail noise	Yes (*n*=227)	14.42 (13.69, 15.15)		0.0742
	No (*n*=1011)	14.83 (14.24, 15.43)		
Migraines	Yes (*n*=289)	14.38 (13.68, 15.07)	A	0.0296
	No (*n*=948)	14.88 (14.24, 15.51)	B	
Dizziness	Yes (*n*=273)	14.22 (13.53, 14.91)	A	0.0004
	No (*n*=965)	15.03 (14.39, 15.67)	B	
Chronic pain	Yes (*n*=293)	14.32 (13.65, 14.99)	A	0.0049
	No (*n*=943)	14.93 (14.28, 15.58)	B	
Chronic bronchitis/emphysema/COPD	Yes (*n*=71)	14.16 (13.30, 15.03)	A	0.0140
	No (*n*=1165)	15.09 (14.53, 15.64)	B	
Diagnosed sleep disorder	Yes (*n*=119)	14.27 (13.50, 15.03)	A	0.0167
	No (*n*=1119)	14.99 (14.37, 15.60)	B	

Tables 3a and 3b. In both models there was no statistically significant association between WTN levels and the prevalence rates for reporting "*poor*" QOL or "*dissatisfied*" Satisfaction with Health, even after adjusting for the other demographic, wind-turbine related and personal and health-related variables (as listed in Tables 3a and 3b). Prevalence rates for both QOL and Satisfaction with Health were similar in both ON and PEI. Together, these variables accounted for 31% and 29% of the variance in rated QOL (Table 3a) and Satisfaction with Health, respectively (Table 3b).

A summary table highlighting all variables retained in the multiple regression models for the 4 WHOQOL-BREF domains and two stand-alone questions is presented as Table 4.

4. Discussion

The present study findings do not support an association between exposure to WTN up to 46 dBA and any of the WHOQOL-BREF domains (Physical Health, Psychological, Social Relationships and Environment) or the two stand-alone questions pertaining to rated QOL and Satisfaction with Health. Participants who were exposed to higher WTN levels did not rate their QOL or Satisfaction with Health significantly worse than those who were exposed to lower WTN levels, nor did they report having significantly worse outcomes in terms of factors that comprise the 4 domains. This is contrary to the findings of Shepherd et al. (2011) who also measured QOL using the WHOQOL-BREF questionnaire. Shepherd et al. (2011) reported significantly lower mean Physical and Environment domain scores and QOL rating among the 39 participants (drawn from 56 dwellings) within 2 km of a wind turbine compared to the 158 participants (drawn from 250 dwellings) that were located at least 8 km from a wind farm. It is difficult to compare these findings with the current study insofar as the participants living within 2 km of a wind turbine in Shepherd et al. (2011) were reportedly exposed to WTN levels ranging from 20 to 50 dB. This encompasses the entire range of exposure in the present study.

A study by Nissenbaum et al. (2012) assessed QOL using the SF-36® questionnaire and utilized an approach similar to Shepherd et al. (2011). Nissenbaum et al. (2012) compared QOL scores among two distance groups from two wind farms. These authors reported lower mean scores for the mental component of the SF-36® among a group of 38 participants from 65 identified adults living between 375 m and 1400 m from the nearest wind turbine when compared to a group of 41 participants living between 3.3 km and 6.6 km away. For the same reasons outlined above concerning Shepherd et al. (2011), it is difficult to compare the findings from the current study to those reported by Nissenbaum et al. (2012). Additionally, a different QOL instrument, the SF-36®, was used in the Nissenbaum et al. (2012) study. The SF-36®, also used in a Polish wind turbine study by Mroczek et al. (2012), is a valuable tool in assessing health and functional status. However, the SF-36® does not examine perceptions of health and well-being to the same degree as the WHOQOL-BREF, nor does it include satisfaction with the living environment and neighbourhood (Asnani et al., 2009; Cruice et al., 2000). The inclusion of

Table 2d
Multiple linear regression model: Environment domain.

Variable	Groups in variable	LSM (95%CI) (R^2=0.24, n=985)	PWC	p-Value
WTN levels (dB)	< 25 (n=84)	16.28 (15.58, 16.98)		0.3681
	25–< 30 (n=95)	15.71 (14.99, 16.44)		
	30–< 35 (n=304)	15.75 (15.16, 16.34)		
	35–< 40 (n=521)	15.82 (15.28, 16.36)		
	40–46 (n=234)	15.73 (15.17, 16.28)		
Province	PEI (n=227)	15.76 (15.15, 16.36)		0.2759
	ON (n=1011)	15.96 (15.45, 16.47)		
Personal benefit from having wind turbines in the area	Yes (n=110)	15.92 (15.26, 16.57)		0.6324
	No (n=1075)	15.80 (15.31, 16.29)		
Age group	≤ 24 (n=72)	16.34 (15.56, 17.12)	A	< 0.0001
	25-44 (n=331)	15.45 (14.90, 16.00)	B	
	45-64 (n=547)	15.42 (14.89, 15.95)	B	
	65+ (n=288)	16.22 (15.63, 16.82)	A	
Level of education	≤ High school (n=678)	15.60 (15.06, 16.14)	A	0.0228
	Trade/certificate/college (n=469)	15.67 (15.13, 16.21)	A	
	University (n=90)	16.31 (15.63, 16.99)	B	
Income	< 60k (n=531)	15.33 (14.78, 15.89)	A	< 0.0001
	60–100k (n=300)	15.95 (15.37, 16.52)	B	
	≥ 100k (n=220)	16.29 (15.72, 16.87)	B	
Property ownership	Own (n=1076)	16.05 (15.52, 16.58)		0.0591
	Rent (n=162)	15.66 (15.06, 16.27)		
Façade type	Fully bricked (n=340)	16.09 (15.53, 16.64)		0.0790
	Partially bricked (n=218)	15.74 (15.12, 16.35)		
	No brick/other (n=680)	15.75 (15.21, 16.30)		
Number of years hearing the wind turbines	Do not hear wind turbines (n=651)	15.89 (15.38, 16.39)		0.0731
	Less than 1 year (n=61)	16.10 (15.35, 16.86)		
	1 year or more (n=522)	15.59 (15.05, 16.12)		
Visual annoyance to turbines	High (n=159)	15.58 (14.97, 16.18)		0.0096
	Low (n=1075)	16.14 (15.60, 16.68)		
Turbine shadow flicker annoyance	High (n=96)	16.08 (15.43, 16.73)		0.0916
	Low (n=1137)	15.64 (15.11, 16.16)		
Alcohol use	Do not drink alcohol (n=274)	15.79 (15.22, 16.37)		0.0690
	≤ 3 Times per month (n=474)	15.73 (15.19, 16.28)		
	1–3 Times/week (n=325)	16.14 (15.56, 16.72)		
	≥ 4 Times/week (n=164)	15.77 (15.15, 16.39)		
Smoking status	Current (n=284)	15.56 (14.98, 16.13)	A	0.0134
	Former (n=423)	15.95 (15.39, 16.51)	AB	
	Never (n=531)	16.07 (15.51, 16.62)	B	
Migraines	Yes (n=289)	15.68 (15.12, 16.24)	A	0.0354
	No (n=948)	16.04 (15.49, 16.59)	B	
Dizziness	Yes (n=273)	15.58 (15.01, 16.15)	A	0.0013
	No (n=965)	16.14 (15.59, 16.69)	B	
Tinnitus	Yes (n=293)	15.65 (15.09, 16.21)	A	0.0132
	No (n=944)	16.06 (15.51, 16.62)	B	
Chronic pain	Yes (n=293)	15.60 (15.04, 16.16)	A	0.0013
	No (n=943)	16.12 (15.57, 16.66)	B	
Asthma	Yes (n=101)	15.61 (14.96, 16.25)	A	0.0373
	No (n=1137)	16.11 (15.60, 16.62)	B	
Diagnosed sleep disorder	Yes (n=119)	15.51 (14.89, 16.14)	A	0.0020
	No (n=1119)	16.20 (15.68, 16.73)	B	

environmental and neighbourhood satisfaction would seem to be particularly relevant in the context of wind turbines and how they may impact QOL. Although there is some evidence that indicates the WHOQOL-BREF and SF-36® are comparable in measuring QOL among different clinical populations (Asnani et al., 2009; Hsiung et al., 2005), it is not clear whether this would also apply to communities living within the vicinity of wind turbine installations.

In contrast to Nissenbaum et al. (2012), Mroczek et al. (2012) reported significantly improved QOL on all eight scales of the SF-36® among a Polish population of 220 individuals living within 700 m of a wind farm compared to the 424 individuals living beyond 1500 m. Mroczek et al. (2012) noted that some individuals received economic benefit associated with wind turbines, however this variable was not included in their analysis. Furthermore, Mroczek et al. (2012) concluded that close proximity to wind farms did not result in worsening of QOL, and suggested future research include questions about economic benefit from both land rental for wind farm construction and possible employment in the wind industry.

The influence that economic benefit may have on QOL is uncertain. Receiving personal benefit, when analysed alone, was related to all 4 WHOQOL-BREF domains as well as QOL and Satisfaction with Health stand-alone questions. However, when other variables were also considered in the multiple regression models the relationships changed and personal benefit was only found to be (marginally) related to the Physical Health domain (p=0.0415). This finding was independent of WTN exposure. In relation to personal benefit, a similar finding was reported by van den Berg et al. (2008), who

Table 3a
Multiple logistic regression model: QOL rating.

Variable	Groups in variable[a,b]	QOL rating[c] OR (CI)[d]	p-Value[e]
		(n=946, R^2=0.31, H–L p=0.6796)[f]	
Intercept			0.0001
WTN levels (dB)[g]		1.02 (0.80, 1.32)	0.8523
Province	ON/PEI (n=1011, n=227)	0.66 (0.30, 1.45)	0.3030
Personal benefit[h]	No/yes (n=1075, n=110)	2.51 (0.55, 11.54)	0.2361
Marital status	Married/common-law (n=848)	0.40 (0.18, 0.91)	0.0293
	Widowed/separated/divorced (n=215)	0.37 (0.14, 0.98)	0.0444
	Single, never been married (n=172)	Reference	
Employment	Yes/no (n=722, n=515)	0.56 (0.31, 1.01)	0.0521
Sensitivity to noise	High/low (n=175, n=1059)	1.90 (1.00, 3.62)	0.0516
Dizziness	Yes/no (n=273, n=965)	3.34 (1.88, 5.95)	$<$0.0001
Chronic pain	Yes/no (n=293, n=943)	3.43 (1.93, 6.09)	$<$0.0001
Asthma	Yes/no (n=101, n=1137)	3.72 (1.76, 7.86)	0.0006
High blood pressure	Yes/no (n=372, n=862)	3.06 (1.69, 5.55)	0.0002
Heart disease	Yes/no (n=95, n=1142)	0.42 (0.15, 1.16)	0.0927
Diagnosed sleep disorder	Yes/no (n=119, n=1119)	4.56 (2.33, 8.94)	$<$0.0001

CI, confidence interval; dB, decibel; H–L, Hosmer–Lemeshow; ON, Ontario; OR, odds ratio; PEI, Prince Edward Island; QOL, quality of life; WTN, wind turbine noise.

[a] The sample size for each variable does not always sum to the study sample size (n=1238) as not all participants responded to each question.
[b] Where a reference group is not specified it is taken to be the last group.
[c] The multiple logistic regression is modeling the probability of a respondent as rating their quality of life as "Poor" which includes those that responded "Poor" and "Very Poor".
[d] OR (CI) odds ratio and 95% confidence interval based on multiple logistic regression model. An OR <1 implies that the category has lower odds of rating QOL as "poor" compared to the reference category.
[e] p-Value significance is in relation to the reference group.
[f] H–L: Hosmer–Lemeshow test, $p>0.05$ indicates a good fit.
[g] WTN level is treated as a continuous scale in the logistic regression model, giving an overall slope and OR for each unit increase in WTN level, where a unit reflects a 5 dB WTN category.
[h] Personal benefit (i.e., rent, payments or other indirect benefits through community improvements) from having wind turbines in the area.

Table 3b
Multiple logistic regression model: Satisfaction with Health

Variable	Groups in variable[a,b]	Satisfaction with Health[c] OR (CI)[d]	p-Value[e]
		(n=989, R^2=0.29, H–L p=0.9214)[f]	
Intercept			$<$0.0001
WTN levels (dB)[g]		0.99 (0.82, 1.18)	0.8726
Province	ON/PEI (n=1011, n=227)	0.94 (0.54, 1.64)	0.8243
Personal benefit[h]	No/yes (n=1075, n=110)	1.21 (0.52, 2.82)	0.6544
Alcohol consumption	Do not drink alcohol (n=274)	Reference	
	$\leq$3 Times/month (n=474)	1.10 (0.68, 1.78)	0.7067
	1–3 Times/week (n=325)	0.50 (0.28, 0.90)	0.0202
	$\geq$4 Times/week (n=164)	0.34 (0.16, 0.74)	0.0062
Hear aircraft	Yes/no (n=609, n=629)	0.54 (0.36, 0.82)	0.0036
Sensitivity to noise	High/low (n=175, n=1059)	1.55 (0.94, 2.53)	0.0834
Migraines[i]	Yes/no (n=289, n=948)	1.60 (1.00, 2.57)	0.0491
Dizziness	Yes/no (n=273, n=965)	2.07 (1.31, 3.26)	0.0017
Chronic pain	Yes/no (n=293, n=943)	3.92 (2.49, 6.18)	$<$0.0001
Arthritis	Yes/no (n=402, n=835)	1.65 (1.06, 2.57)	0.0281
Diabetes	Yes/no (n=113, n=1123)	1.72 (0.94, 3.18)	0.0811
Heart disease	Yes/no (n=95, n=1142)	1.74 (0.91, 3.31)	0.0939
Diagnosed sleep disorder	Yes/no (n=119, n=1119)	2.62 (1.52, 4.52)	0.0005

CI, confidence interval; dB, decibel; H–L, Hosmer–Lemeshow; ON, Ontario; OR, odds ratio; PEI, Prince Edward Island; QOL, quality of life; WTN, wind turbine noise.

[a] The sample size for each variable does not always sum to the study sample size (n=1238) as not all participants responded to each question.
[b] Where a reference group is not specified it is taken to be the last group.
[c] The multiple logistic regression is modeling the probability of a respondent as rating their satisfaction with health as "Dissatisfied" which includes those that responded "Dissatisfied" and "Very Dissatisfied".
[d] OR (CI) odds ratio and 95% confidence interval based on multiple logistic regression model. An OR <1 implies that the category has lower odds of rating QOL as "poor" compared to the reference category.
[e] p-Value significance is in relation to the reference group.
[f] H–L: Hosmer–Lemeshow test, $p>0.05$ indicates a good fit.
[g] WTN level is treated as a continuous scale in the logistic regression model, giving an overall slope and OR for each unit increase in WTN level, where a unit reflects a 5 dB WTN category.
[h] Personal benefit (i.e., rent, payments or other indirect benefits through community improvements) from having wind turbines in the area.
[i] Migraines or headaches (including nausea, vomiting, sensitivity to light and sound).

Table 4
Summary of variables retained in multiple regression models for WHOQOL-BREF

	Domains				Stand-alone questions	
	Physical	Psychological	Social Relationships	Environment	Rated QOL as *poor*	Rated Satisfaction with Health as *dissatisfied*
Demographic variables						
Province		X				
Sex			X			
Age group		X	X	X		
Marital status	X	X	X		x	
Employment	X	X	X		x	
Smoking status	X			X		
Level of education		X		X		
Income				X		
Alcohol use	X	x		x		X
Property ownership				x		
Façade type			X	x		
Audible aircraft						X
Audible rail	x		x			
Wind turbine related variables						
Number of years turbines audible		X		x		
Personal benefit	X					x
Visual annoyance	X			X		
Shadow flicker annoyance				x		
Personal and health-related variables						
Sensitivity to noise		x			x	x
Migraines		X	X	X		X
Dizziness	X	X	X	X	X	X
Chronic pain	X	X	X	X	X	X
Diagnosed sleep disorder	X	X	X	X	X	X
Tinnitus	X	X		X		
Arthritis	X					X
High blood pressure					X	
Medication for high blood pressure	X					
Chronic bronchitis/emphysema/COPD	X		X			
Diabetes	X	x				x
Heart disease					x	x
Asthma				X	X	

All variables marked in the table were statistically significant at $p < 0.10$, variables marked with an upper case X are statistically significant at $p < 0.05$. WHO, World Health Organization; QOL, quality of life. Rated QOL as "Poor" includes participants that responded "Poor" and "Very Poor"; Rating Satisfaction with Health as "Dissatisfied" includes participants that responded "Dissatisfied" or "Very Dissatisfied".

concluded that '*those benefiting are more usually 'healthy farmers', have a more positive view on the visual impact of wind turbines and are relatively young and well educated*'.

Although exposure to WTN was not found to be related to the 4 domains or the QOL or Satisfaction with Health questions, there were specific wind turbine-related variables, beyond personal benefit, that did have an influence on some of these outcomes and which were retained in the multiple regression models. Reporting high visual annoyance from wind turbines was found to be related to lower scores on both the Physical Health and Environment domains of the WHOQOL-BREF, but was unrelated to Psychological, Social Relationships, or rated QOL or Satisfaction with Health. The link between high visual annoyance and lower Environment domain scores is not unexpected as this domain taps into the level of satisfaction respondents report with their physical living space and how healthy and safe they believe their physical environment to be (WHOQOL-BREF, 1996). It is therefore not unreasonable that the Environment domain score would be sensitive to one's annoyance towards the visual presence of wind turbines. In terms of the Physical Health domain, it could be speculated that a high visual annoyance with wind turbines may influence one or more of the facets which comprise this particular domain. It is also possible that the visual perception of wind turbines may have an influence on the perception of the sound levels produced by wind turbines. Visual attributes were found to have an influence on the auditory perception of wind turbines in a controlled laboratory study by Maffei et al. (2013) and may extend to field settings. Although this study represents a relatively new area of investigation, the findings of this study add to existing research that have reported visual disturbance from wind turbines or negative attitudes towards the visual impact of wind turbines on the landscape (Blackburn et al., 2009; Devine-Wright and Howes, 2010; Pasqualetti, 2011; Pedersen and Larsman, 2008; Pedersen and Persson Waye, 2007).

The CNHS study included questions to investigate the length of time respondents reported that wind turbines were audible as a proxy for their history of exposure to WTN. The rationale was to provide insight into whether individuals were adapting or becoming sensitized to WTN exposure over time. Comparisons between participants not hearing wind turbines at all and those who reported hearing them for less than or greater than or equal to 1 year, revealed that those who reported to have heard WTN for less than 1 year had slightly higher (i.e. mean difference between 0.78 and 1.0) scores on the Psychological domain, relative to the absent and greater than or equal to 1 year categories. The small changes between groups, the inconsistent pattern of response with extended audibility and the lack of longer term follow-up make it impossible to draw any meaningful conclusions from these results.

With respect to noise sensitivity, 14% of the respondents indicated that they were either very or extremely (i.e. highly) sensitive to noise in general, which is in line with the prevalence rates of 12% and 15% reported in previous studies (Miedema and Vos, 2003; van Kamp et al., 2004). In the univariate analysis, noise sensitivity was found to be significantly associated with Physical Health, Social Relationships, and Environment domains and marginally with the Psychological domain. In all cases, being highly noise sensitive was related to a worsening of QOL in these areas. Similarly, the odds of reporting poor QOL and Dissatisfaction with Health were higher among those who were highly noise sensitive. However, when considered along with other factors in multiple regression models for the different domains and two stand-alone WHOQOL-BREF questions, noise sensitivity becomes less relevant. This suggests that other factors, which included, but were not limited to, having chronic pain or a chronic disease, being unemployed and suffering from migraines, were more important in explaining the overall variance in the final models.

5. Conclusions

In the current study, the overall variance accounted for in the multiple regression models pertaining to the 4 WHOQOL-BREF domains was between 16% and 45%. The models for the two standalone questions, rated QOL and Satisfaction with Health, were also rather weak at 31% and 29%, respectively. These findings demonstrate that most of the variance in these models cannot be accounted for by the variables included in the current study. Many of the demographic and health-related variables previously shown to be related to QOL were statistically related to multiple QOL parameters assessed using the WHOQOL-BREF questionnaire. This demonstrates that the utilization of this tool in the current study was a sensitive measure for detecting changes in QOL. Therefore, it is notable that WTN levels up to 46 dB were not statistically related to any of the modeled outcomes.

The current study modeled WTN levels using a long term A-weighted metric, however it may be that a noise metric other than, or in addition to the A-weighting may reveal a stronger association with self-reported QOL. In the current study, C-weighted WTN levels were modeled in addition to A-weighted levels, however these results were not presented as the dBC and dBA values were highly correlated (Michaud, 2015). A large-scale wind turbine epidemiological/laboratory study conducted in Japan considered A- C- and G-weighted WTN levels, in addition to amplitude modulation, and concluded that the response to wind turbines was more accurately assessed using the A-weighted metric (Tachibana et al., 2014). However, they concluded that a quantification of amplitude modulation and tonality was warranted in future wind turbine studies, a conclusion echoed in a key finding of the Council of Canadian Academies (2015) following their review of the wind turbine literature. Therefore, a quantification of these sound characteristics may provide further insight into how WTN exposure may influence QOL.

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Appendix A. Supplementary material

Supplementary data associated with this article can be found in the online version at http://dx.doi.org/10.1016/j.envres.2015.06.043.

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The effects of environmental and classroom noise on the academic attainments of primary school children

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The effects of environmental and classroom noise on the academic attainments of primary school children

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While at school children are exposed to various types of noise including external, environmental noise and noise generated within the classroom. Previous research has shown that noise has detrimental effects upon children's performance at school, including reduced memory, motivation, and reading ability. In England and Wales, children's academic performance is assessed using standardized tests of literacy, mathematics, and science. A study has been conducted to examine the impact, if any, of chronic exposure to external and internal noise on the test results of children aged 7 and 11 in London (UK) primary schools. External noise was found to have a significant negative impact upon performance, the effect being greater for the older children. The analysis suggested that children are particularly affected by the noise of individual external events. Test scores were also affected by internal classroom noise, background levels being significantly related to test results. Negative relationships between performance and noise levels were maintained when the data were corrected for socio-economic factors relating to social deprivation, language, and special educational needs. Linear regression analysis has been used to estimate the maximum levels of external and internal noise which allow the schools surveyed to achieve required standards of literacy and numeracy. [DOI: 10.1121/1.2812596]

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I. INTRODUCTION

Children are exposed to many different types of noise while at school. Previous studies have shown that schools may be exposed to high levels of environmental noise, particularly in urban areas.[1,2] Sources include road traffic, trains, aircraft, and construction noise. Inside schools a wide range of noise levels have been measured,[3–7] the levels varying significantly between different types of space and different classroom activities.[1] For much of the day in a primary school classroom, young children are exposed to the noise of other children producing "classroom babble" at levels typically of around 65 dB(A) L_{Aeq},[1] while the typical overall exposure level of a child at primary school has been estimated at around 72 dB(A) L_{Aeq}.[1]

The effects of noise on children and their teachers have been investigated in many studies in the past 40 years. It is generally accepted that noise has a detrimental effect upon the cognitive development of primary school children, and that older children in this age group are more affected than the younger children.[8,9] Two major reviews of previous work in this area, published in the early 1990s, concluded that chronic noise exposure of young children has an adverse effect, particularly upon their reading ability.[10,11]

Most of the previous work has concerned the effects of environmental noise, notably aircraft noise, upon children. Exposure to high levels of aircraft noise has been found to affect memory and reading ability, and to reduce motivation in school children.[11–15] These effects appear to be long term; noise reduction inside a school has been found to have little immediate effect upon children's performance[16] while another study found that when an airport was closed it took several years for the detrimental effects of noise exposure to cease.[13] These results suggest that noise reduces the learning trajectories of the pupils involved so that extended periods of teaching and learning are required for children to reach typical levels of performance.

In addition to aircraft noise other types of environmental noise, including that from railways[17,18] and road traffic,[19] have been found to affect reading. Road traffic noise outside schools, at levels of around 70 dB(A), has also been found to reduce children's attention.[20,21]

While there is a large body of work concerning the effects of external environmental noise upon children at school, there have been far fewer investigations into the effects of typical classroom noise upon children's performance. However in recent years evidence has been found to suggest that noise inside the classroom affects letter, number, and word recognition.[10,22–25]

It is thus now generally accepted that all types of noise exposure at school affect children's learning and academic performance. The majority of the previous studies have com-

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pared the performance of children exposed long term to significant levels of environmental noise with that of children with low noise exposure, or have examined the effects of noise reduction on children's performance. There have been few studies which have demonstrated a dose/response relationship between noise and effects on children's performance, thereby making it difficult to determine threshold levels at which adverse effects occur, which in turn makes it difficult to establish specific guideline values to prevent such effects.[26]

In recent years several countries have introduced standards and guidelines relating to the acoustic design of schools and classrooms. For example, in the United States ANSI standard S12.60,[27] published in 2002, sets out guideline values for noise levels, reverberation times, and sound insulation in schools. Since 2003 new school buildings in England and Wales must comply with the Building Regulations. The acoustic requirements are specified in Building Bulletin 93 (BB93),[28] published in 2003. The requirements of S12.60 and BB93 are similar, for example the maximum noise level specified by both for empty classrooms is 35 dB(A) L_{Aeq}. However, in general the noise specifications for classrooms are based upon speech intelligibility requirements, rather than the levels of noise which have direct detrimental effects upon children's performance in the classroom.

In the study described here noise levels measured outside 142 primary schools in central London (UK), and inside a range of spaces inside 16 schools have been compared with assessment scores of the schools in national standardized tests. The approach taken enables the effects on children at school of different levels and types of noise to be investigated. It is also possible to compare the impact of various types of noise upon different aged children across a variety of academic tasks. In addition, this approach allows the most important property of the noise (for example, its background, maximum, or ambient level) in relation to academic performance to be determined, an issue that has not been considered in previous studies.

A simultaneous study by the authors[29] used experimental testing to investigate the effects of environmental and classroom noise on children's performance on a range of tasks in the classroom. It will be seen that the results of the two investigations are complementary and advance the understanding of the different ways in which children's academic performance and development are affected by noise.

II. MATERIALS AND METHODS

A. Procedure

The study investigated the effects of chronic noise exposure upon children's academic attainments by comparing measured noise levels with recognized standardized measures of children's attainments in primary school. The relationships between attainment scores for individual schools and both external (environmental) and internal noise were examined. The effects of acute exposure to environmental and classroom noise were also investigated in the above-mentioned complementary experimental study.[29]

B. Measures of children's attainments: Standardized assessment tests (SATs)

In the 1990s a standard national curriculum was introduced for all schools in England and Wales. To complement this curriculum, standardized assessment tests (SATs) in various subjects including English, Mathematics, and Science were introduced across the age range at both primary and secondary school level. The majority of children at state schools take these tests at the ages of 7 ("Key Stage 1"), 11 ("Key Stage 2") and 14 ("Key Stage 3") years. Average results for all schools in all subjects are published by the Department for Education and Skills. The published school data consist of the percentages of children in each school who reach a recognized criterion level in each subject at each stage. Average school scores for each stage are also published. Each year the UK government sets targets for literacy and numeracy in primary schools by specifying Key Stage 2 SAT scores which schools must aim to achieve. At the time of the survey the target scores for schools were 75% for Key Stage 2 Mathematics and 80% for Key Stage 2 English.

The study described here concerned children of primary school age. The relevant test data for comparison with noise were therefore Key Stage 1 and Key Stage 2 SAT results. At Key Stage 1 (KS1) the assessment includes both teacher assessments and national standardized tests, which are combined to give a single score for each subject for each child. At Key Stage 2 (KS2) children sit for standard nationwide examinations. Between two and four examinations are taken in each subject, the examination results being averaged to give a single mark for each subject.

The subjects assessed at the two stages at the time of this study were as follows: Key Stage 1 (Year 2 of primary school, 7 years of age on average): Reading; Writing; Spelling; and Mathematics. Key Stage 2 (Year 6 of primary school, 11 years of age on average): English; Mathematics; and Science.

The schools' attainment scores in each subject, plus average scores, at Key Stage 1 and Key Stage 2, were compared with noise levels measured inside and outside the schools.

C. Selection of study areas and schools

The areas chosen for the study were based upon the local government boroughs of London, of which there are 33. It was important for the study that the boroughs chosen should be representative of London as a whole in terms of noise exposure, academic achievements, and demographic characteristics in order to reduce the number of potentially confounding variables.

It was decided that boroughs in which aircraft were the dominant environmental noise source should be excluded from the survey, as there was already a considerable body of research on the effects of aircraft noise on children. There was also a concurrent study of the effects of aircraft noise on children in schools to the west of London, around Heathrow airport.[14] Furthermore, there were fewer detailed studies of the impact of general environmental noise than of aircraft

TABLE I. SAT results, demographic factors, and external noise levels for the three boroughs.

Stage	Subject	Borough A		Borough B		Borough C	
		Mean	s.d.	Mean	s.d.	Mean	s.d.
Key Stage 1 test results	Reading	76.1	14.1	74.7	13.2	78.4	16.9
	Writing	76.8	14.9	74.8	13.9	78.2	16.9
	Spelling	63.8	17.1	59.3	17.2	64.7	18.4
	Maths	86.4	8.9	83.5	12.0	86.4	13.2
Key Stage 2 test results	English	68.5	18.5	69.8	15.7	69.5	16.6
	Maths	66.1	16.2	67.0	15.7	68.2	19.1
	Science	77.9	15.9	81.0	12.6	78.9	17.3
Demographic factors	% FSM	38.8	19.3	41.5	14.2	33.6	10.7
	% EAL	43.9	19.2	35.3	16.8	39.6	17.7
	% SEN	10.3	2.9	28.3	10.0	26.2	7.8
External noise levels	$L_{\mathrm{Aeq,5\ min}}$	57.4	8.8	56.2	9.4	58.9	7.4
	$L_{\mathrm{A10,5\ min}}$	59.4	9.0	58.4	9.9	61.2	7.7
	$L_{\mathrm{A90,5\ min}}$	49.2	7.7	46.5	9.3	50.2	8.2
	$L_{\mathrm{A99,5\ min}}$	47.0	7.4	44.3	9.2	47.8	8.2
	$L_{\mathrm{Amax,5\ min}}$	70.5	10.5	68.3	17.0	72.0	9.0
	$L_{\mathrm{Amin,5\ min}}$	46.0	7.5	41.3	12.4	47.0	8.3

noise. Therefore, in selecting boroughs for the purpose of this study those affected particularly by aircraft noise were excluded.

Remaining boroughs were examined to ensure that their primary school academic attainments and demographic characteristics (see Sec. II D) were typical of London as a whole. The distributions of SAT results in boroughs were studied in order to select boroughs for which (a) test scores displayed an acceptable range, as indicated by the standard deviations of the SAT results in all subjects and (b) the mean scores for reading, writing, and mathematics were not above the mean score of all London boroughs. Of the boroughs selected in this way agreement was obtained from the Directors of Education of three boroughs to participate in the project. Borough A is a suburban London borough, all schools being within approximately 6 miles of central London. Boroughs B and C, on the other hand, are more centrally located, with all schools within a distance of approximately 3 miles from central London. Demographic differences between the boroughs are discussed in Sec. II D.

Means and standard deviations of the subject scores for the three boroughs are shown in Table I. Analysis of variance showed that there was no significant difference between the subject scores for the three boroughs.

It can be seen from Table I that there was in general close agreement between mean subject scores in the three boroughs, while borough C displayed slightly higher standard deviations in most subjects indicating a wider spread of scores in this borough.

D. Demographic characteristics

The socio-economic characteristics of schools in the boroughs were also examined. The data considered were the percentages of children in each school receiving free school meals (FSM); the percentages of children for whom English is an additional language (EAL); and the percentages of children with special educational needs (SEN). The percentage of children receiving free school meals is commonly accepted as a reliable indicator of social disadvantage in an area.[30,31]

The means and standard deviations of these data for the three chosen boroughs are also given in Table I. Analysis of variance showed that there were some differences between the boroughs, particularly in the distributions of children with special educational needs. There were considerably fewer children with special needs in (suburban) borough A while the percentages for the central boroughs were similar and around 2.5 times the percentage in borough A.

A major difference between the boroughs is in the density of population. At the time of the surveys the populations per square kilometer of the three boroughs were approxi-

TABLE II. Internal noise levels.

	School location					Class (age group)								
	Occ teach space	Unocc teach space	Corr/ foyer /stair	Occ hall	Unocc hall	Nurs (3–4)	Rec (4–5)	Yr 1 (5–6)	Yr 2 (6–7)	Yr 3 (7–8)	Yr 4 (8–9)	Yr 5 (9–10)	Yr 6 (10–11)
L_{Aeq}	72.1	47.0	58.1	73.4	53.2	71.9	73.9	74.3	66.3	68.9	69.6	73.2	71.2
L_{A90}	54.1	36.9	44.6	55.1	44.3	57.3	62.3	61.0	51.3	52.5	49.8	53.8	52.9

mately as follows: borough A 7600; borough B 12 200, and borough C 10 100. Boroughs B and C therefore represent the more densely populated inner city areas, while borough A is more typical of suburban boroughs.

E. Noise surveys

Noise levels were measured outside all the state-funded primary schools in boroughs A (N=53) and B (N=50) and outside a majority of the 61 schools in borough C (N=39). Of these, eight schools in boroughs A and B were also selected for internal surveys. The eight schools were chosen to reflect the full range of external noise levels measured, the external L_{Aeq} levels of the 16 schools ranging from 49 to 75 dB(A). The measurement methods, noise levels, and noise sources present have been described elsewhere.[1] The external and internal levels that have been used in examining the impact of noise upon test results are summarized in the following.

1. External levels

Table I also shows the means and standard deviations of various environmental noise parameters measured in the three boroughs. These levels were measured at, or have been normalized to, a distance of 4 m from the school façade during the school day.[1]

It can be seen that the levels were reasonably consistent across the three boroughs, with borough C having slightly higher levels than the other two boroughs. This was to be expected as this borough is the one nearest central London. The mean levels in borough B were slightly lower than might be expected given that this is also an inner city borough. However many of the schools in this area are situated in the middle of housing estates or on side streets, and are thus sheltered to some extent from the noise of road traffic, the main noise source in the areas surveyed.[1] This is illustrated by the larger standard deviations of noise levels in borough B.

2. Internal levels

In the internal school noise survey levels were measured in classrooms and other areas around a school. Most spaces were measured in both occupied and unoccupied conditions. The averaged ambient (L_{Aeq}) and background (L_{A90}) levels for the types of spaces considered in each school are shown in Table II.

Internal levels were also categorized according to the age of the class; the average L_{Aeq} and L_{A90} levels for different age groups in each school are also shown in Table II. For the purposes of analyzing the effects, if any, of noise on SAT results noise levels for Year 2 and Year 6 are the only ones considered in the subsequent discussion.

F. Analyses

In order to study the impact, if any, of noise on children's attainment the noise levels measured inside and outside the schools were correlated with the SAT scores for the academic year in which the noise survey was carried out.

TABLE III. Borough A: Correlation coefficients between test scores and external noise levels.

	L_{Aeq}	L_{Amax}	L_{A90}	L_{A10}
KS1 Reading	-0.34^b	-0.31^b	-0.37^a	-0.33^b
KS1 Maths	-0.34^b	-0.27	-0.43^a	-0.34^b
KS2 English	-0.37^a	-0.39^b	-0.40^a	-0.33^b
KS2 Maths	-0.40^a	-0.46^b	-0.40^a	-0.36^a
KS2 Science	-0.40^a	-0.45^b	-0.42^a	-0.37^a
KS1 average	-0.36^b	-0.32^b	-0.40^a	-0.36^b
KS2 average	-0.41^a	-0.45^a	-0.43^a	-0.37^a

[a]Significant at 1% level.
[b]Significant at 5% level.

For external noise it was found that results for L_{A90}, L_{A99}, and L_{Amin} were very similar, as would be expected and was confirmed by factor analysis. Therefore in the following sections, relationships between SAT results and L_{Aeq}, L_{Amax}, L_{A90}, and L_{A10} only are considered. These are the most commonly cited measures of environmental noise and are generally considered to capture the key features of the noise environment.

Similarly, factor and correlation analysis showed a close relationship among results for KS1 literacy-related tests Reading, Writing, and Spelling, as would be expected. Therefore, in the subsequent analysis and discussion, of these tests, results are presented for KS1 Reading only as being a reliable indicator of the younger children's attainments in literacy.

Correlation and regression analysis were carried out for the noise and test data. The noise levels were correlated with subject and average school SAT scores. Obviously any relationships found between noise and SAT scores in this way could be due to social or other factors rather than representing a direct effect of noise on academic performance. In order to eliminate the effects of socio-economic factors, partial correlations were carried out, in which the schools' data on children with FSM, EAL, and SEN were controlled for.

Current guidance on choosing a site for new school buildings in England and Wales recommends an upper limit of 60 dB $L_{Aeq,30\ min}$ at the boundary of school premises.[28] For this reason, in addition to considering all schools mea-

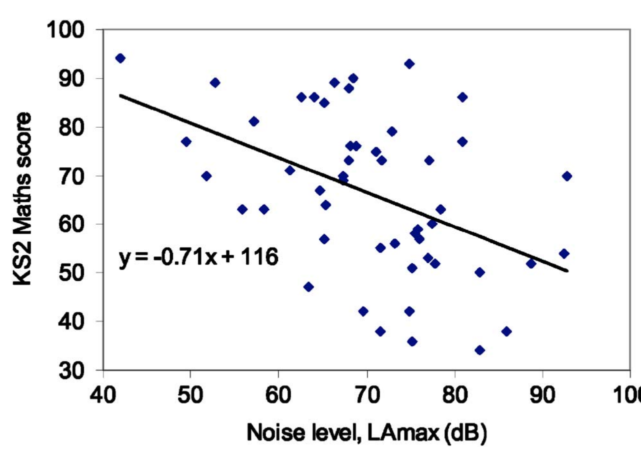

FIG. 1. (Color online) Scatter diagram illustrating relationship between external L_{Amax} and Key Stage 2 Mathematics scores in borough A.

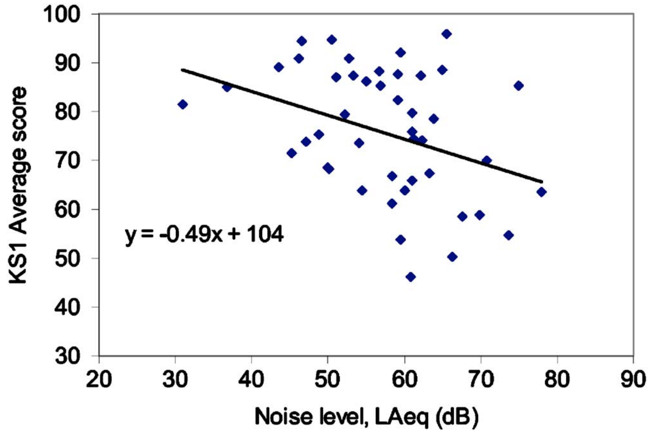

FIG. 2. (Color online) Scatter diagram illustrating relationship between external L_{Aeq} and average Key Stage 1 scores in borough A.

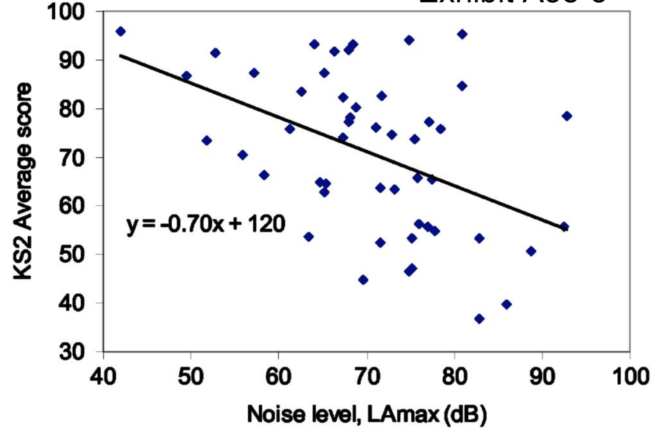

FIG. 3. (Color online) Scatter diagram illustrating relationship between external L_{Amax} and average Key Stage 2 scores in borough A.

sured in each borough, those schools where the measured external L_{Aeq} levels are greater than or equal to 60 dB(A) have been considered separately.

III. RESULTS: RELATIONSHIPS BETWEEN EXTERNAL NOISE AND TEST RESULTS

The values of the noise parameters L_{Aeq}, L_{Amax}, L_{A90}, and L_{A10} measured outside each school were compared with average and subject SAT scores for the younger (aged 7 years) and older (aged 11 years) children.

The Pearson correlation coefficients between average and subject scores and external noise levels were calculated for all schools in boroughs A, B, and C. Table III shows the coefficients for borough A. It can be seen that there were negative relationships between external noise and SATs for all scores, that is, the greater the noise level the lower the school test performance score. Furthermore, all except one of the relationships were significant at the 1% or 5% level. However, for both boroughs B and C the correlation coefficients were very small, varying from −0.15 to 0.28. There were no significant relationships and the coefficients were very similar for the two boroughs. This may be due to the differences between the central and suburban boroughs reflected in the SEN data shown in Table I, and also to the different characteristics of the boroughs as represented by their population densities, discussed in Sec. II D. For this reason the two central boroughs (B and C) are considered together and separately from the suburban borough (A) in the following discussion.

A. Borough A

1. All schools

Table III shows that when all schools in borough A are considered there were significant negative relationships between all SAT scores and all external noise parameters, except for KS1 Mathematics and L_{Amax}. The relationships were stronger for Key Stage 2 subjects, suggesting that noise has more of an impact upon the performance of the older children. A possible explanation for this is that the older children have been exposed to the noise for a longer period of time. This is consistent with the results of previous research demonstrating the effects of long-term noise exposure.[13–16] However, it is also possible that the nature and demands of the tasks for older children differ from those of the younger children and are more vulnerable to the effects of noise.

At Key Stage 1 and for KS2 English the external noise level with the strongest correlation with test scores was the background level, as measured by L_{A90}. For other subjects at Key Stage 2, L_{Amax} was the parameter which had the strongest association with test scores. This suggests that the younger children were affected by general external background noise, while the older children were more affected by individual external noise events such as motorbikes or lorries

TABLE IV. Borough A: Correlation coefficients between test scores and external noise levels corrected for data on FSM, EAL, and SEN.

	L_{Aeq}			L_{Amax}			L_{A90}			L_{A10}		
	FSM	EAL	SEN	FSM	EAL	SEN	FSM	EAL	SEN	FSM	EAL	SEN
KS1 Reading	−0.17	−0.26	−0.32[b]	−0.15	−0.26	−0.29[b]	−0.11	−0.24	−0.35[b]	−0.16	−0.25	−0.31[b]
KS1 Maths	−0.23	−0.28	−0.32[b]	−0.15	−0.22	−0.24	−0.29	−0.35[b]	−0.41[a]	−0.24	−0.28	−0.33[b]
KS2 English	−0.17	−0.27[b]	−0.34[b]	−0.25	−0.38[a]	−0.37[a]	−0.08	−0.23	−0.39[a]	−0.12	−0.22	−0.31[b]
KS2 Maths	−0.23	−0.32[b]	−0.38[a]	−0.36[a]	−0.44[a]	−0.44[a]	−0.10	−0.25	−0.38[a]	−0.19	−0.27	−0.35[a]
KS2 Science	−0.25	−0.32[b]	−0.39[a]	−0.34[b]	−0.42[a]	−0.44[a]	−0.19	−0.30[b]	−0.41[a]	−0.23	−0.29[b]	−0.36[a]
KS1 average	−0.20	−0.29	−0.34[b]	−0.17	−0.27	−0.30[b]	−0.18	−0.29	−0.39[a]	−0.21	−0.28	−0.35[b]
KS2 average	−0.25	−0.33[b]	−0.39[a]	−0.36[a]	−0.45[a]	−0.44[a]	−0.14	−0.28[b]	−0.41[a]	−0.20	−0.28[b]	−0.36[a]

[a]Significant at 1% level.
[b]Significant at 5% level.

TABLE V. Schools in boroughs B and C with external $L_{Aeq} \geq 60$ dB(A): Correlation coefficients between test scores and noise levels.

	L_{Aeq}	L_{Amax}	L_{A90}	L_{A10}
KS1 Reading	−0.40[b]	−0.40[b]	−0.22	−0.36[b]
KS1 Maths	−0.10	−0.09	−0.03	−0.20
KS2 English	−0.39[b]	−0.43[a]	−0.37[b]	−0.38[b]
KS2 Maths	−0.21	−0.31	−0.15	−0.27
KS2 Science	−0.25	−0.36[b]	−0.15	−0.24
KS1 average	−0.31	−0.31	−0.12	−0.28
KS2 average	−0.30	−0.39[b]	−0.24	−0.32

[a]Significant at 1% level.
[b]Significant at 5% level.

passing the school. This is consistent with the findings of previous research,[12–18] which has found that reading is affected by noise caused by individual external sources such as trains or planes. It is also consistent with a questionnaire survey of children carried out by the authors which found that older, Key Stage 2 age, children were more aware of external noise than the younger children at Key Stage 1. The subject showing the strongest negative effect of noise (with background levels at Key Stage 1 and with maximum levels at Key Stage 2) was Mathematics. The mathematics assessment at Key Stage 2 is complex, involving orally presented mental arithmetic, written arithmetic, and word problems. Thus performance at these tasks is vulnerable to the effects of noise on both reading and speeded responses, two areas which have been found to be affected by noise in previous studies.[10–18,29]

Figures 1–3 give examples of scatter diagrams relating external noise levels and SAT scores. Figure 1 shows the relationship between L_{Amax} and Key Stage 2 Mathematics scores; Fig. 2 shows the scatter diagram of L_{Aeq} and average Key Stage 1 score; and Fig. 3 average Key Stage 2 score and L_{Amax}. Regression lines relating external noise levels and SAT scores are also shown in Figs. 1–3. The implications of these relationships are discussed in Sec. V.

Table IV shows the partial correlation coefficients obtained when the data for borough A were controlled for the FSM, EAL, and SEN data. It can be seen that when social deprivation (as measured by FSM data) was taken into account there was still a negative relationship between external noise and test scores, but there were fewer significant relationships than with the uncorrected data. However, L_{Amax} was still significantly correlated with two subject scores (Mathematics and Science) and the average score at Key Stage 2. The strongest relationship was again with the Mathematics scores. When potential language demands (as indicated by EAL data) were accounted for there were still strong associations between L_{Amax} and all subjects at Key Stage 2, with Mathematics again being the subject most strongly related to noise. As with the uncorrected data, KS1 Mathematics scores were most strongly, and significantly, related to the external background noise level. When controlling for SEN, it can be seen that the pattern was very similar to that for the uncorrected data, with KS2 Mathematics and Science again being the subjects most affected by external noise, and L_{Amax} having the strongest negative relationship with test scores at Key Stage 2.

2. Schools with external L_{Aeq} levels of 60 dB(A) or greater

When considering only those schools with external L_{Aeq} levels of 60 dB(A) or more in borough A ($N=22$), KS1 Mathematics was the only subject significantly related to noise, being significantly related at the 5% level to L_{A90}. This significant relationship was maintained when the data were corrected for socio-economic factors, becoming significant at the 1% level when correcting for SEN.

B. Boroughs B and C

1. All schools

As mentioned previously, there were no significant relationships between test scores and external noise for the central London boroughs when all schools in the two boroughs were considered. The reason for the difference between these schools and those in borough A is unclear, but may be related to the discrepancies in the percentages of children with special needs in the central and suburban boroughs, or to the differing population characteristics between the boroughs.

2. Schools with external L_{Aeq} levels of 60 dB(A) or greater

If only those schools where the external level exceeds 60 dB L_{Aeq} in the two boroughs were considered ($N=35$) then there were stronger negative relationships between SAT

TABLE VI. Schools in boroughs B and C with external $L_{Aeq} \geq 60$ dB(A): Correlation coefficients between test scores and noise levels corrected for data on FSM, EAL, and SEN.

	L_{Aeq}			L_{Amax}			L_{A90}			L_{A10}		
	FSM	EAL	SEN	FSM	EAL	SEN	FSM	EAL	SEN	FSM	EAL	SEN
KS1 Reading	−0.35[b]	−0.40[b]	−0.35[b]	−0.40[b]	−0.41[b]	−0.43[a]	−0.13	−0.22	−0.16	−0.23	−0.36[b]	−0.29
KS1 Maths	−0.00	−0.08	−0.02	−0.04	−0.10	−0.10	0.09	0.05	0.07	−0.04	−0.15	−0.10
KS2 English	−0.34[b]	−0.37[b]	−0.32	−0.46[a]	−0.46[a]	−0.48[a]	−0.30	−0.28	−0.29	−0.23	−0.32	−0.29
KS2 Maths	−0.09	−0.18	−0.11	−0.30	−0.32[b]	−0.34[b]	−0.01	−0.06	−0.05	−0.06	−0.21	−0.16
KS2 Science	−0.16	−0.23	−0.20	−0.35[b]	−0.37[b]	−0.37[b]	−0.03	−0.08	−0.09	−0.06	−0.19	−0.17
KS1 average	−0.25	−0.31	−0.25	−0.29	−0.31	−0.33	−0.02	−0.11	−0.04	−0.14	−0.28	−0.21
KS2 average	−0.22	−0.28	−0.23	−0.41[b]	−0.41[b]	−0.43[a]	−0.13	−0.16	−0.16	−0.13	−0.26	−0.22

[a]Significant at 1% level.
[b]Significant at 5% level.

TABLE VII. Internal noise: Correlation coefficients between test scores and Year 2 and Year 6 noise levels.

	Year 2 $N=11$		Year 6 $N=13$	
	L_{Aeq}	L_{A90}	L_{Aeq}	L_{A90}
KS1 Reading	0.01	−0.12		
KS1 Maths	−0.17	−0.33		
KS2 English			−0.45	−0.48
KS2 Maths			−0.04	−0.00
KS2 Science			−0.36	−0.11
KS1 average	−0.15	−0.29		
KS2 average			−0.33	−0.25

scores and noise, as shown in Table V. For most external noise parameters, as with borough A schools, the relationships were stronger for Key Stage 2 results, and in general L_{Amax} was the parameter most closely related to test results. In these boroughs, however, English was the subject showing the greatest effect of noise. Both KS1 Reading and KS2 English scores were significantly related to external L_{Aeq}, L_{Amax}, and L_{A10} levels, while KS2 English was also significantly related to the background L_{A90} level. Unlike the suburban borough, Mathematics scores were not significantly related to any external noise parameter.

Table VI shows the correlations when the data were corrected for socio-economic factors. In all cases the results were very similar to those for the uncorrected data. KS1 Reading and KS2 English were the subjects most affected by external noise, KS2 English being significantly correlated with L_{Amax} at the 1% level and L_{Amax} again being the noise parameter with the strongest correlations with test scores. When correcting for EAL and SEN, all subjects at KS2 were significantly related to L_{Amax}. Relationships between KS2 English and L_{Amax} were significant at the 1% level, and stronger than for the uncorrected data.

IV. RESULTS: RELATIONSHIPS BETWEEN INTERNAL NOISE AND TEST RESULTS

In investigating relationships between internal noise and SATs, average and subject Key Stage 1 and Key Stage 2 SAT scores were correlated with relevant internal noise data. For this analysis, correlations were carried out for the complete set of 16 schools (eight in borough A and eight in borough B) for which internal noise data were available. The internal noise data that were used consisted of the L_{Aeq} and L_{A90} levels for Year 2 and Year 6 (as these are the years in which children sit for SATs); and in the various school locations which were measured.

A. Correlation with year group levels

Table VII shows the correlations between KS1 test scores and Year 2 noise levels, and between KS2 scores and Year 6 levels. It can be seen that there were negative relationships between all scores and noise levels, except for Key Stage 1 Reading; however, none of the correlations were significant, possibly because of the small sample size. The subject showing the strongest effect of internal noise was KS2 English, which was related to both L_{Aeq} and L_{A90} levels. This is consistent with the results of the parallel experimental testing,[29] which showed that classroom babble affected all tasks both verbal and nonverbal.

When the data were corrected for socio-economic factors KS2 English was still the subject most strongly affected by internal noise; when correcting for FSM there was a significant negative relationship ($r=-0.59$, $p<0.05$) between background noise (L_{A90}) in Year 6 classrooms and test scores for this subject.

B. Correlation with location levels

Table VIII shows the correlation coefficients between L_{Aeq} and L_{A90} levels for different school locations and subject test scores. There were negative correlations between all subject scores and all noise levels measured in occupied classrooms, unoccupied classrooms, and corridors and foyers. In general the relationships were strongest for occupied classrooms, with the background (L_{A90}) level being significantly related to test scores for most subjects. The subject most strongly affected by internal noise was again KS2 English, which was significantly correlated at the 1% level with occupied classroom L_{A90}. KS1 Mathematics was significantly related to L_{A90} in both occupied and unoccupied classrooms.

Figures 3–6 show scatter diagrams relating internal noise and KS2 English scores, KS1 average scores, and KS2

TABLE VIII. Internal noise: Correlation coefficients between test scores and school location noise levels.

	Occ class $N=16$		Unocc class $N=14$		Corridor/foyer $N=14$		Occ hall $N=8$		Unocc hall $N=7$	
	L_{Aeq}	L_{A90}	L_{Aeq}	L_{A90}	L_{Aeq}	L_{A90}	L_{Aeq}	L_{A90}	L_{Aeq}	L_{A90}
KS1 Reading	−0.11	−0.60[b]	−0.33	−0.46	−0.38	−0.39	0.32	0.06	0.14	0.18
KS1 Maths	−0.12	−0.57[b]	−0.52	−0.55[b]	−0.38	−0.40	0.36	0.21	0.43	0.34
KS2 English	−0.55[b]	−0.77[a]	−0.08	−0.20	−0.53[b]	−0.62[b]	−0.12	−0.28	0.47	0.49
KS2 Maths	−0.22	−0.46	−0.06	−0.21	−0.47	−0.49	0.18	0.03	0.28	0.36
KS2 Science	−0.41	−0.50[b]	−0.14	−0.32	−0.38	−0.39	−0.09	−0.31	−0.19	−0.04
KS1 average	−0.16	−0.58[b]	−0.41	−0.51	−0.41	−0.39	0.24	0.06	0.15	0.18
KS2 average	−0.43	−0.64[a]	−0.10	−0.46	−0.49	−0.35	−0.00	0.03	0.15	0.35

[a]Significant at 1% level.
[b]Significant at 5% level.

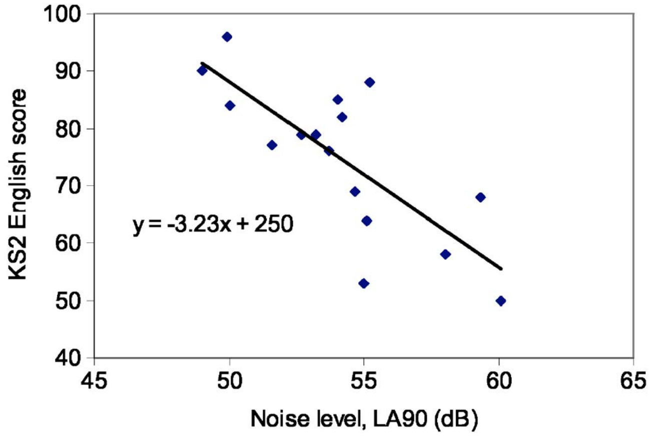

FIG. 4. (Color online) Scatter diagram illustrating relationship between occupied classroom L_{A90} and Key Stage 2 English scores.

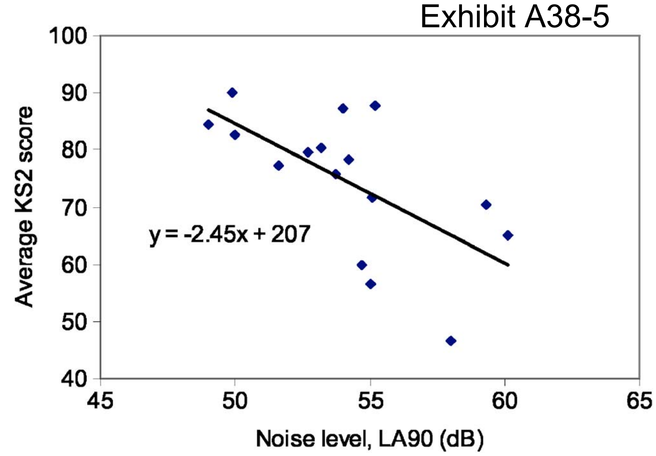

FIG. 6. (Color online) Scatter diagram illustrating relationship between occupied classroom L_{A90} and average Key Stage 2 scores.

average scores, respectively. Regression lines relating internal noise levels and SAT scores are also shown in Figs. 3–6 and are discussed in more detail in Sec. V.

It is interesting to note that there were consistently negative correlations between test scores and all noise levels in corridors and foyers, being significant again for KS2 English. While carrying out internal noise surveys it was subjectively apparent that the noise in such spaces gave a good indication of the general "noise climate" in a school.

It can be seen that there was no relationship between noise levels in school halls, occupied or unoccupied, and test scores. This is as would be expected and validates the fact that there are strong negative relationships between noise in classrooms and test results.

Tables IX and X show the correlation coefficients between test scores and L_{Aeq} and L_{A90} levels, respectively, in classrooms and circulation areas when the data were corrected for socio-economic factors. In general, relationships were slightly less strong when correcting for FSM and EAL but when correcting for SEN correlations coefficients were similar to those for the uncorrected data. KS2 English was still significantly correlated with L_{Aeq} in occupied classrooms and in corridors/foyers. When correcting for all factors there were significant correlations between KS2 English and L_{A90} in occupied classrooms and corridors/foyers.

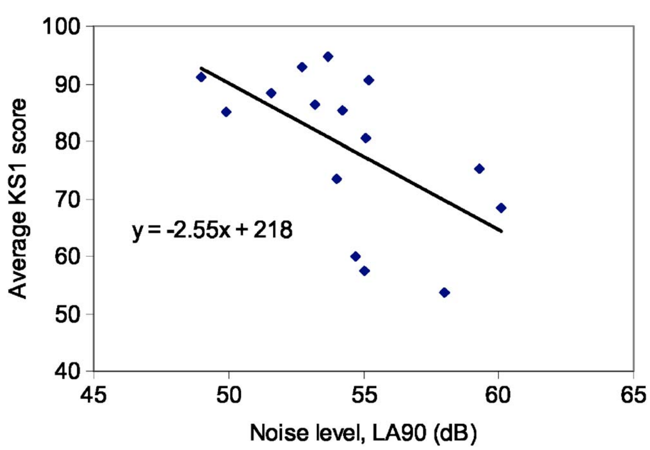

FIG. 5. (Color online) Scatter diagram illustrating relationship between occupied classroom L_{A90} and average Key Stage 1 scores.

V. QUANTIFYING THE EFFECTS OF NOISE

The regression lines relating noise levels and SAT scores for the most significant results have been calculated. In borough A these relationships have been used to investigate the implications of increases in external L_{Aeq}, L_{Amax}, and L_{A90} levels, and to establish the noise levels in this borough which correspond to the UK government targets in numeracy and literacy at the time of the survey (80% of children achieving required level in KS2 English and 75% in KS2 Mathematics). Similar analysis has been carried out for internal background (L_{A90}) levels in occupied classrooms.

A. External noise

The equations of the regression lines relating external noise (L_{Aeq}, L_{Amax}, and L_{A90} levels) and Key Stage 2 English and Mathematics scores in borough A are shown in Table XI. For completeness the relationships between noise and average Key Stage 1 and 2 scores are also shown. These linear relationships have been used to estimate the percentage decreases in the numbers of children achieving the required level for each 10 dB increase in external noise; these are also shown in Table XI. Table XI also shows the external noise levels, derived from the regression lines, which correspond to the UK government targets in English and Mathematics.

It can be seen that an increase of 10 dB(A) in external L_{Aeq}, L_{Amax}, and L_{A90} levels in borough A causes 5%, 4%, and 6% drops, respectively, in the number of children achieving the required levels at Key Stage 1, and drops of 7%, 9% and 9%, at Key Stage 2. This further illustrates the greater detrimental effect of noise on the older children in the primary school age range. The external L_{Aeq}, L_{Amax}, and L_{A90} levels corresponding to the UK government target for literacy are 42 dB(A), 54 dB(A), and 37 dB(A), respectively; for numeracy the corresponding levels are 44, 58, and 38 dB(A). It should be noted that these refer to external levels at a point 4 m from the school façade, and should be interpreted with caution as discussed in Sec. VI.

TABLE IX. Internal noise: Correlation coefficients between test scores and school location L_{Aeq} levels corrected for FSM, EAL, and SEN.

	Occupied classroom $N=16$			Unoccupied classroom $N=14$			Corridor/foyer $N=14$		
	FSM	EAL	SEN	FSM	EAL	SEN	FSM	EAL	SEN
KS1 Reading	0.11	0.13	−0.09	−0.05	−0.19	−0.34	−0.25	−0.33	−0.49
KS1 Maths	0.15	0.18	−0.14	−0.28	−0.42	−0.52	−0.23	−0.33	−0.42
KS2 English	−0.45	−0.44	−0.53[b]	0.32	0.11	−0.10	−0.43	−0.50	−0.71[a]
KS2 Maths	−0.07	−0.09	−0.24	0.23	0.07	−0.05	−0.38	−0.43	−0.51
KS2 Science	−0.33	−0.32	−0.38	0.04	−0.03	−0.15	−0.31	−0.34	−0.53
KS1 average	0.09	0.08	−0.15	−0.12	−0.29	−0.41	−0.27	−0.36	−0.49
KS2 average	−0.32	−0.31	−0.42	0.21	0.05	−0.12	−0.39	−0.45	−0.62[b]

[a]Significant at 1% level.
[b]Significant at 5% level.

B. Internal noise

The regression lines relating internal background L_{A90} levels in occupied classrooms and Key Stage 2 English and Mathematics scores are shown in Table XII. The linear relationships between noise and average Key Stage 1 and 2 scores are also shown. Table XII also shows the percentage decreases in the numbers of children achieving the required level in SATs for each 5 dB increase in internal background noise, plus the internal background noise levels in occupied classrooms, derived from the regression lines, which correspond to the UK government targets in English and Mathematics.

Table XII shows that there is a 13% reduction in the number of children achieving the required level at Key Stage 1 and a 12% reduction at Key Stage 2, for each 5 dB(A) increase in the background noise level in occupied classrooms. The background noise level corresponding to the government target for literacy is 53 dB(A) L_{A90}, while for numeracy it is 50 dB(A) L_{A90}. As with external levels, care is needed in interpreting these figures as discussed in Sec. VI.

VI. DISCUSSION

The study described here has shown that chronic exposure to noise at school has a detrimental effect upon children's academic performance, as measured by standard assessment testing in schools in England and Wales. These are consistent with the findings of previous studies and with the results of experimental testing of children carried out by the authors, as will be discussed in the following. Both external environmental noise heard inside a school and noise generated within a school have an impact upon children's test scores, but affect children in different ways. In addition to different subjects being affected by external and by school noise, the particular characteristics of the noise which impact upon children's performance differ between the two types of noise.

A. External noise

It was seen that different results were obtained for the suburban (A) and central (B and C) boroughs. For borough A there were strong relationships between all noise parameters and all test scores when all schools were considered, but for the other boroughs significant relationships were found when only the schools on the noisier sites were considered. The reasons for the discrepancies are not fully understood but may relate to differences in demographic, population, and/or noise characteristics between the boroughs. There may be "floor" effects for the inner city boroughs in that, however low the noise levels, the overall school test scores would not improve above a certain level. As was noted earlier the two central boroughs considered had high levels of children with SEN. The parallel experimental study carried out by the authors[29] showed that children with SEN were particularly vulnerable to the effects of noise so it is possible that this factor limits the overall achievements of these schools.

TABLE X. Internal noise: Correlation coefficients between test scores and school location L_{A90} levels corrected for FSM, EAL, and SEN.

	Occupied classroom $N=16$			Unoccupied classroom $N=14$			Corrifor/foyer $N=14$		
	FSM	EAL	SEN	FSM	EAL	SEN	FSM	EAL	SEN
KS1 Reading	−0.44	−0.47	−0.60[b]	−0.21	−0.30	−0.45	−0.26	−0.30	−0.40
KS1 Maths	−0.36	−0.40	−0.60[b]	−0.30	−0.40	−0.57[b]	−0.25	−0.29	−0.40
KS2 English	−0.66[a]	−0.69[a]	−0.76[a]	0.19	0.03	−0.17	−0.55[b]	−0.58[b]	−0.64[b]
KS2 Maths	−0.30	−0.36	−0.49	0.06	−0.07	−0.22	−0.40	−0.43	−0.48
KS2 Science	−0.42	−0.42	−0.48	−0.18	−0.21	−0.29	−0.31	−0.33	−0.40
KS1 average	−0.38	−0.44	−0.59[b]	−0.24	−0.36	−0.51	−0.26	−0.31	−0.41
KS2 average	−0.51[b]	−0.54[b]	−0.63[a]	0.01	−0.10	−0.26	−0.44	−0.47	−0.54

[a]Significant at 1% level.
[b]Significant at 5% level.

TABLE XI. Borough A: Regression lines relating external noise levels and SAT scores.

	L_{Aeq}			L_{Amax}			L_{A90}		
	Regression equation	% drop ≈10 dB increase	Level≈target	Regression equation	% drop ≈10 dB increase	Level≈target	Regression equation	% drop ≈10 dB increase	Level≈target
KS2 English	$y=-0.76x+112$	8	42	$y=-0.70x+118$	7	54.2	$y=-0.95x+115$	10	36.8
KS2 Maths	$y=-0.72x+107$	7	44.4	$y=-0.71x+116$	7	57.7	$y=-0.82x+106$	8	37.8
KS1 average	$y=-0.49x+104$	5	⋯	$y=-0.37x+102$	4	⋯	$y=-0.63x+107$	6	⋯
KS2 average	$y=-0.73x+113$	7	⋯	$y=-0.70x+120$	7	⋯	$y=-0.87x+114$	9	⋯

In general, for the suburban borough and for the noisier schools in the inner city boroughs correlations between noise and test scores were stronger for Key Stage 2 scores than for those at Key Stage 1 suggesting that external noise has more of an effect on the older children. It has previously been found that the negative effects of environmental noise are long term.[13,16] The greater effect upon the older children may therefore reflect the fact that these children have been exposed to noise at school for a longer period than the younger children. It may also be due to the higher task demands required of the older children in their tests.

In general, over all boroughs, the noise parameter with the highest and most significant correlations with test scores was L_{Amax}, implying that noise of individual events may be the most important in affecting children's performance. However, in the suburban borough external background noise levels, L_{A90}, were also significantly related to test scores.

Significant relationships between tests scores and noise were maintained when the data were corrected for factors relating to social deprivation, non-native speaking, and additional educational needs. In particular in all boroughs (considering just the noisier schools in the inner city boroughs) all KS2 subjects remained significantly related to L_{Amax} while KS1 Reading was also significantly related to some noise parameters.

The dominant external noise source in the schools considered was road traffic.[1] These findings are thus consistent with the findings of other studies which have found that road traffic noise has an impact upon children's performance at school.[19–21] Furthermore, although schools exposed to aircraft noise were not included in the study, the close relationships between L_{Amax} and test scores suggest that the noise of individual events has an impact upon children's performance. This is thus consistent with the results of other studies which have found that both aircraft[12–16] and railway[17] noise affect children's performance.

The results also complement the findings of a questionnaire survey of children carried out by the authors which found that the older (Year 6) children were more aware of external noise than the younger children.[32] This is consistent with the finding that the test results of these children were more affected by noise than those of the younger children. Furthermore, annoyance caused by external noise among children was significantly related to external maximum noise levels, the levels that are found to have the most effect upon test scores.

Regression analysis has been used to estimate the noise levels corresponding to UK government targets in English and Mathematics in the suburban borough. In this borough those schools where the external L_{Amax} level 4 m from the school façade exceeds 54 dB(A), or L_{Aeq} exceeds 42 dB(A), fail to meet literacy and numeracy targets. These levels are considerably lower than those recommended in current guidelines,[28] and should be interpreted with caution. As can be seen from Figs. 1–3 there is considerable scatter around the regression lines; many schools with levels greater than these do achieve the SAT targets. Furthermore, there are many other factors apart from noise which may affect children's attainments; the regression analysis was carried out for uncorrected data where additional factors which may impact upon learning are not accounted for. These results may therefore not apply to schools in general.

TABLE XII. Regression lines relating L_{A90} in occupied classrooms and SAT scores.

	Occupied classrooms L_{A90}		
	Regression equation	% drop ≈5 dB increase	Level≈target
KS2 English	$y=-3.23x+250$	16	52.6
KS2 Maths[a]	$y=-1.87x+169$	9	50.3
KS1 average	$y=-2.55x+218$	13	⋯
KS2 average	$y=-2.45x+207$	12	⋯

[a]Correlation ($r=-0.46$) not significant.

B. Internal noise

There were consistent negative relationships between test scores and L_{Aeq} and L_{A90} levels measured in occupied and unoccupied classrooms and corridors and foyers. The internal noise levels which had the strongest relationships with test scores were the background (L_{A90}) levels in occupied classrooms. All subjects except KS2 Mathematics were significantly correlated with these levels. KS1 Mathematics was also significantly correlated with L_{A90} measured in unoccupied classrooms and KS2 English with L_{Aeq} and L_{A90} measured in corridor and foyer areas. Many of the relationships, particularly those for KS2 English, were maintained when the data were corrected for socio-economic factors.

These results complement the results of the controlled experimental testing of children carried out by the authors in which children performed various tasks in different classroom noise conditions.[29] Classroom babble was found to decrease performance on both verbal and nonverbal tasks, with verbal tasks of reading and spelling being particularly affected. This is consistent with the finding that KS2 English test scores are strongly and significantly related to the ambient and background noise levels in classrooms.

Regression analysis showed that of the schools surveyed, in general those in which background (L_{A90}) levels in occupied classrooms exceed 50 dB(A) failed to meet government targets in literacy and numeracy. Current guidelines specify internal levels in classrooms in terms of ambient L_{Aeq} when both classrooms and the whole school are unoccupied. It is difficult, without further extensive noise surveys in schools both empty and occupied, to compare the occupied classroom background noise level with those in current standards. Furthermore, as with the external levels there is considerable scatter around the regression lines as can be seen in Figs. 4–6; therefore care should be taken when interpreting these results.

VII. CONCLUSION

This study has shown that chronic exposure to both external and internal noise has a detrimental impact upon the academic performance and attainments of primary school children. For external noise it appears to be the noise levels of individual events that have the most impact while background noise in the classroom also has a significant negative effect. Older primary school children, around 11 years of age, appear to be more affected by noise than the younger children.

In order to minimize the impact of noise upon children at school it is therefore necessary to consider two factors. The siting and the internal layout of a school should be such that classrooms are not exposed to high levels of noise from external sources such as road traffic. In addition it is essential to minimize background noise levels in the classroom to ensure that optimum conditions for teaching and learning are achieved.

Further field and experimental studies are required to determine the levels at which different types of external and internal noise affect children's academic performance in different circumstances.

ACKNOWLEDGMENTS

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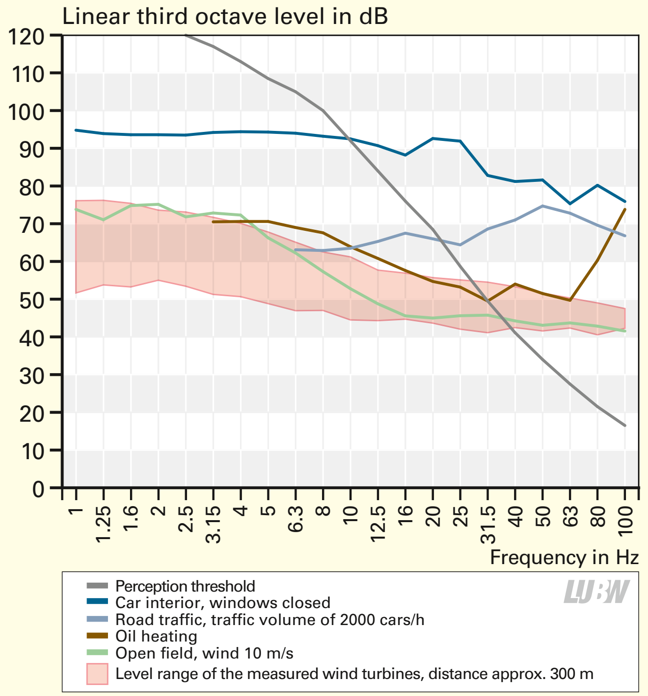

Comparison of noise levels within a passenger car, near a road, on an open field, and from an oil heating with the level range of the measured wind turbines as well as the human perception threshold

CONCLUSION

Infrasound and low-frequency noise are an everyday part of our technical and natural environment. Compared with other technical and natural sources, the level of infrasound caused by wind turbines is low. Already at a distance of 150 m, it is well below the human limits of perception. Accordingly, it is even lower at the usual distances from residential areas. Effects on health caused by infrasound below the perception thresholds have not been scientifically proven. Together with the health authorities, we in Baden-Württemberg have come to the conclusion that adverse effects relating to infrasound from wind turbines cannot be expected on the basis of the evidence at hand.

The measurement results of wind turbines also show no acoustic abnormalities for the frequency range of audible sound. Wind turbines can thus be assessed like other installations according to the specifications of the TA Lärm (noise prevention regulations).

It can be concluded that, given the respective compliance with legal and professional technical requirements for planning and approval, harmful effects of noise from wind turbines cannot be deduced.

FURTHER INFORMATION

Detailed information on the measuring project is included in the document „Low-frequency noise incl. infrasound from wind turbines and other sources – Report on the results of the measurement project 2013-2015“. It can be downloaded in the LUBW online shop at www.lubw.de/servlet/is/262445.

Further information about wind energy and infrasound can be found in the leaflet „Windenergie und Infraschall – Tieffrequente Geräusche durch Windenergieanlagen“, which the LUBW has issued in cooperation with the public health authorities of Baden-Württemberg, and the publication „Fragen und Antworten zu Windenergie und Schall – Behauptungen und Fakten“. Both publications are in German language and can be downloaded or ordered using the search field on the LUBW home page www.lubw.de.

PICTURE CREDITS

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Comparative table of results

	Level in dB(G)
Wind turbines (at wind speed of 2-15 m/s)	
Turbine off, 120-190 m distance	50-75
Turbine on, 120-190 m distance	55-80
Turbine off, 650-700 m distance	50-75
Turbine on, 650-700 m distance	50-75
Road traffic	
Inner city (measured on balcony)	50-75
Inner city (measured in living quarters)	40-65
Inner city (traffic noise measuring station Karlsruhe)	65-75
Inner city (traffic noise measuring station Reutlingen)	70-80
Motorway (A5 near Malsch), 80 m distance	75
Motorway (A5 near Malsch), 260 m distance	70
Noise in passenger car (windows closed, 130 km/h)	105
Noise in minibus (windows closed, 130 km/h)	100
Urban environment	
Museum roof	50-65
City square	50-65
Interior	45-60
Rural area (at wind speed of 10 m/s)	
Open field (130 m from forest)	55-65
Edge of forest	50-60
Forest	50-60
Sources of noise in residential buildings	
Washing machine (all operating phases)	50-85
Heating (oil and gas, full load)	60-70
Refrigerator (full load)	60
Sea surf (literature source Turnbull/Turner/Walsh)	
Beach (25 m distance)	75
Rock cliff (250 m distance)	70

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Exhibit A38-6

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Low-frequency noise incl. infrasound from wind turbines and other sources

Results of the measurement project 2013-2015

Baden-Württemberg

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THE ISSUE AT HAND

In addition to the usual audible sound, the noise coming from wind turbines also contains low frequencies including infrasound. Sound below the audible range, i. e. with frequencies of less than 20 hertz (Hz), is called infrasound. Noise is defined as low-frequency noise if substantial parts of it are in the frequency range below 100 hertz (Hz). Infrasound is thus a part of low-frequency sound.

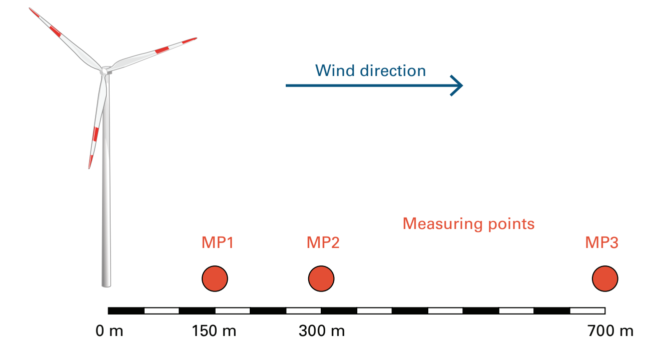
Our hearing is very insensitive to low frequencies. However, in the context of the development of wind power utilization, fears are often expressed that wind power plants might produce a great amount of infrasound. But how much infrasound do wind turbines really produce? This is the question the LUBW examined in an extensive measurement project. This leaflet summarizes the main results of the survey.

THE MEASUREMENT PROJECT

The acoustic examinations were carried out in the years 2013 through 2015 in cooperation with the company Wölfel Engineering GmbH & Co. KG in the vicinity of six wind turbines by different manufacturers and of different sizes. Additional vibration measurements were also carried out at one wind turbine. In order to appropriately classify the data collected, low-frequency sound from other sources was also measured and evaluated: effects of an urban road outside and inside a residential building, near a motorway, at two LUBW measuring stations for road traffic noise, as well as inside driving cars. Measurements without direct source reference were taken in the city centre of Karlsruhe. Furthermore, noise from technical home appliances, such as washing machine,

Evaluation of noise

Depending on the issue, the frequencies of sound are weighted differently. A-weighting is customary and expressed as dB(A), which roughly corresponds to human auditory perception. However, for the range of infrasound, so-called G-weighting, expressed in dB(G), is used. The G-weighting is focused at 20 Hz: The contributions of sound between 10 Hz and 25 Hz are strongly incorporated into the level, the contributions above and below only slightly. Unweighted levels (linear levels) are normally used for frequency analysis and the comparison with the perception threshold. In this case, all frequencies are weighted equally. The Figures in this leaflet show unweighted third octave spectra or narrow-band spectra.



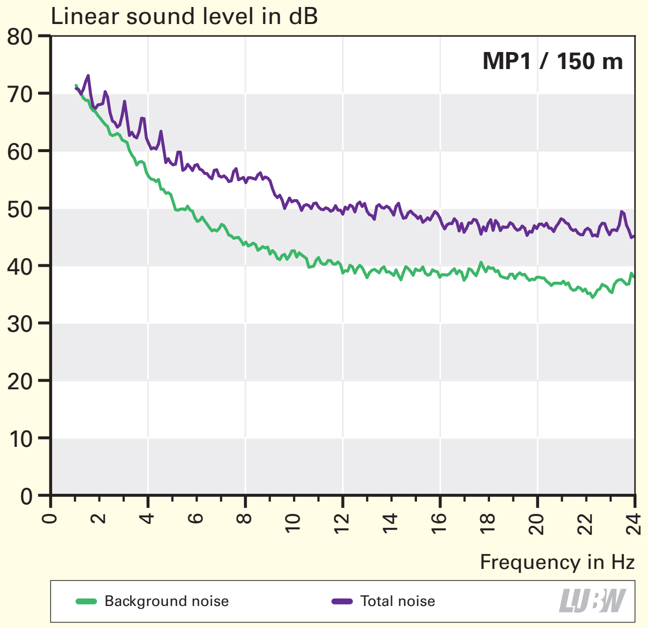
Exemplary measuring arrangement (not to scale)

refrigerator or heating, were also analysed in the way that they occur indoors. Additional measurements of natural infrasound in an open field, at the edge of a forest and in a forest rounded off the measurement programme.

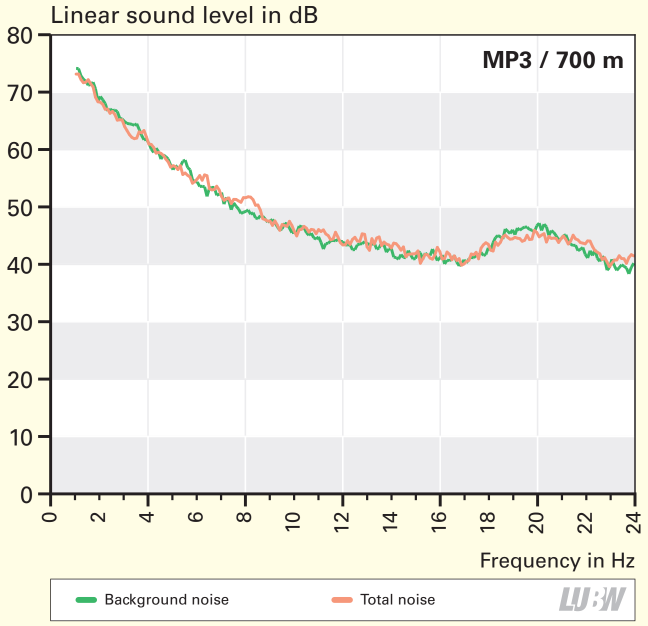
WIND TURBINES

Depending on the respective local conditions, the measurements at the six wind turbines were carried out at distances of approx. 150 m, 300 m and 700 m. The turbines covered a power range from 1.8 to 3.2 megawatts. It turned out that the infrasound coming from wind power plants can be detected by measurement rather well in the vicinity of the power plants. In addition to the noise of the wind turbine, sound generated by wind in the vicinity as well as wind-induced sound at the microphone are also generally picked up. In the narrowband spectrum, a typical sawtooth pattern can be seen below 8 Hz. This is due to the uniform movement of the rotor blades, which appears as a fundamental oscillation with harmonic waves (see Figure top of page 4).

With values of between 45 and 75 dB (unweighted), the infrasound third octave levels measured around the wind turbines are well below the human perception threshold as defined by DIN 45680 (draft 2013) even at close distances of around 150 m. The measured values show a wide range of variation. This is due to different environmental conditions and the varying noise components of the wind. At a distance of 700 m from the wind turbines, it was observed that when the turbine is switched on, the measured infrasound level did not increase notably or only to a limited



Background noise (turbine off) and total noise (background noise plus noise of the wind turbine) at a distance of 150 m at 6.5 m/s wind speed



Background noise (turbine off) and total noise (background noise plus noise of the wind turbine) at a distance of 700 m at 6.5 m/s wind speed

extent. At this distance, the infrasound is mainly induced by the wind and not generated by the power plants (see Figure bottom of page 4).

The vibrations caused by the wind turbine being examined were already minimal at a distance of less than 300 m. The readings were well below the reference values in accordance with DIN 4150 Part 2. This standard applies for the assessment of vibrations that affect people in buildings. At distances required in the vicinity of residential areas for noise protection reasons alone, no relevant effects can thus be expected for residential buildings.

ROAD TRAFFIC

As expected, the measurements of noise from traffic showed a clear correlation between noise and traffic density. The higher the volume of traffic, the higher was the low-frequency noise level. Contrary to the situation with wind turbines, the levels caused by road traffic also occur directly near residential buildings. The G-rated infrasound levels near residential buildings were between 55 and 80 dB(G). Increased level values were observed mainly in the frequency range between 30 and 80 Hz. These noise components are well above the perception threshold in accordance with DIN 45680 (2013 draft). The measured low-frequency noise from road traffic is significantly louder than in the vicinity of wind turbines (see Figure on page 7). The infrasound and low-frequency noise levels dropped at night.

Much higher levels occur in the interior of a medium-sized car driving at 130 km/h. This does not actually concern an immission in an open environment, but it is an everyday situation, which many people are often exposed to for longer periods of time. The infrasound here is greater by several orders of magnitude than in the vicinity of wind turbines (see Figure page 7).

CITY CENTRE

The measurements in the city centre of Karlsruhe showed G-weighted infrasound levels that were mostly between 55 and 65 dB(G). At times, values above 70 dB(G) were even reached.

In the evenings, the G-level declined steadily. In the frequency range between 25 and 80 Hz, relatively high third octave levels of up to 60 dB (unweighted) were observed. These are probably due to traffic noise in the wider vicinity. G-levels of between 45 and 60 dB(G) were measured indoors.

TECHNICAL EQUIPMENT IN RESIDENTIAL BUILDINGS

The measurement of appliances in a residential building showed the highest G-weighted infrasound levels with up to 85 dB(G) during the spin cycle of washing machines. In some frequency ranges, the levels reach the human perception threshold in accordance with DIN 45680 (2013 draft). The linear third octave levels caused by an oil heating were between 50 and 75 dB (see Figure page 7).

RURAL ENVIRONMENT

The noise situation with the wind blowing in an open field, at the edge of a forest and in a forest is similar to that in the vicinity of a wind turbine. At a wind speed of 10 m/s in the open field, the measurements of 55 to 65 dB(G) on the open field showed slightly higher G-weighted infrasound levels than at the edge of the forest and in the forest, where 50 to 60 dB(G) were measured. This can be explained by the lower wind speed at the edge of the forest and in the forest. For audible sound, the noise level rises at the edge of the forest and in the forest compared to the open field. This is due to the rustling of leaves (see Figure page 7).

COMPARISON OF DIFFERENT SOURCES

The Figure on page 7 again illustrates the breadth of the linear third octave level for the respective wind turbines at a distance of approx. 300 m (red band). For comparison, the measurement results for the sound of traffic and nature as well as an oil heating system are also shown. What becomes apparent is the large distance between the turbine noise and the human perception threshold in the infrasound range.

LUBW

Landesanstalt für Umwelt, Messungen und
Naturschutz Baden-Württemberg

Low-frequency noise incl. infrasound from wind turbines and other sources

Report on results of the measurement project 2013-2015

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1 Background and introduction

There are currently (as of 31.12.2015) 445 wind turbines in operation in Baden-Wuerttemberg and 100 more under construction [1]. In the coming years many more will be added to that number. When it comes to the expansion of wind energy, the effects on humans and the environment need to be taken into account. Wind turbines make noise. In addition to the usual audible sound, they also generate low-frequency sounds or infrasound, i.e. extremely low tones.

Infrasound is described as the frequency range below 20 hertz (for explanations of important technical terms, please refer to Appendix A3). From a physical point of view, these noises are generated particularly through aerodynamic and mechanical processes, e.g. the flow around rotor blades, machine noise or the vibration of equipment components. Our hearing is very insensitive to low-frequency noise components. The wind energy decree of Baden-Wuerttemberg [1] includes, among other things, regulations and statements to protect the population against low-frequency noise and infrasound. However, within the scope of wind energy development, fears are commonly expressed that this infrasound may affect people or jeopardize their health.

In September 2012, the LUBW Landesanstalt für Umwelt, Messungen und Naturschutz Baden-Wuerttemberg presented the concept for a measuring project, with which current data on low-frequency noise incl. infrasound from wind turbines and other sources was to be collected. As a result, the LUBW was entrusted with the implementation of the project by the Ministry of Environment, Climate and Energy Baden-Wuerttemberg. The company Wölfel Engineering GmbH + Co. KG was taken on board as a supporting measuring institute. The detailed planning and work was thus begun together at the beginning of 2013.

Within the project, numerous measurements near wind turbines and other sources as well as the associated analyses and evaluations were carried out. The results obtained are summarized in this measurement report. The LUBW wishes to use it as a contribution towards providing objectivity to the discussion. The report is aimed at the interested public as well as administrative bodies and professionals.

At this point we would like to thank all participants for enabling the measurements as well as the friendly support during the implementation, in particular the operators of wind turbines, the involved administrative authorities in Baden-Wuerttemberg and Rhineland-Palatinate, the State Museum of Natural History Karlsruhe and the Education Authority of Karlsruhe. The Bavarian State Office for the Environment and the State Office for the Environment, Nature Conservation and Geology Mecklenburg-Western Pomerania were kind enough to provide a number of pictures.

1) The terms "wind power plant" and "wind turbine" are synonymous. For our measurement project we have used the term "wind turbine" in the title. The German term is embedded in immissions law (fourth regulation on the implementation of the Federal Immission Control Act – Regulation on licensing requirements Appendices – 4. BImSchV, Appendix 1 no. 1.6.1 [2] [3]). In the text of this report the common term "wind power plant" may also be used.

2 Summary

In cooperation with Wölfel Engineering GmbH + Co. KG, the LUBW carried out the measurement project "Low-frequency noise incl. infrasound from wind turbines and other sources", which began in 2013. This report provides information on the results of the measurement project.

Figure 2-1: *Wind turbines – how much infrasound do they emit? Photo: Wölfel company*

The aim of the project is to collect current data on the occurrence of infrasound (from 1 Hz) and low-frequency noise in the area of wind turbines and other sources. For this purpose, measurements were taken up to the end of 2015 in the areas around six wind turbines by different manufacturers and with different sizes, covering a power range from 1.8 to 3.2 megawatts (MW). Depending on local conditions, the distances to the wind turbines were approx. 150 m, 300 m and 700 m. The results of the measurements at the wind turbines are described and illustrated by means of graphs in Chapter 4. In addition to the acoustical analyses, vibration measurements were performed in the vicinity of a wind power plant in order to determine possible vibration emissions of the power plant on the environment. The procedure and the difficulties encountered are explained accordingly.

Since road traffic is also considered to be a source of infrasound and low-frequency noise, it stood to reason to extend the measurement project to cover that too. Chapter 5 provides results of measurements at an urban road, which took place both outside as well as inside a residential building. In addition, the data from the LUBW measurement stations for road traffic noise in Karlsruhe and Reutlingen were analysed and illustrated with respect to low-frequency noise and infrasound. Furthermore, results of own measurements at a motorway are also illustrated. This is supplemented by data from sound level measurements inside a moving car.

Measurements without reference sources during the day and at night took place in the centre of Karlsruhe on the Friedrichsplatz. At the same time, measurements were also taken on the roof of the natural history museum and in an interior room of the education authority (Chapter 6). Typical noise occurring in residential buildings through widespread technical equipment, such as washing machines, refrigerators or heating equipment, was also recorded and is presented in Chapter 7. In order to enable statements about natural sources of infrasound, measurements were taken on an open field, near a forest and in a forest. The measurement of low-frequency sound through sea surf is also introduced based on literature (Chapter 8). In Chapter 9, considerations are made for a monitoring station for the continuous monitoring of low-frequency noise incl. infrasound. Such an independently operating permanent measuring station could possibly be used when it comes to complaint cases.

The report at hand extends the previous interim report through further findings and contains a multiplicity of measurement results. It is aimed at both professionals as well as the interested general public. Great interest for our analyses was shown by the public and administrative bodies during the entire duration of the project. SWR TV even aired a report about the measurements. The LUBW will continue to pursue the issue in the future.

In addition to general information about infrasound, the appendices provide extensive explanations of technical terms and the technology used, as well as information on the sources.

***Figure 2-2**: Impressions of the measurements during the execution of the measurement project. a) Construction of a wind measuring mast (top left) and b) of a measurement point (top right) during measurement at a wind turbine. c) and d) Setup of measurement points in the city centre of Karlsruhe (bottom). Photos: LUBW*

RESULTS

In summary, the measurements lead to the following findings:

- The infrasound being emanated from the wind turbines can generally be measured well in the direct vicinity. Discrete lines occur below 8 Hz in the frequency spectrum, which are attributed to the uniform movement of the individual rotor blades.

- For the measurements carried out even at close range, the infrasound level in the vicinity of wind turbines is – at distances between 120 m and 300 m – well below the threshold of what humans perceive in accordance with DIN 45680 (2013 Draft) [5] or ***Table A3-1***.

- At a distance of 700 m from the wind turbines, it was observed by means of measurements that when the turbine is switched on, the measured infrasound level did not increase or only increase to a limited extent. The infrasound was generated mainly by the wind and not by the turbines.

- The determined G-weighted levels [2)] at distances between 120 m and 190 m were between 55 dB(G) and 80 dB(G) with the turbine switched on, and between 50 dB(G) and 75 dB(G) with the turbine switched off. At distances of 650 m and 700 m, the G-levels were between 50 dB(G) and 75 dB(G) for both turbines switched

2) The G-level – expressed as dB(G) – represents a frequency-weighted single value of the noise in the low-frequency and infrasound range. The human ear is insensitive to any influences in this frequency range (for definition and measurement curve see Appendix A3).

on as well as off, see ***Table 2-1***. The large fluctuations are caused, among other things, by the strongly varying noise components due to the wind, as well as various different surrounding conditions.

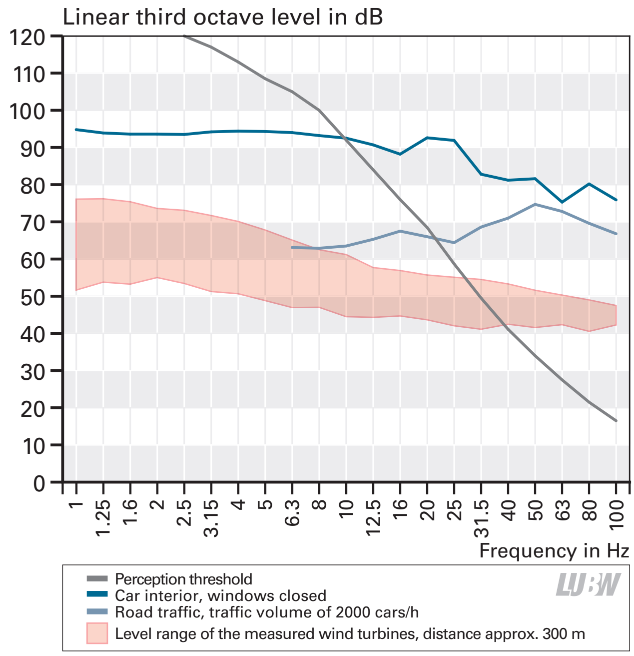


Figure 2-3: *Comparison of road noise inside and outside of motor vehicles with the level range of wind turbines at a distance of approx. 300 m as well as the perception threshold according to Table A3-1 regarding infrasound and low-frequency noise. For measuring corrections, see Section 4.1.*

- The infrasound and low-frequency noise measured in the vicinity of operating wind turbines consists of a proportion that is generated by the wind turbine, a proportion that occurs by itself in the vicinity due to the wind, and a proportion that is induced by the wind at the microphone. In this case the wind itself is thus always an "interference factor" when determining the wind turbine noise. The measured values are therefore subject to a wide spread.

- The vibrations caused by the wind turbine being examined were already minimal at a distance of less than 300 m. At distances provided for residential areas alone due to noise protection issues, no relevant effects are to be expected for residential buildings.

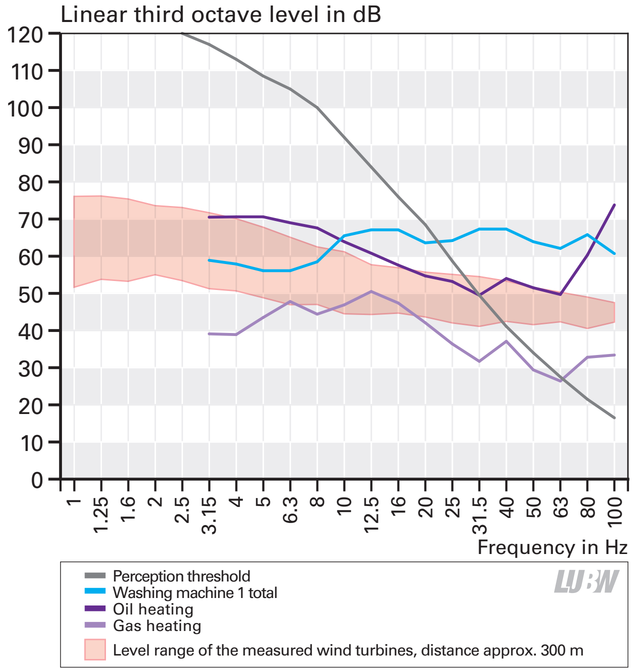
- It was possible to carry out the measurements for the low-frequency noise incl. infrasound resulting from road traffic during times without interfering wind noise. Contrary to the case with wind turbines, the measured levels also occur directly in areas with adjacent residential buildings. As expected, it was observed that the infrasound and low-frequency noise levels fell at night. Clear correlations with the amount of traffic were also ascertained. The higher the amount of traffic, the higher the low-frequency noise and infrasound levels.

- The infrasound noise levels of road traffic in the area of residential buildings in the vicinity in the individual third octave bands were a maximum of approx. 70 dB (unweighted), while the G-weighted level was in the range between 55 dB(G) and 80 dB(G).

- When it comes to the immission measurements of road traffic noise, increased levels in the area between approx. 30 Hz and 80 Hz were ascertained in the frequency spectra. The low-frequency noise in this area lies well above the perception threshold according to ***Table A3-1*** and is therefore more relevant with regards to its effect than the subliminal infrasound levels below 20 Hz. The levels of low-frequency noise in the observed situations of road traffic are significantly higher than in the vicinity of wind turbines (***Table 2-1***).

- The measurements in the city centre of Karlsruhe (Friedrichsplatz) showed that the G-weighted levels dropped from 65 dB(G) during the day to levels of around 50 dB(G) at night. Wind noise played no role for these measurements. Relatively high third octave levels up to 60 dB (unweighted) could be observed between 25 Hz and 80 Hz, probably deriving from traffic noise, even though the Friedrichsplatz is not located directly on a busy road.

- The highest levels in the context of the measurement project were measured in the interior of a mid-range car travelling at 130 km/h. Even though these are not immission levels that occur in a free environment, they are an everyday situation that many people are frequently subjected to for a longer period of time. The measured values for both the infrasound as well as the other



***Firgure 2-4**: Comparison of noise of technical appliances in residential buildings with the level range of wind turbines at a distance of approx. 300 m as well as the perception threshold according to Table A3-1 regarding infrasound and low-frequency noise. For measuring corrections, see Section 4.1.*

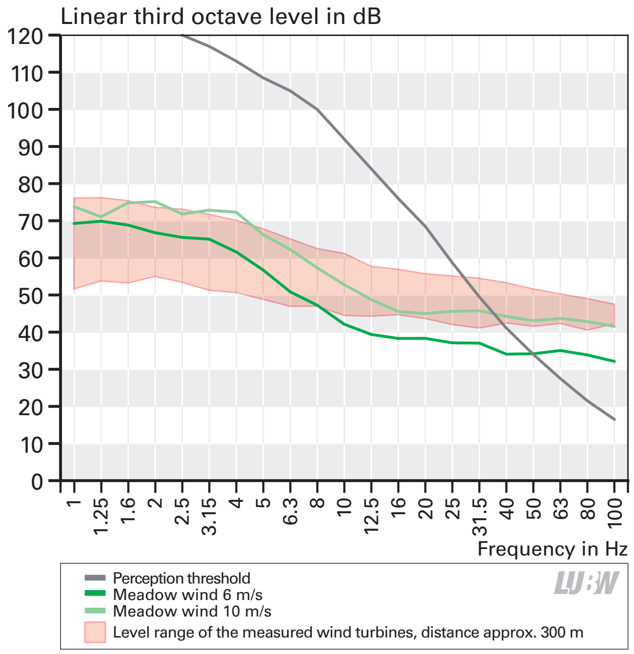


***Figure 2-5**: Comparison of noise situation in an open field (without source reference) with the level range of wind turbines at a distance of approx. 300 m as well as the perception threshold according to Table A3-1 regarding infrasound and low-frequency noise. For measuring corrections for wind turbines, see section 4.1.*

low-frequency areas are higher by several orders of magnitude than the values measured in road traffic or at the wind turbines.

- The measurement of appliances in a residential building showed the highest infrasound levels during the spin cycle of washing machines. In individual third octaves the levels reached the perception threshold according to ***Table A3-1***. As expected, it turned out that building components deaden higher-frequency noise significantly better than the low frequencies below 20 Hz.

- In a rural area, the spectral distribution of noise on an open field, the edge of a forest, in a forest with wind is in principle similar to in the vicinity of a wind turbine (***Figure 2-5***). For open fields, linear levels that are up to 30 dB higher than in a forest can be seen in the narrowband spectrum. Above 16 Hz, the differences are no longer as pronounced. Higher levels occur for A-weighted audible sound in the forest, which is attributable to the rustling of leaves.

CONCLUSION

Infrasound is caused by a large number of different natural and technical sources. It is an everyday part of our environment that can be found everywhere. Wind turbines make no considerable contribution to it. The infrasound levels generated by them lie clearly below the limits of human perception. There is no scientifically proven evidence of adverse effects in this level range.

The measurement results of wind turbines also show no acoustic abnormalities for the frequency range of audible sound. Wind turbines can thus be assessed like other installations according to the specifications of the TA Lärm (noise prevention regulations). It can be concluded that, given the respective compliance with legal and professional technical requirements for planning and approval, harmful effects of noise from wind turbines cannot be deduced.

***Table 2-1**: Comparative overview of results. The readings were often subject to considerable fluctuations. Here they were rounded to the nearest 5 dB, some are based on different averaging times. More information can be found in the relevant sections of the report. To enable a comparison of the results (measurements with/without reverberant plate) a correction was carried out; for more information see Section 4.1.*

Source/situation	Section	G-weighted level in dB(G)	Infrasound third octave level ≤ 20 Hz in dB [1]	Low-frequency third octave levels 25-80 Hz in dB [1]
Wind turbines [2]		**WT on / off**	**WT on**	**WT off**
– WT 1	4.2	700 m: 55-75 / 50-75 150 m: 65-75 / 50-70	– 150 m: 55-70	– 150 m: 50-55
– WT 2	4.3	240 m: 60-75 / 60-75 120 m: 60-80 / 60-75	– 120 m: 60-75	– 120 m: 50-55
– WT 3	4.4	300 m: 55-80 / 50-75 180 m: 55-75 / 50-75	– 180 m: 50-70	– 180 m: 45-50
– WT 4	4.5	650 m: 50-65 / 50-65 180 m: 55-65 / 50-65	– 180 m: 45-55	– 180 m: 40-45
– WT 5	4.6	650 m: 60-70 / 55-65 185 m: 60-70 / 55-65	– 185 m: 50-65	– 185 m: 45-50
– WT 6	4.7	705 m: 55-65 / 55-60 192 m: 60-75 / 55-65	– 192 m: 55-65	– 192 m: 45-50
Road traffic				
– Würzburg inner city, balcony [3] – Würzburg inner city, living quarter [3]	5.1	50-75 40-65	35-65 20-55	55-75 35-55
– Karlsruhe, noise measurement station [3]	5.2	65-75	45-65	55-70
– Reutlingen, noise measurement station [3]	5.2	70-80	50-70	55-75
– Motorway A5 near Malsch, 80 m [4] – Motorway A5 near Malsch, 260 m [4]	5.3	75 70	55-60 55-60	60-70 55-60
– Interior noise in passenger car 130 km/h [4] – interior noise in minibus at 130 km/h [4]	5.4	105 100	90-95 85-90	75-95 80-90
Urban background, Karlsruhe [3]				
– roof of natural history museum – Friedrichsplatz – Interior	6	50-65 50-65 45-60	35-55 35-50 20-45	up to 60 up to 60 up to 55
Noise sources in residential buildings [5]				
– Washing machine (all operating modes)	7.1	50-85	25-75	10-75
– Heating (oil and gas, full load)	7.2	60-70	40-70	25-60
– Refrigerator (full load)	7.2	60	30-50	15-35
Rural environment [6]		**Wind 6 / 10 m/s**	**Wind 6 / 10 m/s**	**Wind 6 / 10 m/s**
– open field, 130 m from forest	8.1	50-65 / 55-65	40-70 / 45-75	35-40 / 40-45
– Edge of forest	8.1	50-60 / 50-60	35-50 / 45-75	35-40 / 40-45
– Forest	8.1	50-60 / 50-60	35-40 / 40-45	35-50 / 35-40
Sea surf				
– Beach, 25 m away	8.2	75	55-70	not reported
– Rock cliff, 250 m away	8.2	70	55-65	not reported

1) Linear third octave level (unweighted)
2) For wind turbines: From 10-second values (see illustrations of the G-level depending on the wind speed)
3) For road traffic (Würzburg) and urban background (Karlsruhe): From averaging levels over an hour
4) For federal motorway and car interior level: From averaging over several minutes
5) For noise sources in residential building: From averaging levels of typical operating cycles
6) The wind measurement was always carried out at the measurement point MP1 (open field).

3 Scope of analysis

The scope of analysis includes the following measurements and examinations:

- Measurement of low-frequency noise, including infrasound, from 1 Hz at a total of six different wind turbines at a distance of approx. 150 m, 300 m and 700 m respectively (if possible). In the process, the turbines were each turned on and off. The distances roughly correspond to the set reference intervals for emission measurements at close range (approx. 150 m), a roughly double distance in the immediate vicinity (approx. 300 m) and a distance that can occur for real noise immissions (700 m, see also planning information in the wind energy statute of Baden Wuerttemberg [1]).

- Comparative measurement of the noise immission in the sphere of influence of a road both outside as well as inside a residential building.

- Determination of low-frequency effects from 6.3 Hz of road traffic on the permanent monitoring stations in Karlsruhe and Reutlingen as well as at the A5 motorway near Malsch at different distances.

- Measuring of the infrasound levels within a passenger car travelling at 130 km/h.

- Determination of the urban background through a comparative measurement of the noise situation in Karlsruhe (Friedrichsplatz) without specific source reference both outside as well as inside a building.

- Comparative measurement of the noise situation in a rural area without a concrete source reference.

- Measurement of oscillations (vibrations) in the ground in the vicinity of a wind turbine.

- Elaboration of a feasibility concept for the conception of a self-sufficient permanent measuring station for low frequency noise incl. infrasound, in order to possibly measure the effects over a longer period of time (e.g. several weeks).

The following planned steps of the project have not yet been completed:

- Measurement of the direction dependency in the low-frequency frequency range based on four measurement points around a wind turbine. – This is where technical problems occurred during the measurement. They therefore have to be repeated.

- Measurement of low-frequency noise, including infrasound, from 1 Hz at a wind farm, incl. indoor measurement in a residential building at a distance of approx. 700 m to the nearest turbine. The wind turbines are switched on and off in the process. – The necessary meteorological conditions did not occur at the planned measuring location since commissioning in August 2014. It was therefore not possible to carry out a standard-compliant measurement. The measurement is to be carried out at a later date.

4 Wind turbines

The results of the six measurements that took place in the context of this project at wind turbines in Baden-Wuerttemberg, Rhineland-Palatinate and Bavaria are presented in the following (***Table 4-1***). The measurements were carried out by Wölfel Engineering GmbH + Co. KG, Höchberg, on behalf of the LUBW. The graphical representations of the emissions and immissions in the low-frequency range, both with the turbines switched on and off, are an integral part. The third octave levels enable a comparison with the human perception threshold. The A and G-weighted sound pressure levels are represented depending on the wind velocity for three different distances from the turbine. The A-weighted sound level – specified as dB(A) – simulates the human hearing sensitivity. The G-level – specified as dB(G) – represents a singular value, which rates only infrasound and parts of the low-frequency frequency range. The human ear is very insensitive to these frequency ranges (for more info please refer to ***Figure A3-1*** in Appendix A3). Additionally recorded narrow band spectra, all specified with a resolution of 0.1 Hz, are able to depict more clearly specific features of the noise characteristics of wind turbines. The level values in a spectrum depend on the selected resolution. Therefore, narrow band levels cannot be compared with third octave levels. Only third octave levels are suitable for comparisons with the hearing threshold, as it also corresponds to third octave levels.

All the following results of measurements on operating wind turbines also include the noise caused by the wind itself in the vicinity. In addition, in the case of strong wind, noise will inevitably be induced at the microphones despite the use of double wind screens. Therefore, the results of a measurement cannot be attributed to the respective wind turbine alone. The differences shown by the comparison of situations with the turbine switched on and off are therefore all the more important. When it comes to the noise measurements at roads (Chapter 5) and in the city centre (Chapter 6), the effects related to the wind are irrelevant. Thus, the measuring results for wind turbines and roads designate different situations, which cannot be directly compared with one another.

The selection of the wind turbines that were to be measured proved to be rather difficult. The initial contacts with operators were kindly set up by the Baden-Wuerttemberg approval authorities (district offices) after the LUBW had carried out a corresponding query. The participation of the turbine operators was on a voluntary basis. Some operators had concerns about participating in the project.

First, the locations were qualified from an acoustic perspective. Sites near busy roads, or other disruptive noise sources – including forests – were deemed unsuitable and thus rejected. Regarding more powerful turbines, the site search had to be extended by the LUBW to include Rhineland-Palatinate. In this case constructive support was also provided several times by the authorities. Not only weather-related restrictions had to be coped with (matching wind directions and wind speeds; strong winds resulting in termination of measuring due to automatic shutdown; snowfall in the vicinity) during the project. One wind power plant broke down shortly before the measurement and was

Table 4-1: *Overview of the wind power plants where measurements were carried out in the context of this project. The individual power plants and the associated results are described in more detail in Sections 4.2 to 4.7.*

Wind turbine (WT)	WT 1	WT 2	WT 3	WT 4	WT 5	WT 6
Manufacturer Model	REpower* MM92	Enercon E-66	Enercon E-82	REpower* 3.2M114	Nordex N117/2400	Enercon E-101
Nominal capacity	2.0 MW	1.8 MW	2.0 MW	3.2 MW	2.4 MW	3.05 MW
Rotor diameter	92 m	70 m	82 m	114 m	117 m	101 m
Hub height	100 m	86 m	138 m	143 m	140.6 m	135.4 m

* Senvion since 2014

inoperable for a longer period of time. One operator withdrew his consent to the measurement as the proposed turbine had difficulties with the acceptance inspection. A construction site was set up in the vicinity of another wind turbine, which caused background noise and thus made the measurement of the turbine noise impossible. This is just to show some of the challenges that had to be overcome during the project. The delays that were thus incurred were not foreseeable from the start.

***Figure 4-1**: Model type WT 1, REpower MM92*

***Figure 4-2**: Model type WT 2, Enercon E-66*

***Figure 4-3**: Model type WT 3, Enercon E-82*

***Figure 4-4**: Model type WT 4,* REpower 3.2M114

***Figure 4-5**: Model type WT 5,* Nordex N117/2400

***Figure 4-6**: Model type WT 6,* Enercon E-101

These images convey an impression of the examined wind power plants, covering the common power range between 1.8 MW and 3.2 MW. The hub height varies between 86 m and 143 m, the rotor diameter varies between 70 m and 117 m. Photos: batcam.de (left column), LUBW (Fig. 4-2 and 4-4), Lucas Bauer wind-turbine-models.com (Fig. 4-6)

4.1 Measurements and evaluations

The noise measurements were carried out according to DIN EN 61400-11 [6] and the technical guidelines for wind turbines [7] respectively. Furthermore, the noise immissions in the frequency range from 1 Hz were measured and further guidelines [8] [9] used if necessary.

These regulations describe noise measurement methods for determining the sound emissions of a wind turbine. They establish the procedures for the measurement, analysis and presentation of results of noise emitted by wind turbines. Likewise, requirements for the measuring devices and calibration are provided in order to ensure the accuracy and consistency of the acoustic and other measurements. This is where special microphones that can be applied from levels of 1 Hz onwards were used. The non-acoustic measurements that are necessary in order to determine the atmospheric conditions that are relevant for the determination of the noise emission are also described in more detail. All the parameters that are to be measured and illustrated, as well as the necessary data processing to determine these parameters are defined. For more details on measurement techniques, please refer to Appendix A4.

Based on the measurements, which – if possible – should be made at distances of approx. 150 m, 300 m and 700 m from the turbine (it was not always possible to observe these distances exactly), statements about emissions and immissions of the turbines can be made. The wind turbines that were to be measured were each operated in open operating mode, where the system is geared towards performance optimization. Experience has shown that the highest noise levels can be expected in this mode.

Over the entire measurement time, both third octave as well as octave bandwidths in the frequency range of 6.3 Hz to 10 Hz were formed and stored with the sound level meters used (see Appendix A4). From the recorded audio files, third octave and octave spectra were formed in the range of 1 Hz to 10 kHz as well as narrowband spectra in the range of 0.8 Hz to 10 kHz by means of digital filters. Times with extraneous noise were marked during the measurements and not used for the evaluations. The microphones were each mounted on a reverberant floor plate and provided with a primary and secondary wind screen (see ***Firgure 4.3-1***), in order to reduce or even avoid wind noise induced at the microphone. The use of a reverberant plate results in a doubling of sound pressure at the microphone, resulting in higher readings. When determining the sound power level, a correction of -6 dB therefore has to be undertaken afterwards. The correction was carried out in this report for the presentation of measured values only in the case of a comparison of results that emerged through different measuring arrangements (see ***Firgures 2-3 to 2-5*** as well as ***Table 2-1***) or comparisons with the perception threshold, e.g. in ***Figure 4.2-5***.

For some representations of the measuring results, the human perception threshold was inserted into the graphics as a comparison. This is where we used the values of DIN 45680 (2013 draft) [5]. These values are somewhat lower than those of the currently valid DIN 45680 (1997) [4] that are to be applied in accordance with the TA Lärm [10]. Below 8 Hz, the values of the standard work were supplemented by data from literature [11], see ***Table A3-1***. Further information is listed in Appendix A1 for the difficulties regarding the hearing and perception threshold. Graphical comparisons of the hearing and perception threshold are also presented there (***Figure A1-2***).

In addition to the sound level measurements, vibration measurements were also carried out at the foundation of wind turbine 5, and at distances of 32 m, 64 m and 285 m (see Section 4.8).

4.2 Noise at wind turbine 1: REpower MM92 – 2.0 MW

BASIC CONDITIONS

The wind turbine 1 (WT 1) is a power plant made by the company Repower, model MM92/100 (***Figure 4-1***) with a nominal generator capacity of 2.05 MW at a wind speed of 12.5 m/s at hub height. The rotor diameter is 92 m, the hub height above ground is 100 m. The immediate vicinity of the wind turbine is defined by agricultural land with individual trees scattered around. Adjacent to it are areas with conifer tree culitvation and forest. Further wind power plants are located in the wider vicinity of the wind turbine

Figure 4.2-1: Wind measurement mast with view in direction of the wind power plant being measured. Photo: Wölfel company

being measured. These were switched off during the measurement period. A path in close proximity is allowed to be used only by agricultural traffic and is used only seldom. The measurements were carried out on 11.04.2013 between 8:00 a.m. and 4:00 p.m. The position of the microphone at the measurement point MP1 was at a distance of 150 m to the power plant in a downwind direction. This was in order to take into account the worst case scenario (support of sound propagation through the wind). Further measurement points MP2 and MP3 were located at intervals of 300 and 700 m in a downwind direction. ***Figure 4.2-1*** provides an impression. The measurement was carried out in a wind speed range of 5 to 14 m/s, a temperature range of 10 to 12 °C and an atmospheric pressure range of 946 to 951 hPa. The entire power range of the power plant was covered up to the nominal power. The turbulence intensity, which is basically a measure of the gustiness of the wind (see Appendix A3), was 18 %.

RESULTS: NARROW BAND LEVEL

Figure 4.2-2 shows the narrow band spectra of background noise and overall noise at the measurement point MP1 at a distance of 150 m with a resolution of 0.1 Hz. The wind speed was 6.5 m/s. With the power plant switched on, six discrete maxima can be clearly seen in the infrasound range between 1 Hz and 5.5 Hz. This concerns infrasound generated by the rotor due to its motion. The measured frequencies correspond to the passage frequency of a rotor blade of approximately 0.75 Hz, which corresponds with a frequency of the rotor of 15 rpm and the harmonic overtones at 1.5 Hz, 2.2 Hz, 3.0 Hz, 3.7 Hz, 4.5 Hz and 5.2 Hz (***Figure 4.2-2***). Further maxima were measured at 25 Hz and

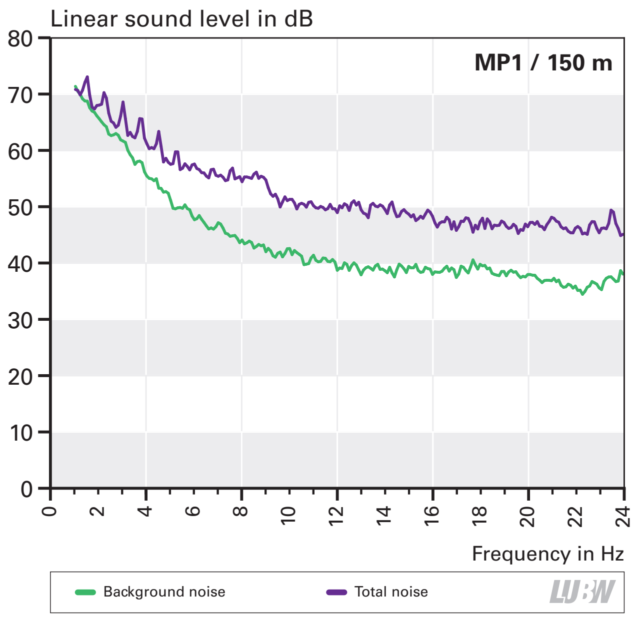


Figure 4.2-2: Narrow band spectra of background noise and total noise in the vicinity of the wind turbine WT 1 for the frequency range of infrasound

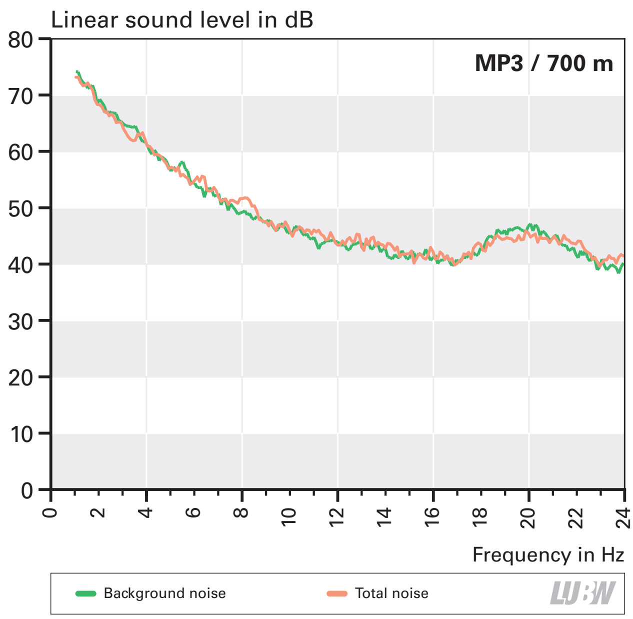


Figure 4.2-3: Narrow band spectra of background noise and total noise at a far range from the wind turbine WT 1 for the frequency range of infrasound

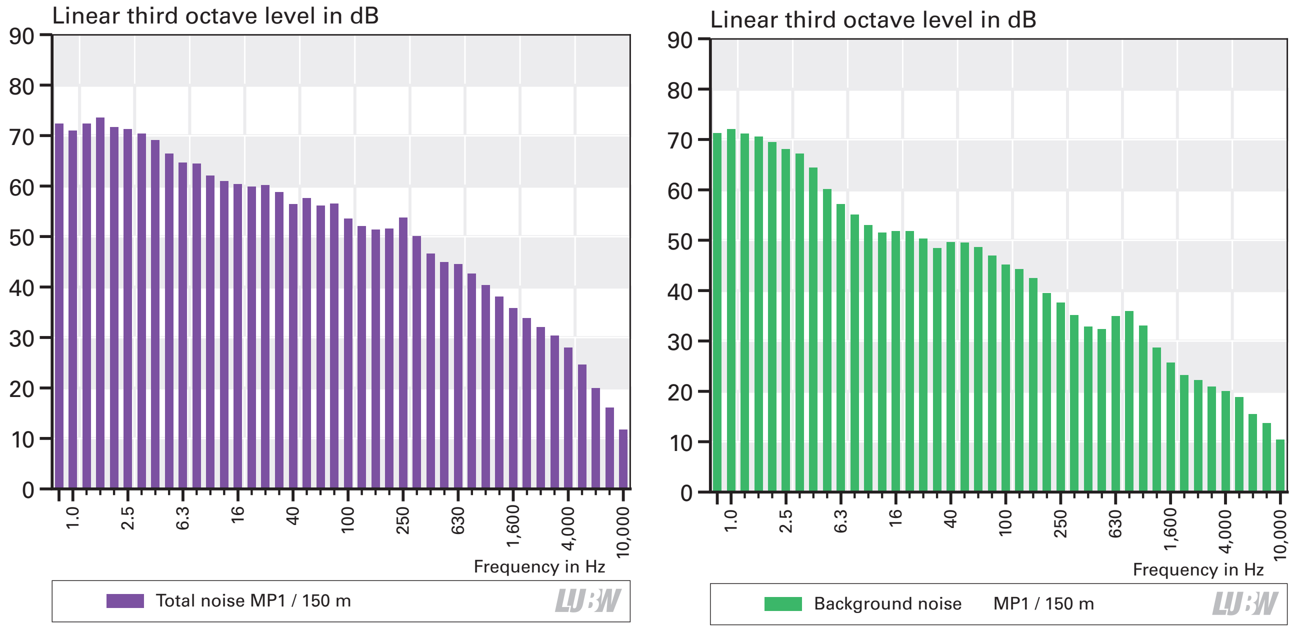


Figure 4.2-4*: Third octave spectra of total noise and background noise in the vicinity of the wind turbine WT 1*

50 Hz, These are at a much lower level, and are attributable to the operation of the generator. The peaks disappear when the power plant is switched off.

Figure 4.2-3 shows the narrow band spectra of background noise and overall noise at the measurement point MP3 at a distance of 700 m. At this distance, no discrete infrasound maxima can be distinguished anymore when the power plant is on. There were no measurable differences in infrasound between the conditions "turbine on" and "turbine off" for this measurement at a distance of 700 m. This was apparently caused by the noise of wind and the surroundings. Here too, the wind speed was 6.5 m/s.

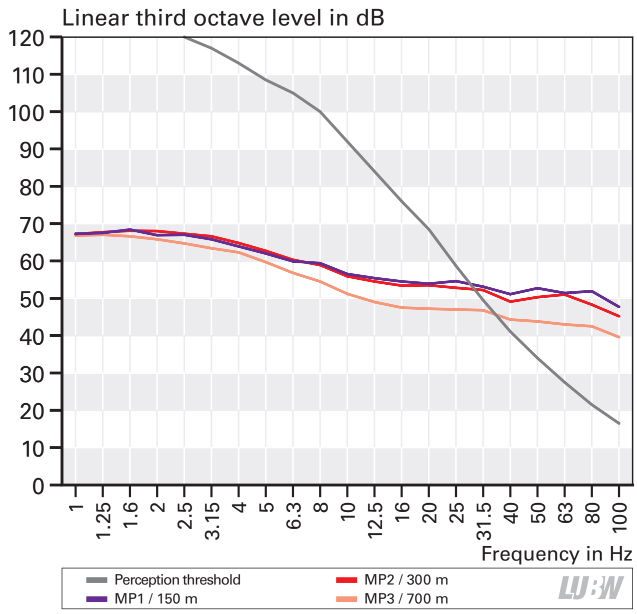


Figure 4.2-5*: Third octave spectra of total noise at the measurement points MP1 (150 m), MP2 (300 m) and MP3 (700 m) of WT 1, with the perception threshold according to Table A3-1 in comparison. The measured values were corrected according to Section 4.1.*

RESULTS: THIRD OCTAVE LEVEL

Figure 4.2-4 shows the third octave spectra of background noise and overall noise at the measurement point MP1 (150 m) for the frequency range from 0.8 Hz to 10,000 Hz. The wind speed was 6.5 m/s. The level reduction due to the shutdown of the power plant is visible here in a considerably broader spectral range.

COMPARISON WITH THE PERCEPTION THRESHOLD

Figure 4.2-5 shows the third octave spectra of the total noise at the measurement points MP1, MP2 and MP3 for the frequency range from 1 Hz to 100 Hz along with the perception threshold in comparison. The wind speed was 6.8 m/s. It must be kept in mind that the background noise of wind and vegetation are also included. These may vary at the respective measurement point. It is apparent that from about 6-8 Hz the overall noise becomes less with increasing distance to the power plant. The differences become clearer with increasing frequency. In terms of audible sound, this constitutes an audible effect. At the measurement point located at a distance of 700 m, the turbine is no longer constantly and at most only slightly noticeable; the curve is almost the same as for the background noise. In the infrasound range, the curves are well below the perception threshold.

INFLUENCE OF WIND SPEED

The above charts reflect a concrete individual situation at a given wind speed (6.5 or 6.8 m/s respectively) as an example. However, the results were presented at different frequencies. Of course this is where the question arises as to what the relationships are like at different wind speeds. These were also measured, and the results are shown in ***Figure 4.2-6***. This figure is not easy to understand straight away and should therefore be explained step by step.

The three graphs represent the relationships at the respective measurement points at a distance of 150 m (upper figure), 300 m (middle figure) and 700 m (lower figure). The wind speed of 4.5 to 10.5 m/s is placed on the bottom, horizontal axis. The vertical axis represents the sound level values. Each point corresponds to a single measurement sequence of 10 seconds at a given wind speed. Violet dots, which depict the lower value area, represent audible sound with the turbine on, expressed in dB(A). It is easy to see at distances of 150 and 300 m that the audible sound increases slightly at wind speeds of 4.5 m/s up to just above 5.5 m/s, but then remains constant at higher wind speeds. How does this behave with low-frequency sound or infrasound respectively? In order to find out, the dependency of the G-weighted sound level, specified as dB(G), was examined.

The red dots represent the G-weighted sound level when the turbine is switched on, the green dots when the turbine is switched off. In the vicinity of the power plant, at a distance of 150 m (upper image), you can see clearly that the sound level is similarly dependent on the wind speed also in the low-frequency range (incl. infrasound) as is the case for audible sound when a power plant is switched on. Furthermore, it is also visible that there is a clear difference between the turbine being on and the turbine being off. The G levels are significantly higher when the turbine is on (red dots) than when it is switched off (green dots). At a distance of 300 m (middle image) this difference is already less pronounced, and at 700 m it is no longer recognizable. There is virtually no difference anymore between the red cluster of dots (turbine on) and the green cluster of dots (turbine off), regardless of the wind speed.

These readings also show clearly that the background noise through wind and vegetation, measured when the turbine is switched off (green dot cluster), is subject to strong scattering, i.e. particularly noticeable natural fluctuations. The values span a range of up to 20 dB(G). The measured sequences of the turbine noise, on the other hand, scatter significantly less, at least in the near-field.

LEVEL DEVELOPMENT DURING THE MEASUREMENT

Figure 4.2-7 shows the A and G-weighted level curves between 11:00 a.m. and 3:00 p.m. at a distance of 150 m and 700 m. In addition, the operating conditions of the wind turbine (green = turbine on, light blue = turbine off) as well as periods of time with external noise (violet) are depicted. For the two level developments of measurement point MP1, the operational phase "turbine off" is easily recognisable through the considerably declining level developments. At the measurement point MP3, a drop in the level with the turbine turned off is barely distinguishable due to the fluctuating background noise – only the minima of the A level development are slightly lower than when the turbine is on. The G level development, however, covers nearly the same range of values as when the turbine is switched off.

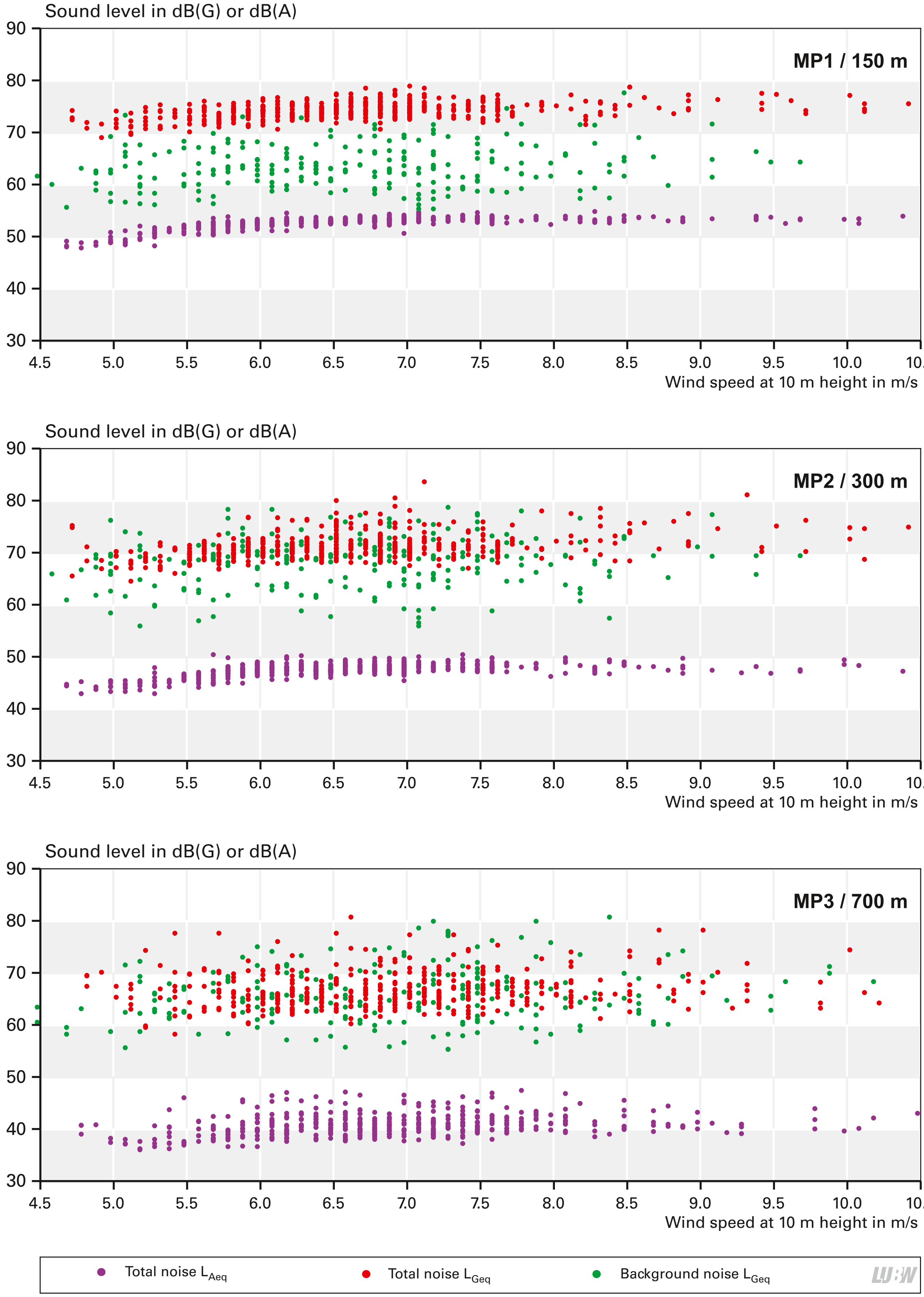


***Figure 4.2-6**: Audible sound level (A level) and infrasound level (G level) depending on the wind speed for the wind turbine WT 1. The G levels when the turbine is switched on (red dots) and when the turbine is switched off (green dots) are shown, as are the A levels with the turbine switched on (violet dots).*

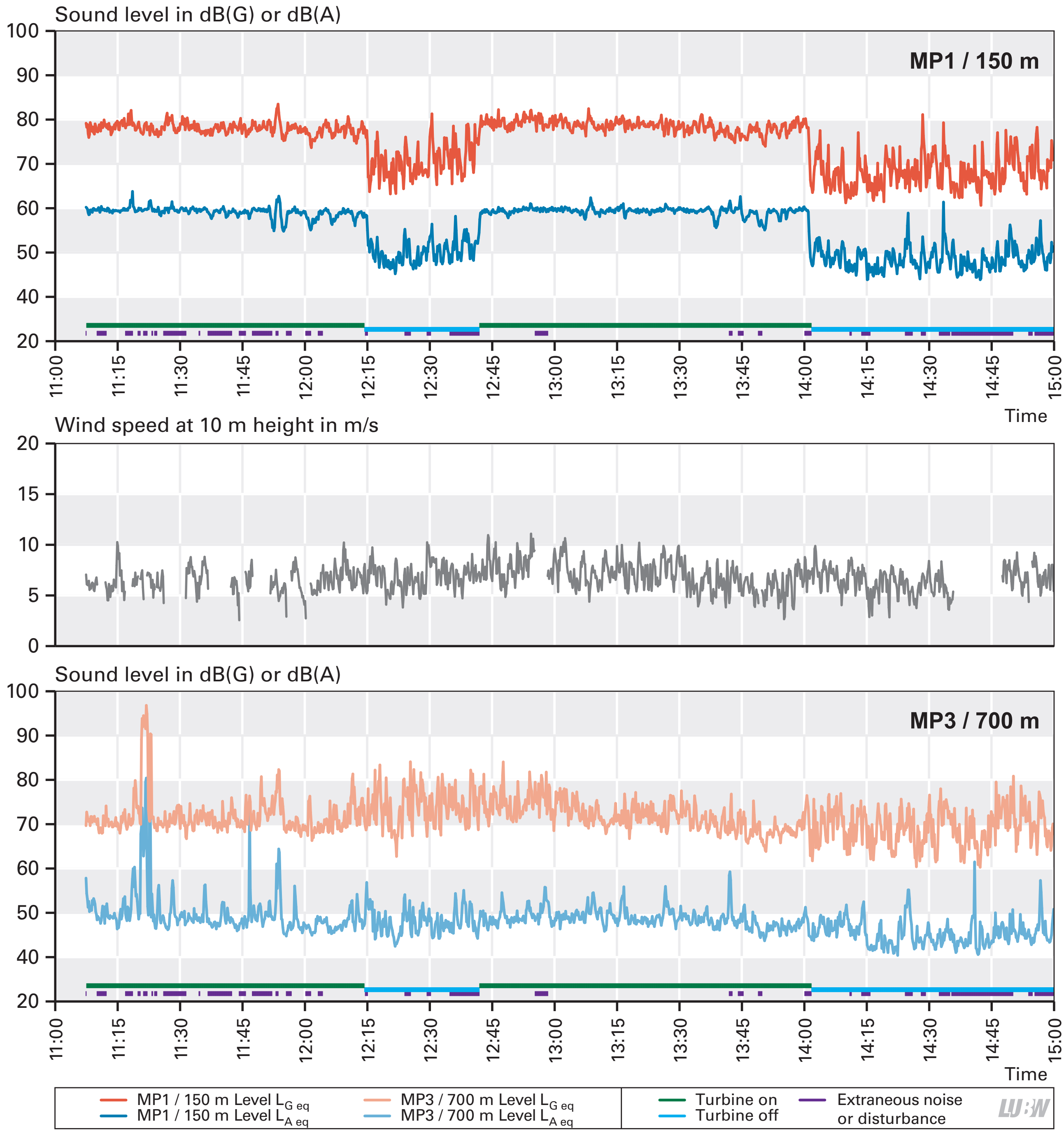


***Figure 4.2-7**: Chronological sequence of audible sound level (A level), infrasound level (G level), as well as the wind speed during the measurements of the wind turbine WT 1*

4.3 Noise at wind turbine 2: Enercon E-66 – 1.8 MW

BASIC CONDITIONS

The wind turbine 2 (WT 2) is a gearless unit by the company Enercon, Model E-66 18/70 (***Figure 4-2***) with a nominal generator capacity of 1.8 MW. The rotor diameter is 70 m, the hub height above ground is 86 m. The immediate vicinity of the turbine consists of agricultural land, with forest partly adjacent to it. Further wind turbines are located in the vicinity. These were completely turned off during the measurement period in order to prevent extraneous noise. A further wind power plant is located at a distance of about 1.5 km; this was in operation during the measurement period. A path in close proximity is allowed to be used only by agricultural traffic and is used very seldom. The measurements were carried out on 02.11.2013 between 10:00 a.m. and 6:00 p.m. The position of the microphone at the measurement point MP1 was at a distance of 120 m from the power plant, measurement point MP2 at a distance of 240 m, both in a downwind direction (in order to take into account the propagation of sound through the wind). The microphone at the measurement point MP3 was positioned at a distance of 300 m from the tower axis and deviated by 30° from the prevailing wind direction. A measurement point at a distance of 700 meters was not possible at this site. ***Figure 4.3-1*** provides an impression.

Figure 4.3-1: *Measurement point MP1 with microphone, reverberant plate and dual wind screen. In the background: wind turbine WT 2 at a distance of 120 m. Photo: Wölfel company.*

The measurement was performed in a wind speed range of 5 to 15 m/s (measured at 10 m height), a temperature range of 11 to 12.5 °C, an air pressure range of 926 to 927 hPa and in a power range of 0 to 1,800 kW. The turbulence intensity (see Appendix A3) during the measurement was 28 % and thus relatively high.

RESULTS: NARROW BAND LEVEL

Figure 4.3-2 shows the narrow band spectra of background noise and overall noise at the measurement point MP1 at a distance of 120 m with a resolution of 0.1 Hz. The wind speed was 9 m/s. With the turbine turned on, several discrete maxima can be observed in the infrasound range below 8 Hz. This concerns infrasound generated by the rotor due to its motion. The measured frequencies are in accordance with the passage frequency of a rotor blade and its harmonic overtones. At 22.5 rpm, the speed at which the turbine was running, one can mathematically determine the peaks at 2.2 Hz, 3.4 Hz, 4.5 Hz, 5.6 Hz, 6.8 Hz and 7.9 Hz with good conformance. They disappear when the turbine is turned off; at a distance of 300 m they occur

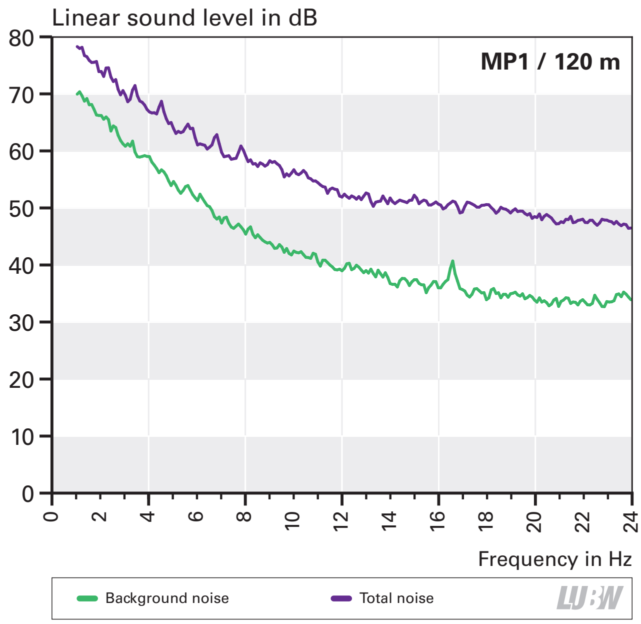
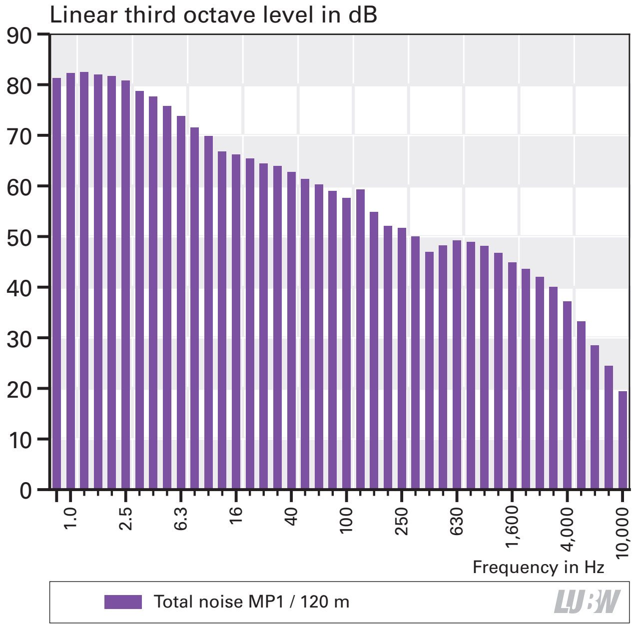


Figure 4.3-2 *Narrow band spectra of background noise and total noise in the vicinity of the wind turbine WT 2 for the frequency range of infrasound*



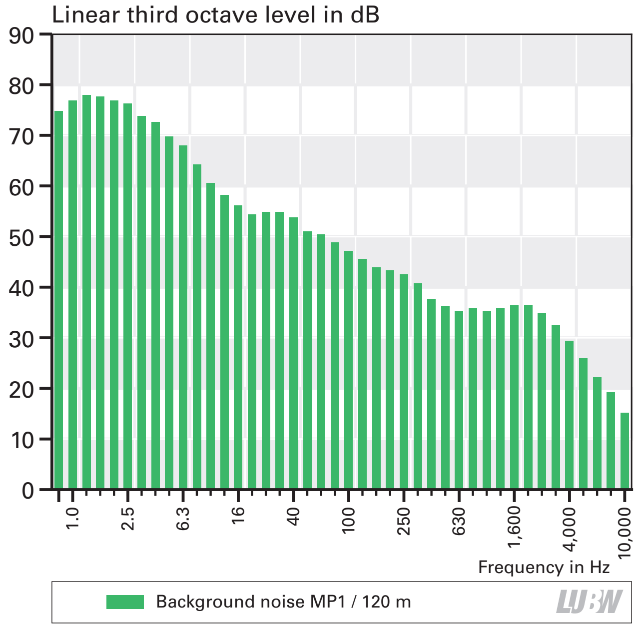


***Figure 4.3-3**: Third octave spectra of total noise and background noise in the vicinity of the wind turbine WT 2*

only faintly (not shown). The level peak at approx. 17 Hz that is clearly visible in the background is probably due to extraneous noise.

RESULTS: THIRD OCTAVE LEVEL

Figure 4.3-3 shows the third octave spectra of background noise and overall noise at the measurement point MP1 at a distance of 120 m for the frequency range from 0.8 Hz to 10,000 Hz. The wind speed was 9 m/s. The level reduction through switching off the turbine is recognizable in a much broader spectral range here.

COMPARISON WITH THE PERCEPTION THRESHOLD

Figure 4.3-4 shows the third octave spectra of the total noise at the measurement points MP1, MP2 and MP3 for the frequency range from 1 Hz to 100 Hz along with the perception threshold in comparison. The wind speed was 9 m/s. The background noise of wind and vegetation are also included. These may vary at the respective measurement point. The measurement points MP2 and MP3 are further away from the turbine than measurement point MP1 (240 m and 300 m compared to 120 m). This is where somewhat lower values are also measured, which becomes more apparent with increasing frequency. In the range of infrasound, the curves are well below the perception threshold.

INFLUENCE OF WIND SPEED

In order to investigate the dependency of low-frequency emissions on wind speed, numerous readings were taken and are depicted in ***Figure 4.3-5***. The three charts represent the conditions at distances of 120 m (MP1, upper figure), 240 m (MP2, middle figure) and 300 m with a lateral displacement by 30° to the wind direction (MP3, lower figure). The violet dots in the lower range of values represent audible sound, expressed in dB(A). In the upper image it

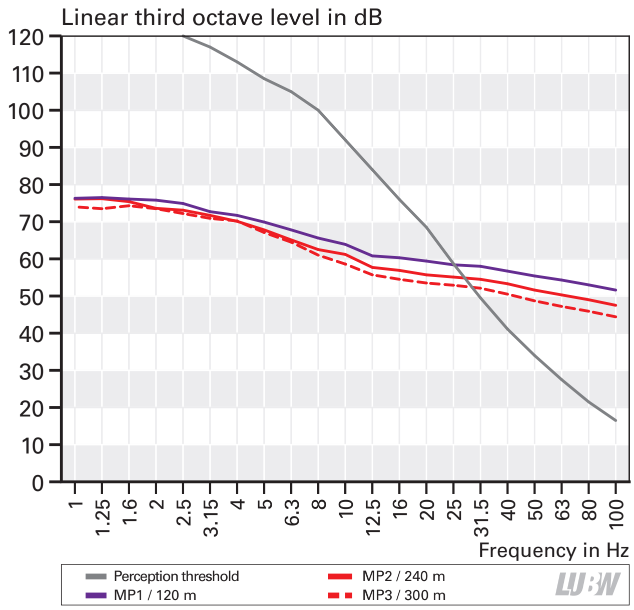


***Figure 4.3-4**: Third octave spectra of total noise at the measurement points MP1 (120 m), MP2 (240 m) and MP3 (300 m) of WT 2, with the perception threshold according to Table A3-1 in comparison. The measured values were corrected according to Section 4.1.*

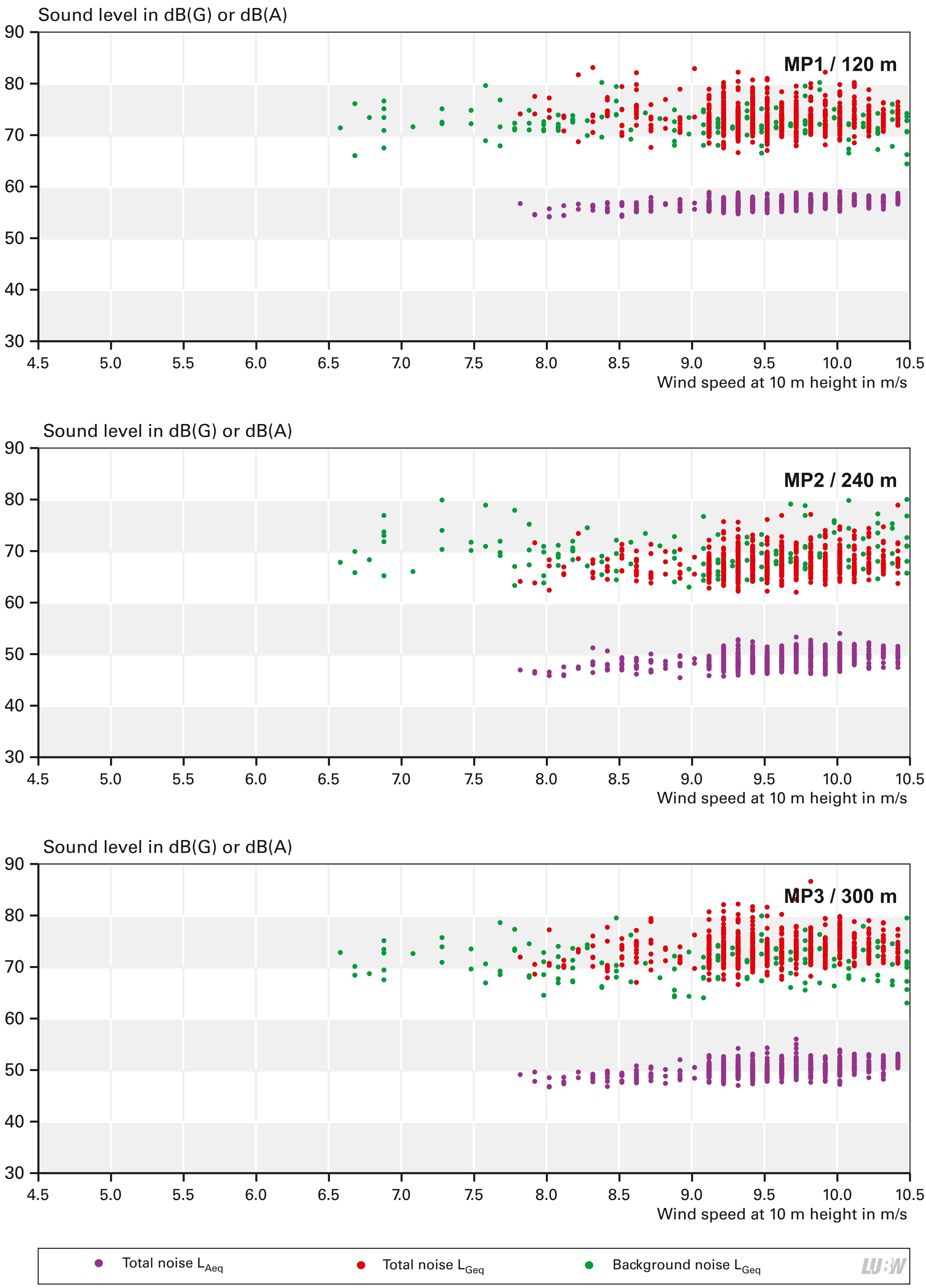


***Figure 4.3-5**: Audible sound level (A level) and infrasound level (G level) depending on the wind speed for the wind turbine WT 2. The G levels when the turbine is switched on (red dots) and when the turbine is switched off (green dots) are shown, as are the A levels with the turbine switched on (violet dots).*

can be seen clearly that the measured A levels are higher at a distance of 120 m than at the measurement points at a distance of 240 m and 300 m from the power plant. The turbine was perceived to be louder at a distance of 120 m than at a distance of 240 m.

The red dots represent the G-weighted sound level when the turbine is switched on, the green dots when the turbine is switched off. The upper image shows that at the measurement point MP1, i.e. in the near field at a distance of 120 m from the power plant, the G-weighted sound pressure level during operation of the wind power plant is approximately constant and minimally higher than that of the background noise when the turbine is not running. A similar situation is given at the measurement points MP2 and MP3. Hardly any differences can be seen between the measured values, as the red and green dot clusters pretty-much overlap each other.

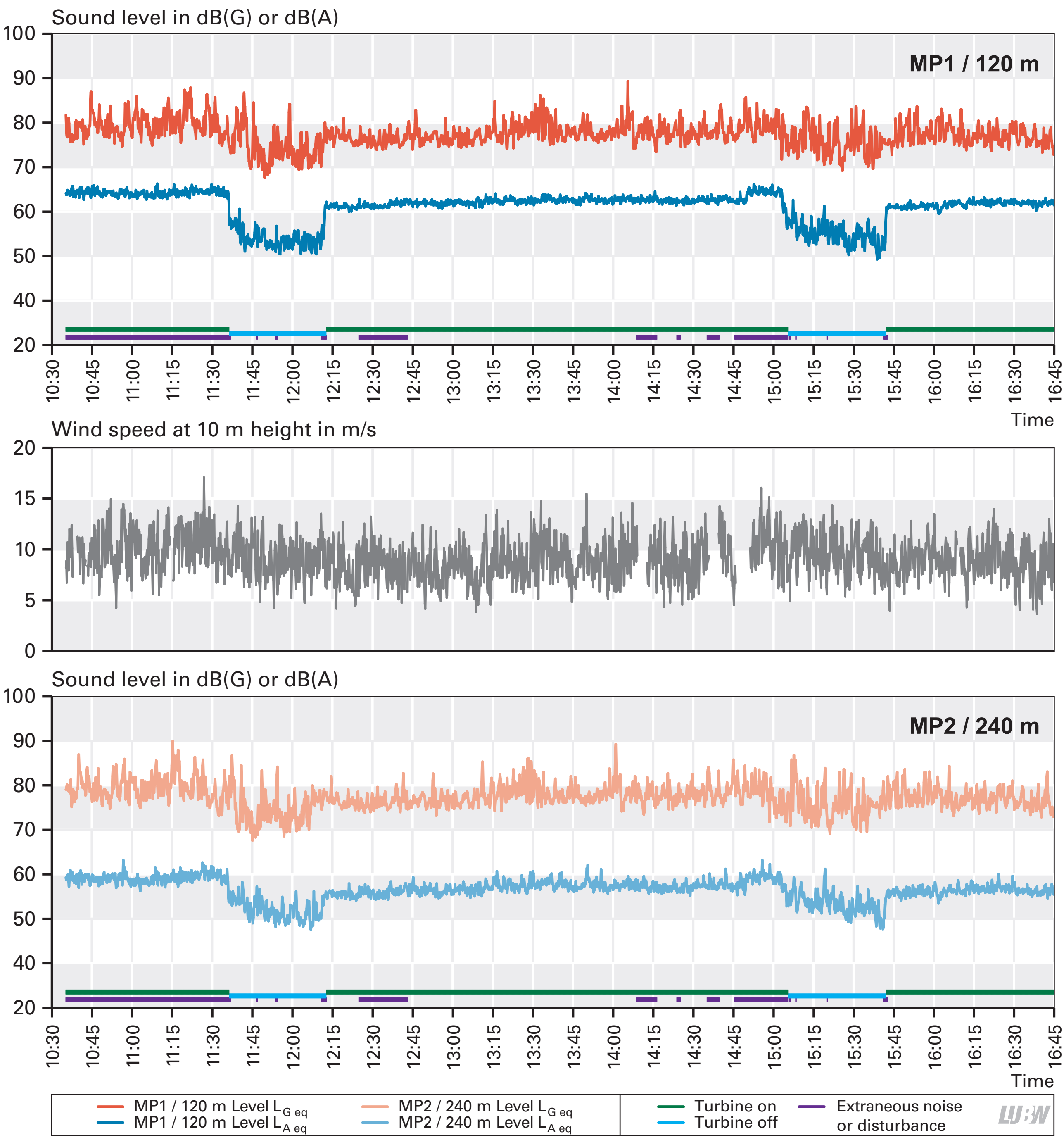


***Figure 4.3-6**: Chronological sequence of audible sound level (A level), infrasound level (G level), as well as the wind speed during the measurements at the wind turbine WT 2*

The relatively large scattering of the measured values for when the turbine is running and when it is not running, and the relatively high G-weighted sound pressure level – even when the turbine is off – are in this case probably due to the high wind speeds prevailing throughout. The measurements with the turbine in operation were taken in the range of 8 to 11.5 m/s (10 m height). In this case, part of the effect is potentially also attributable to wind-induced noise at the microphones.

LEVEL DEVELOPMENT DURING THE MEASUREMENT

Figure 4.3-6 shows the A and G-weighted level curves between 10:30 a.m. and 5:00 p.m. at a distance of 120 m and 240 m. In addition, the operating conditions of the wind turbine (green = turbine on, light blue = turbine off) as well as periods of time with external noise (violet) are depicted. For the two level developments of measurement point MP1, the operational phase "turbine off" is recognisable through the considerably declining level developments. At measurement point MP2, the level drop is less pronounced when the turbine is off, but still clearly recognizable.

Figure 4.4-1*: Wind turbine WT 3 in surroundings used for agricultural purposes. The measurement point with reverberant plate and dual wind screen can be seen in the foreground. Photo: Wölfel company*

4.4 Noise at wind turbine 3: Enercon E-82 – 2.0 MW

BASIC CONDITIONS

The wind turbine 3 (WT 3) is a gearless unit by the company Enercon, Model E-82 E2 (***Figure 4-3***) with a nominal generator capacity of 2.0 MW. The rotor diameter is 82 m, the hub height above ground is 138 m. As can be seen in ***Figure 4.4-1***, agriculturally used areas are located in the closer vicinity. An adjacent wooded area is located at a distance of about 400 meters. A dirt road is located in the immediate vicinity of the power plant, which is used only seldom by agricultural and forestry vehicles. A road is located at a distance of approx. 450 m from the power plant. During the measurement, no traffic noise was noticeable. Further wind turbines from other operators are located at a distance of 1,500 meters. These power plants located further away were in operation during the measurement period. The immissions were not subjectively noticeable during the background noise measurements. The nearest residential building is more than 1,000 meters away. The measurement was carried out on 15.10.2013 between 10:30 a.m. and 3 p.m. The microphone at the measurement point MP1 was located at a distance of 180 meters in a downwind direction from the tower axis, at the measurement point MP2 it was 300 m in a downwind direction. The microphone at the measurement point MP3 was also positioned at a distance of 300 meters, however at an angle of 90° to the downwind direction. A measurement point at a distance of 700 meters was not feasible due to the local conditions.

The measurement was performed in a wind speed range of 2 to 12 m/s (measured at 10 m height), a temperature range of 9 to 13 °C, an air pressure range of 931 to 934 hPa and in a power range of 0 to 2,070 kW. The turbulence intensity (see Appendix A3) during the measurement was 25 % and thus relatively high.

RESULTS: NARROW BAND LEVEL

Figure 4.4-2 shows the narrow band spectra of background noise and overall noise at the measurement point MP1 at a distance of 180 m with a resolution of 0.1 Hz. With the turbine turned on, several discrete maxima can be clearly observed in the infrasound range below 8 Hz. This con-

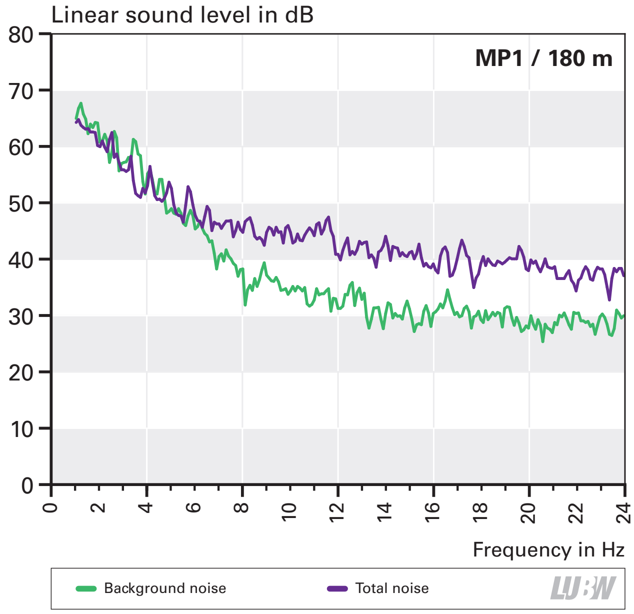


Figure 4.4-2: *Narrow band spectra of background noise and total noise in the vicinity of the wind turbine WT 3 for the frequency range of infrasound*

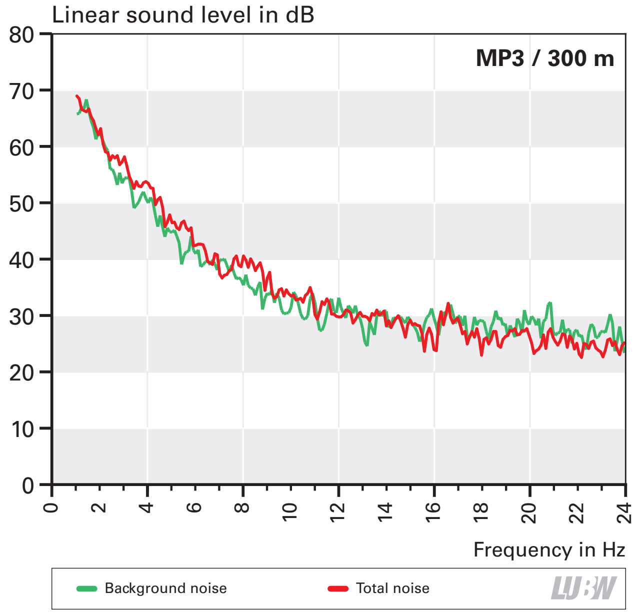
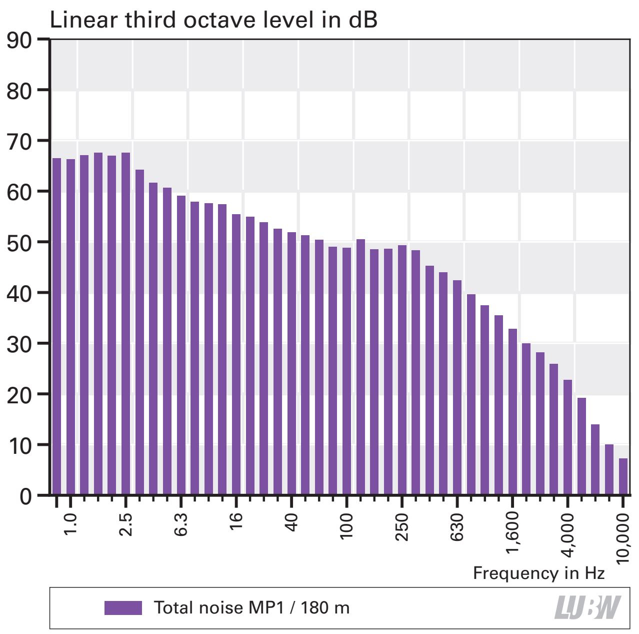


Figure 4.4-3: *Narrow band spectra of background noise and total noise in the far range of the wind turbine WT 3 for the frequency range of infrasound*

cerns infrasound generated by the rotor due to its motion. The measured frequencies correspond to the passage frequency of a rotor blade (here about 0.83 Hz) and the associated harmonic overtones (2.5 Hz, 3.3 Hz, 4.1 Hz, 5 Hz, 5.8 Hz). The peaks disappear when the power plant is switched off, and occur only slightly at a distance of 300 m (***Figure 4.4-3***). The wind speed was 6 m/s during both measurements.

RESULTS: THIRD OCTAVE LEVEL

Figure 4.4-4 shows the third octave spectra of background noise and overall noise at the measurement point MP1 at a distance of 180 m for the frequency range from 0.8 Hz to 10,000 Hz. The wind speed was 6 m/s. Here the level reduction through switching off the turbine is recognizable in a much broader spectral range.



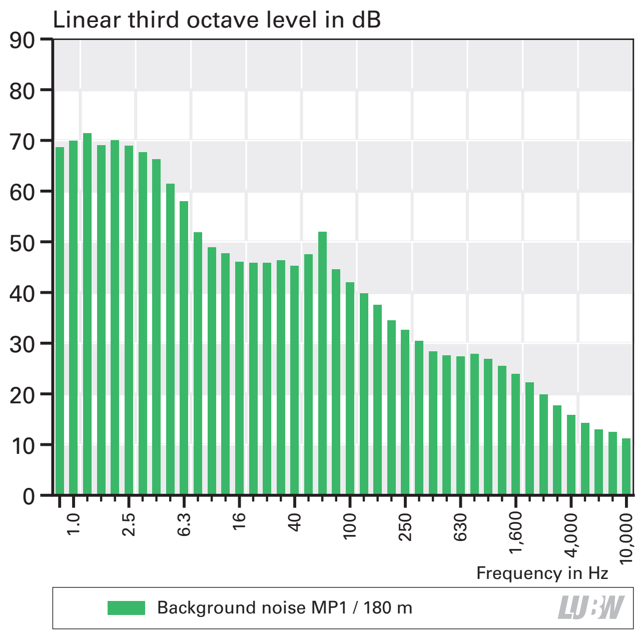


Figure 4.4-4: *Third octave spectra of total noise and background noise in the vicinity of the wind turbine WT 3*

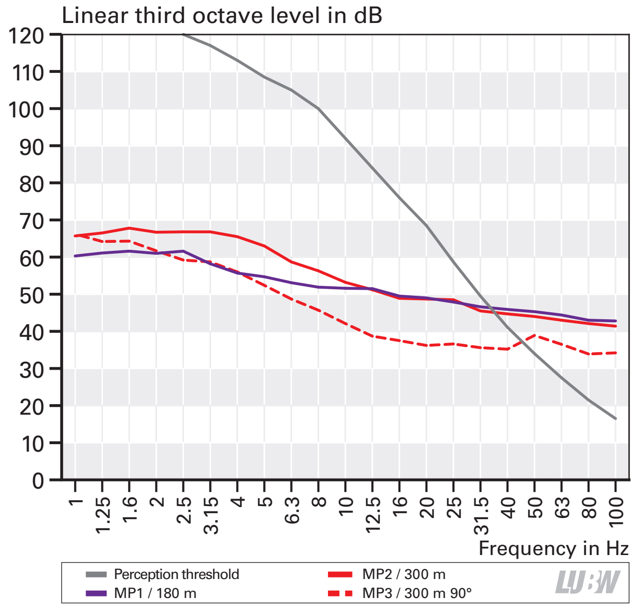


***Figure 4.4-5**: Third octave spectra of the total noise at the measurement points MP1 (180 m), MP2 (300 m) and MP3 (300 m, offset by 90 °) of wind turbine 3, perception threshold according to Table A3-1 for comparison. The measured values were corrected according to Section 4.1.*

COMPARISON WITH THE PERCEPTION THRESHOLD

Figure 4.4-5 shows the third octave spectra of the total noise at the measurement points MP1, MP2 and MP3 for the frequency range from 1 Hz to 100 Hz along with the perception threshold in comparison. The wind speed was 9 m/s. It must be kept in mind that the background noise of wind and vegetation are also included. These may vary at the respective measurement point. The measurement points MP2 and MP3 are further away from the power plant than measurement point MP1 (300 m compared to 180 m). Measurement point MP3 is offset to the downwind direction by 90°. Lower values are thus measured there than at measurement point MP2, which is equally far away. The measurement point MP2 is also closer to an existing nearby road than the measurement points MP1 and MP3, which could also be a reason for the slightly higher values. In the range of infrasound, the curves are well below the perception threshold.

INFLUENCE OF WIND SPEED

In order to investigate the dependency of low-frequency emissions on wind speed, numerous readings were recorded and graphically depicted in ***Figure 4.4-6***. The three charts represent the relationships at the respective measurement points at the distances 180 m (top), 300 m (centre) and 300 m with lateral offset by 90° to the downwind direction (bottom). Violet dots, which depict the lower curve, represent audible sound, expressed in dB(A). It can be clearly seen that at a distance of 180 m (top image) the measured A levels are higher than at the measurement points at a distance of 300 m from the turbine. The turbine was thus also clearly more perceptible at a distance of 180 m than at a distance of 300 m. The A level first rises with increasingly higher wind speed.

The red dots represent the G-weighted sound level when the wind power plant is switched on, the green dots when the power plant is switched off. Similarly to the A level, it can also be seen for the G level that – despite higher scattering – it increases somewhat with increasing wind speed, and then remains constant.

The top image shows that at MP1, i.e. in the near field at a distance of 180 m from the turbine, the G-weighted sound pressure level during operation of wind turbine 3 is significantly higher than the background noise when the turbine is off. This is far less pronounced at a distance of 300 meters (centre image) and barely detectable at a distance of 300 meters with 90° offset to the downwind direction (bottom image). The red and green dot clusters then overlap each other in many areas.

LEVEL DEVELOPMENT DURING THE MEASUREMENT

Figure 4.4-7 shows the A and G-weighted level development between 10:15 a.m. and 2:45 p.m. for distances of 180 m and 300 m. In addition, the operating conditions of the wind power plant (green = turbine on, light blue = turbine off) as well as periods of extraneous noise (violet) are shown. For the two level developments of measurement point MP1, the operational phase "turbine off" is recognisable through the considerably declining level developments. At measurement point MP2, the recognisable level drop is significantly weaker with the turbine switched off due to the fluctuating background noise.

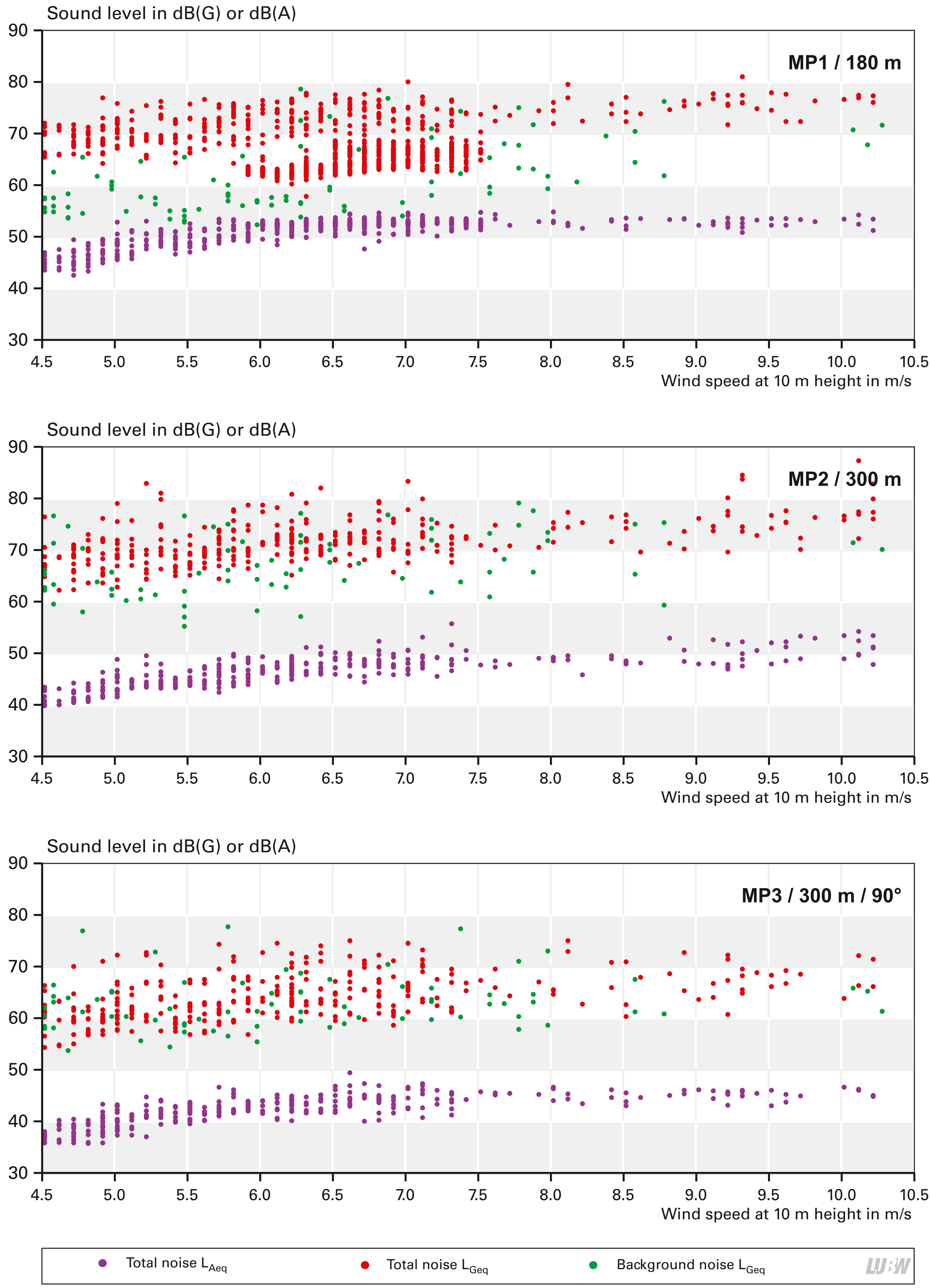


***Figure 4.4-6**: Audible sound level (A level) and infrasound level (G level) depending on the wind speed for the wind turbine WT 3. The G levels when the turbine is switched on (red dots) and when the turbine is switched off (green dots) are shown, as are the A levels with the turbine switched on (violet dots).*

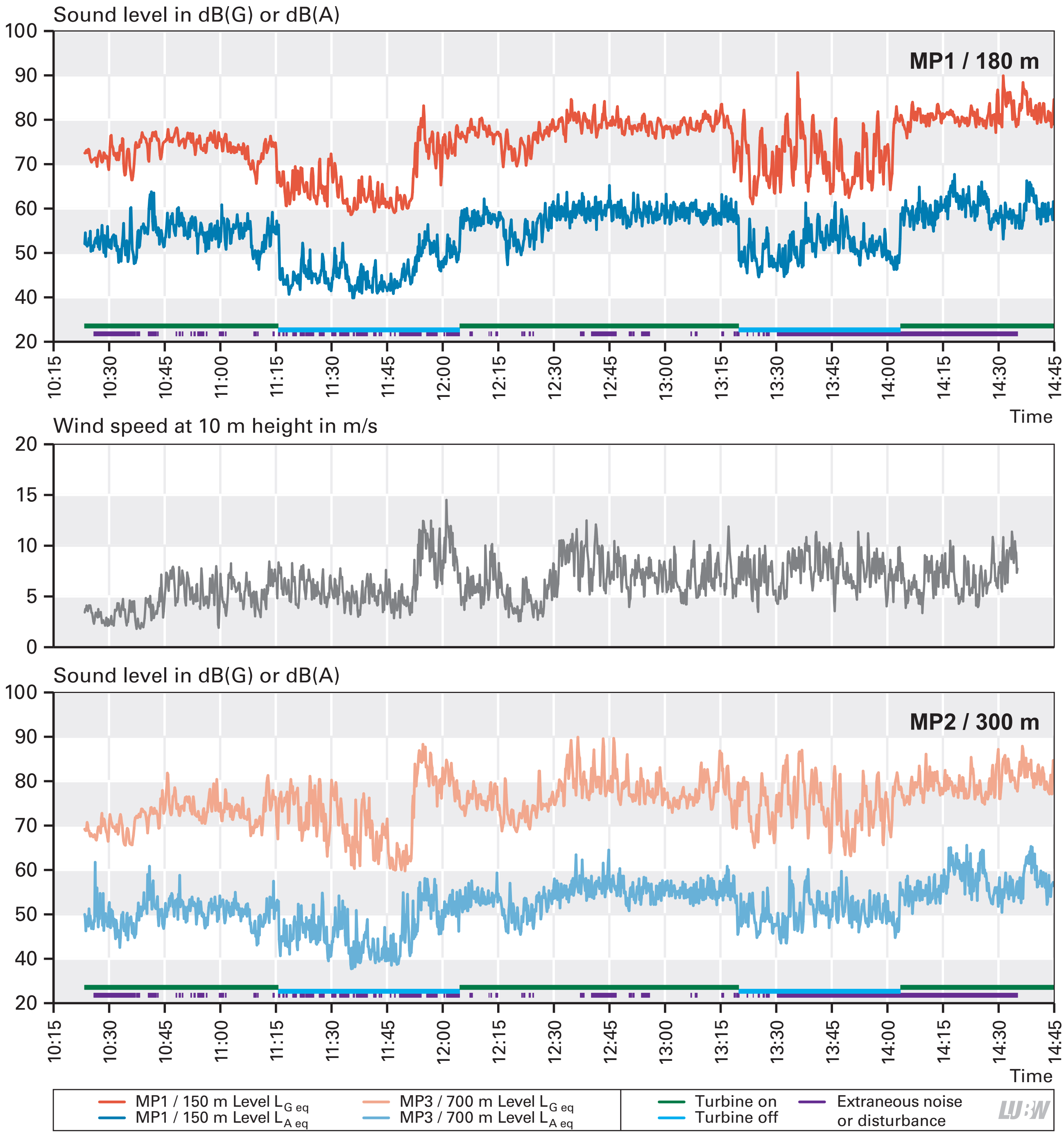


***Figure 4.4-7**: Chronological sequence of audible sound level (A level), infrasound level (G level), as well as the wind speed during the measurements of the wind turbine WT 3*

4.5 Noise at wind turbine 4: REpower 3.2M114 – 3.2 MW

BASIC CONDITIONS

The wind turbine 4 (WT 4) is a unit by the company REpower, type 3.2M114 (***Figure 4-4***) with a nominal generator capacity of 3.2 MW. The rotor diameter is 114 m, the hub height 143 m.

The measured wind turbine is part of a wind farm with several other wind turbines. The adjacent turbines were completely turned off during the measurement period in order to prevent extraneous noise. The vicinity of the turbine consists of agricultural land. A dirt road in the immediate vicinity of the measured turbine is rarely used by agricultural traffic. A forest is located further away. Further wind turbines were in operation at distances of 0.7 km and 2 km, in the opposite direction to the measurement points. Their noise could not be subjectively perceived at any time. The measurements were carried out on 20.03.2014 between 10:00 a.m. and 9:30 p.m. The position of the microphone at the measurement point MP1 was at a distance of 180 m from the turbine, measurement point MP2 and MP3 at a distance of 300 m and measurement point MP4 at a distance of 650 m, in a downwind direction respectively, in order to take into account the most adverse case (promotion of sound propagation through the wind). The measurement point MP2, located directly next to measurement point MP3, served as a comparative measurement point. Its microphone was provided with a primary wind screen and placed into an approx. 50 cm deep hole that was dug especially for that purpose. A secondary wind screen covered the hole flush. The parallel measurements were taken at the measurement points MP2 and MP3 in order to enable a comparison of the measurement values and enable conclusions to be made regarding wind-induced sound components arising at the microphone. The two measurement points MP2 and MP3, as well as the measured turbine, can be seen in ***Figure 4.5-1***. ***Figures 4.5-2 to 4.5-5*** provide an impression of the conditions on site and the measurement technology used.

The measurement was performed in a wind speed range of 3 to 7 m/s (measured at 10 m height), a temperature range

Figure 4.5-1 *(right): Measurement points MP2 and MP3 at a distance of 300 m from the tower axis. Reverberant plate and double wind screen (left), spanned hole in the ground (right). Photo: Wölfel company*

Figure 4.5-2: *View inside the power plant with 143 m hub height. Photo: LUBW*

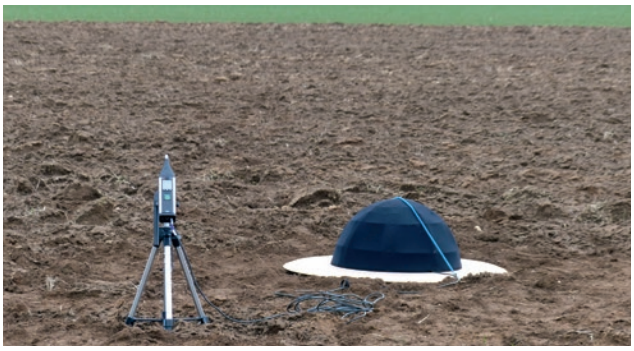


Figure 4.5-3: *Reverberant plate with mounted microphone and dual wind screen. The type DUO measurement device is mounted on a tripod next to it and is connected to the microphone via a measuring cable. Photo: LUBW*

Figure 4.5-4: Anemometer mast for measuring wind speed and wind direction, air pressure, humidity and temperature. The mast is extended to 10 m (not yet extended in the image). Photo: LUBW

Figure 4.5-5: Data is constantly collected inside the system during the measurement and transmitted by radio (left). Photo: LUBW

of 15 to 19 °C, an air pressure range of 979 to 981 hPa and in a power range of 0 to 3,170 kW. The turbulence intensity (see Appendix A3) during the measurement was 15 %.

RESULTS: NARROW BAND LEVEL

Figure 4.5-6 shows the narrow band spectra of background noise and overall noise at the measurement point MP1 at a distance of 180 m with a resolution of 0.1 Hz. With the turbine turned on, clearly visible maxima can be seen in the infrasound range. The measured frequencies correspond to the passage frequency of a rotor blade (here approximately 0.6 Hz) and its harmonic overtones at 1.2 Hz, 1.8 Hz, 2.4 Hz, 3 Hz, etc. This concerns infrasound generated by the rotor due to its motion. The peaks disappear when the turbine is switched off. ***Figure 4.5-7*** shows the narrowband spectra of background noise and total noise at the measurement point MP4 at a distance of 650 m. At this location the discrete infrasound maxima (see measurement point MP1) are still detectable with the wind power plant turned on. The recognizable slightly higher levels at measurement point MP4, with frequencies lower than 5 Hz, cannot be attributed to turbine operation. The cause for

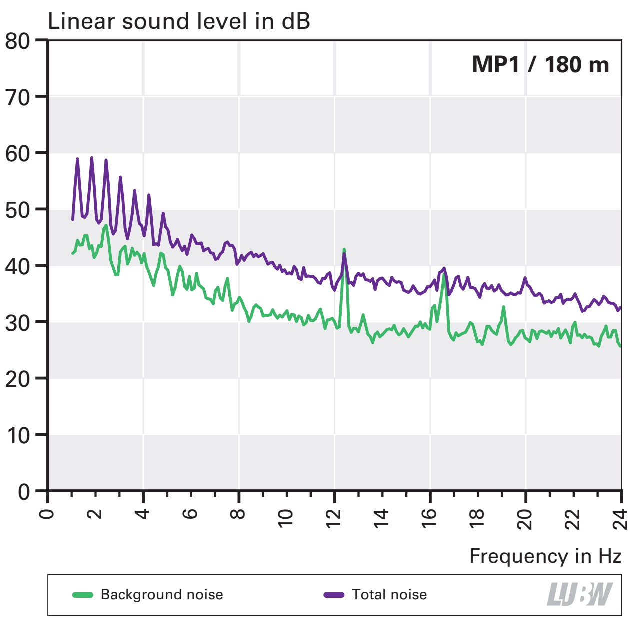


Figure 4.5-6: Narrow band spectra of background noise and total noise in the vicinity of the wind turbine WT 4 for the frequency range of infrasound

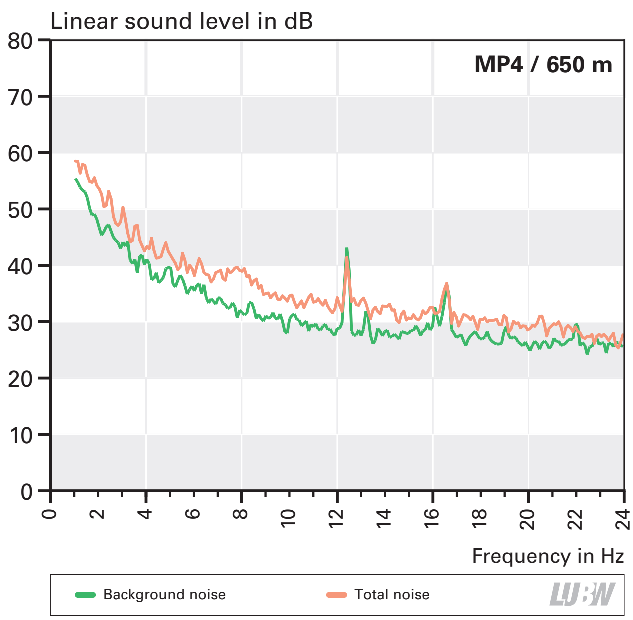


Figure 4.5-7: Narrow band spectra of background noise and total noise in the far range of the wind turbine WT 4 for the frequency range of infrasound

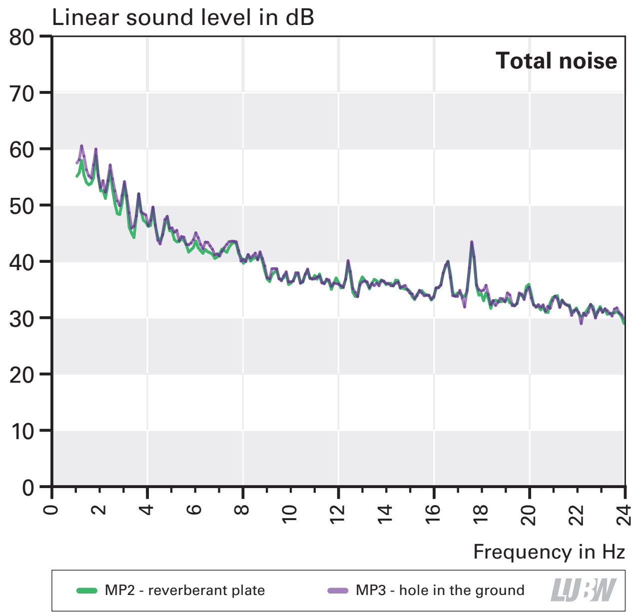


Figure 4.5-8: *Narrowband spectra of the total noise at the measurement points MP2 (reverberant plate) and MP3 (hole in the ground) of the wind turbine WT 4 for the range of infrasound. The distance from the turbine was 300 m*

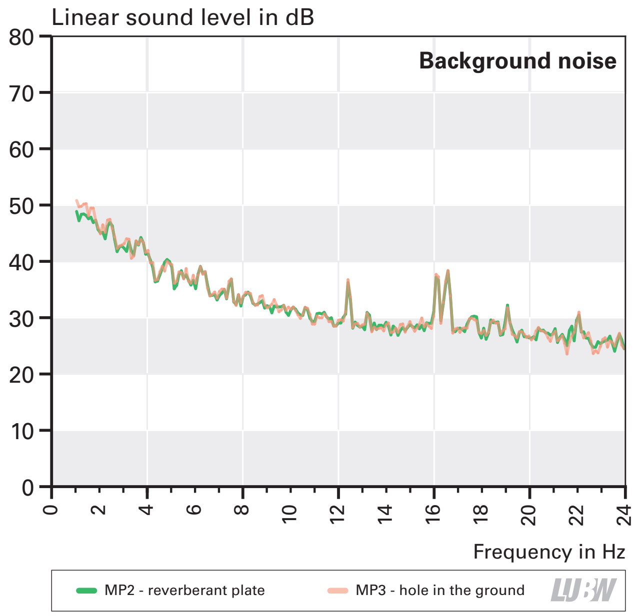


Figure 4.5-9: *Narrowband spectra of the background noise at the measurement points MP2 (reverberant plate) and MP3 (hole in the ground) of the wind turbine WT 4 for the range of infrasound. The distance from the turbine was 300 m.*

the up to 10 dB higher values is another background noise at the measurement point MP4 compared to the measurement point MP1. The wind speed was 5.5 m/s for both measurements.

The comparison of narrowband spectra for the two measurement points MP2 and MP3 in ***Figures 4.5-8 to 4.5-9*** shows that there is no significant difference between the two measurement points for the range of infrasound. The wind speed was 5.5 m/s respectively. It can therefore be assumed that below 20 Hz neither the absorption of the secondary wind screen nor the ground influences play a role. The increase in level towards lower frequencies was present in this measurement to an equal extent both with and without a hole in the ground. The expected reduction in the wind-induced background noise in the infrasound range cannot be observed in a direct comparison between the two measurement points. Further investigations regarding the issue of noise at the microphone induced by the wind were thus not deemed necessary.

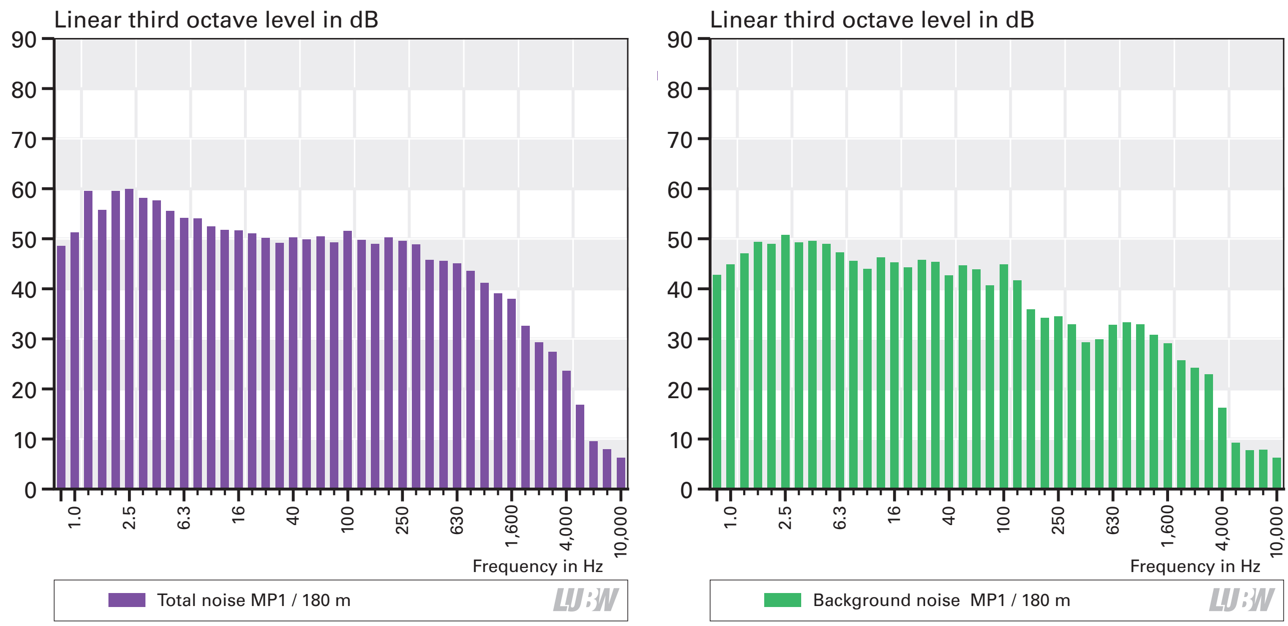


Figure 4.5-10: *Third octave spectra of total noise and background noise in the vicinity of the wind turbine WT 4*

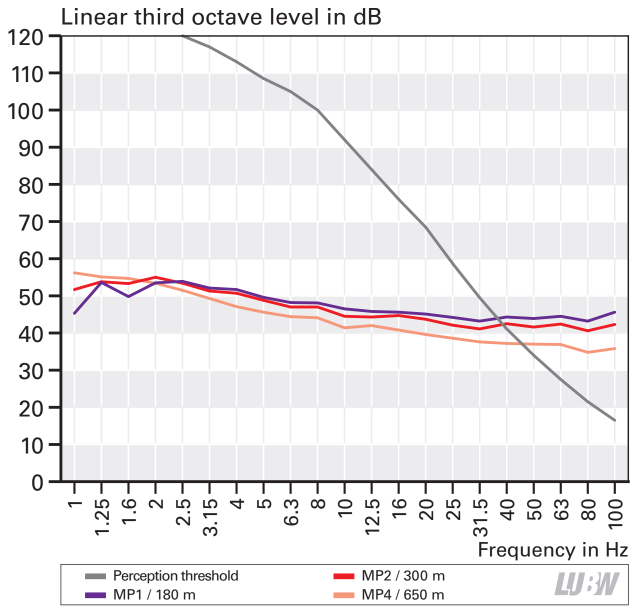


Figure 4.5-11: *Third octave spectra of total noise at the measurement points MP1 (180 m), MP2 (300 m) and MP4 (650 m) of WT 4, with the perception threshold according to Table A3-1 in comparison. The measured values were corrected according to Section 4.1.*

RESULTS: THIRD OCTAVE LEVEL

Figure 4.5-10 shows the third octave spectra of background noise and overall noise at the measurement point MP1 at a distance of 180 m for the frequency range from 0.8 Hz to 10,000 Hz. The wind speed was 5.5 m/s. Here the level reduction through switching off the turbine is recognizable in a much broader spectral range.

COMPARISON WITH THE PERCEPTION THRESHOLD

Figure 4.5-11 shows the third octave spectra of the total noise at the measurement points MP1, MP2 and MP4 for the frequency range from 1 Hz to 100 Hz along with the perception threshold in comparison. The wind speed was 5.5 m/s. It must be kept in mind that the background noise of wind and vegetation are also included. These may vary at the respective measurement point. The measurement points MP2 and MP4 are further away from the turbine than MP1 (300 m and 650 m compared to 180 m). This is where somewhat lower values are also measured, which becomes more apparent with increasing frequency. In the range of infrasound, the curves are well below the perception threshold.

INFLUENCE OF WIND SPEED

In order to investigate the dependency of low-frequency emissions on wind speed, numerous readings were recorded and graphically depicted in ***Figure 4.5-12***. The three charts represent the relationships at the respective measurement points at the distances 180 m (top), 300 m (centre) and 650 m (bottom). Violet dots, which depict the lower value area, represent audible sound, expressed in dB(A). It can be seen clearly that the measured A levels are higher at a distance of 180 m (upper image) than at the measurement points at a distance of 300 m and 650 m from the turbine.

The red dots represent the G-weighted sound level when the wind turbine is switched on, the green dots when the turbine is switched off. The data shows that the G-weighted sound pressure level of the tested measurement points increases slightly during operation of the wind turbine with increasing wind speed. For the G-weighted sound pressure level of the background noise, no connection can be ascertained with the wind speed for the main part of the measuring period. However, the readings are also in a similar order with the turbine switched off due to strongly fluctuating wind conditions (gusts, turbulence). Lower levels were observed for the background noise merely for a late, roughly 30-minute measurement period from 8:50 p.m. onwards. During this period, the mean normalized wind speed was relatively constant at 5.5 m/s.

LEVEL DEVELOPMENT DURING THE MEASUREMENT

Figure 4.5-13 shows the A and G-weighted level development between 4:00 p.m. and 9.00 p.m. for the distances of 180 m and 650 m. In addition, the operating conditions of the wind power plant (green = turbine on, light blue = turbine off) as well as periods of extraneous noise (violet) are shown. For the two level developments of measurement point MP1, the operational phase "turbine off" is recognisable through the considerably declining level developments. A level drop is also evident with the turbine switched off at measurement point MP3.

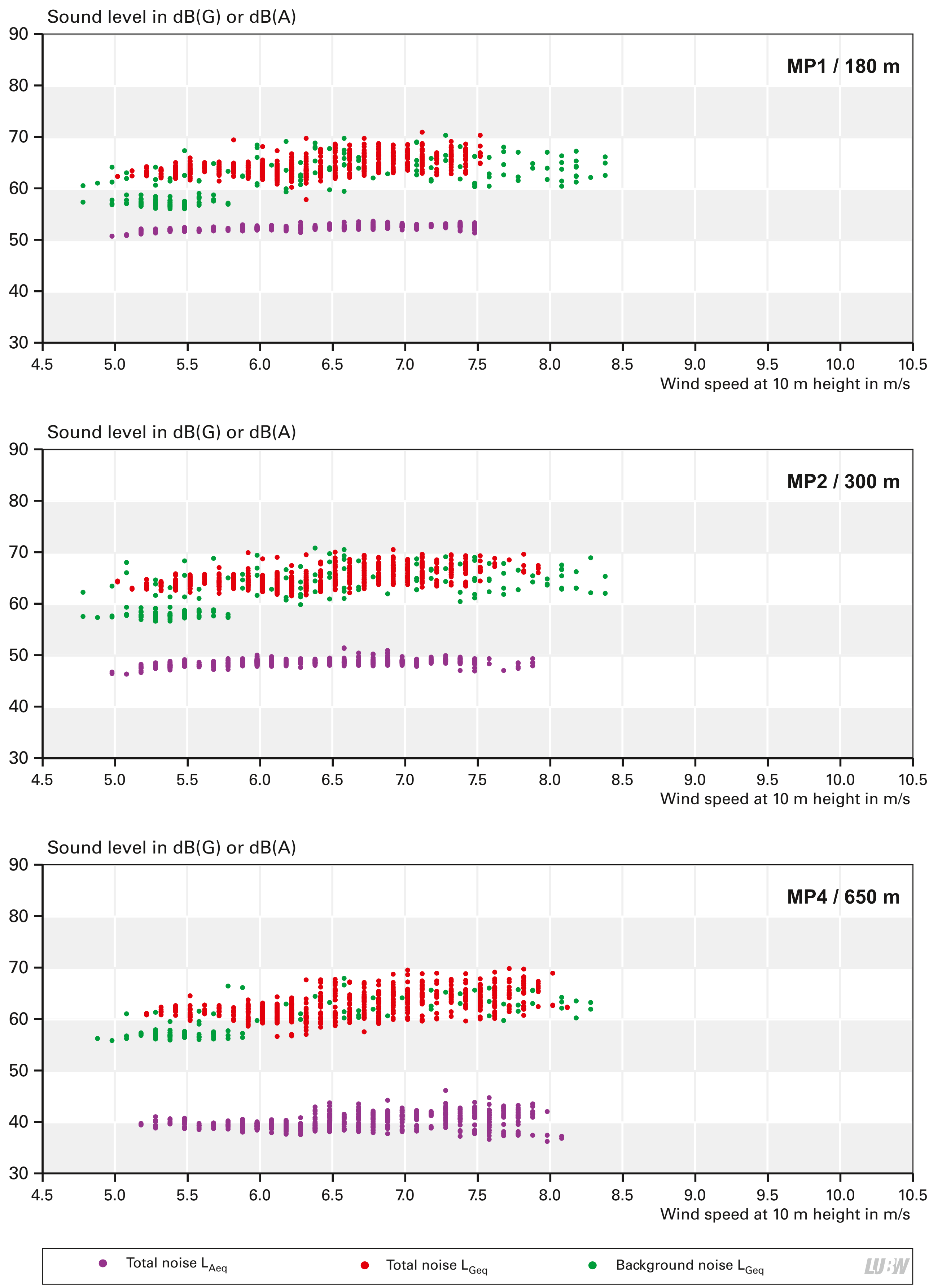


***Figure 4.5-12**: Audible sound level (A level) and infrasound level (G level) depending on the wind speed for the wind turbine WT 4. The G levels when the turbine is switched on (red dots) and when the turbine is switched off (green dots) are shown, as are the A levels with the turbine switched on (violet dots).*

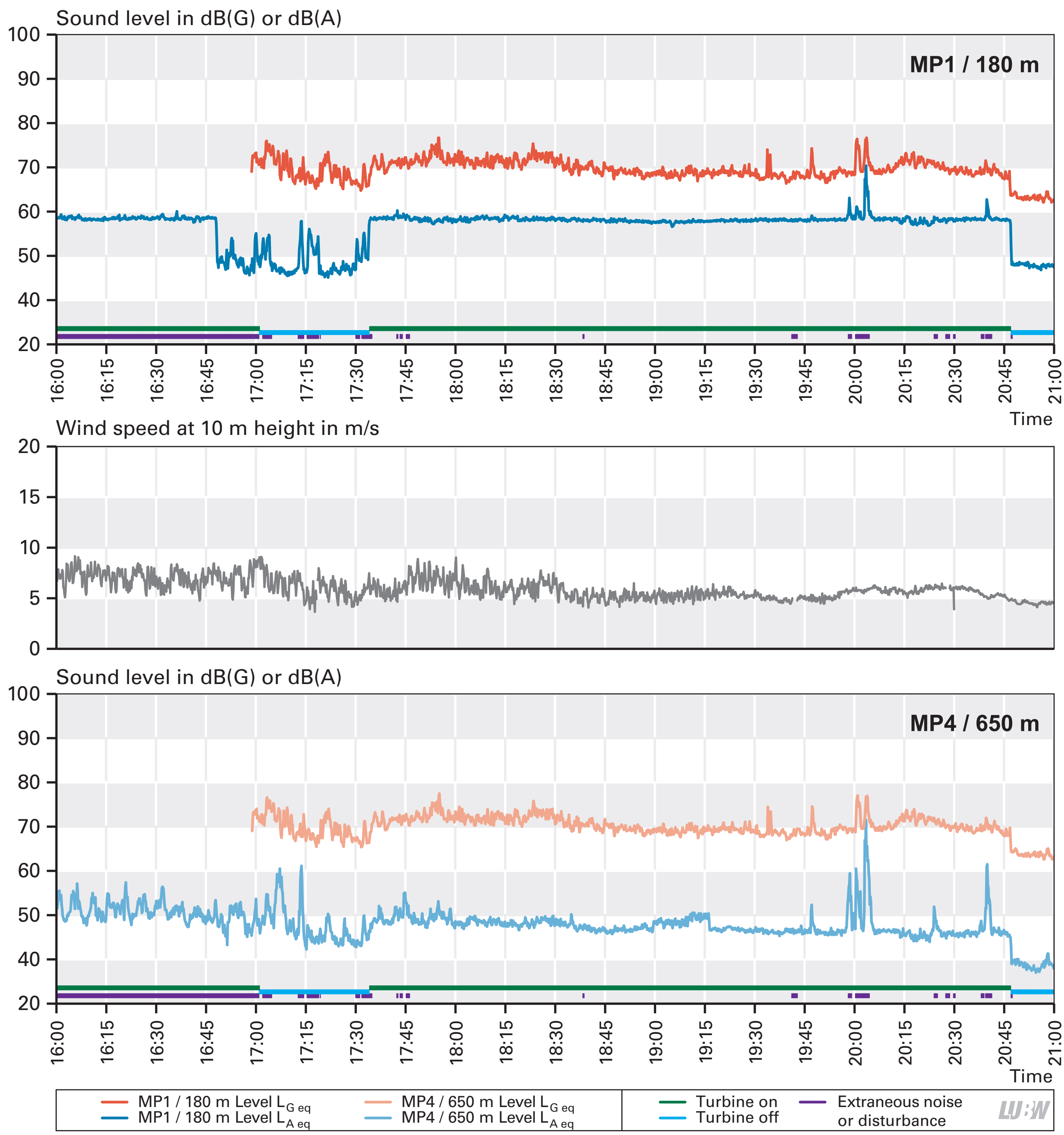


***Figure 4.5-13**: Chronological sequence of audible sound level (A level), infrasound level (G level), as well as the wind speed during the measurements at wind turbine WT 4*

4.6 Noise at wind turbine 5: Nordex N117 – 2.4 MW

BASIC CONDITIONS

The wind turbine 5 (WT 5) is a unit by the company Nordex, type N117/2400, with a nominal generator capacity of 2.4 MW (***Figure 4-3 and 4.6-1***). The rotor diameter is 117 m, the hub height above ground is 140.6 m.

The measured turbine is part of a wind farm with several wind turbines. The adjacent turbines were completely turned off during the measurement period in order to prevent extraneous noise. The vicinity of the turbine consists of agricultural land. A dirt road is located in the immediate vicinity of the turbine, which is used only very seldom by agricultural and forestry vehicles. A district road is located about 400 meters south of the investigated wind power plant, and another road roughly 1,000 m east. During the measurement, no traffic noise was subjectively perceptible. A forest is located further away. The measurements were carried out on 13.01.2015 between 11:00 a.m. and 4:00 p.m. The microphone position of the measurement point MP1 was 185 meters from the turbine, the measurement point MP2 300 m and the measurement points MP3 and MP4 each 650 m from the turbine. All measurement points were located in a downwind direction in order to take into account a generally unfavourable situation (promotion of sound propagation through the wind). The measurement points MP3 and MP4 were immediately next to one another and served as a comparison. The microphone MP3 was provided with a primary wind screen and placed into an approx. 50 cm deep hole that was dug especially for that purpose. A secondary wind screen covered the hole flush. The parallel measurements were taken at the measurement points MP3 and MP4 in order to enable a comparison of the levels and allow conclusions to be made regarding wind-induced sound components arising at the microphone.

Figure 4.6-1: *Wind turbine WT 5 in surroundings used for agricultural purposes. In the foreground you can see the 10 m high wind measurement mast. Photo: Wölfel company*

The measurement was performed in a wind speed range of 5 to 12 m/s (measured at 10 m height), a temperature range of 10 to 13 °C, an air pressure range of 975 to 979 hPa and in a power range of 0 to 2,400 kW. The turbulence intensity (see Appendix A3) during the measurement was 13 %.

RESULTS: NARROW BAND LEVEL

Figures 4.6-2 to 4.6-5 show narrow band spectra of background noise and total noise for different measurement locations with a resolution of 0.1 Hz. The wind speed was 7.6 m/s during the measurement of the total noise and 6.9 m/s during the measurement of the background noise.

Figure 4.6-2 shows the results of measurement point MP1 at a distance of 185 m. With the turbine turned on, several discrete maxima can be seen in the infrasound range below 6 Hz. This concerns infrasound generated by the rotor due to its motion. The measured frequencies correspond to the passage frequency of a rotor blade of about 0.6 Hz and its harmonized overtones at 1.2 Hz, 1.7 Hz, 2.3 Hz, 2.9 Hz, 3.5 Hz, 3.9 Hz, etc. The peaks disappear when the turbine is switched off.

Figure 4.6-3 shows the narrow band spectra of background noise and overall noise at the measurement point MP4 at a distance of 650 m. At this distance, the infrasound maxima

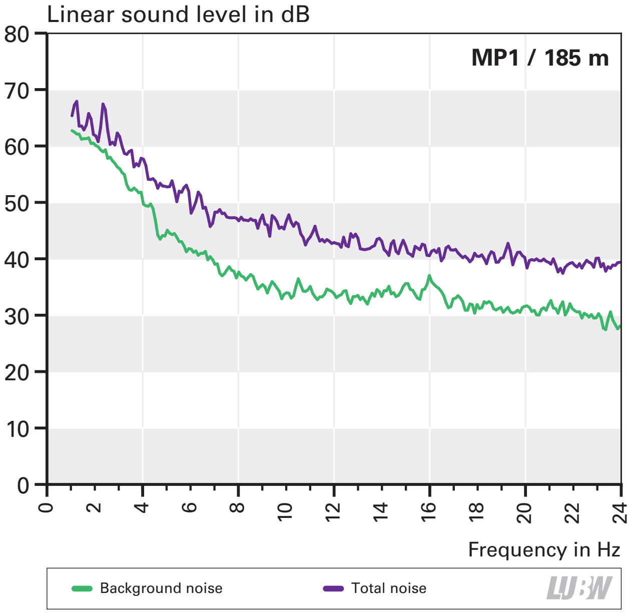


__Figure 4.6-2__: Narrow band spectra of background noise and total noise in the vicinity of wind turbine WT 5 for the frequency range of infrasound

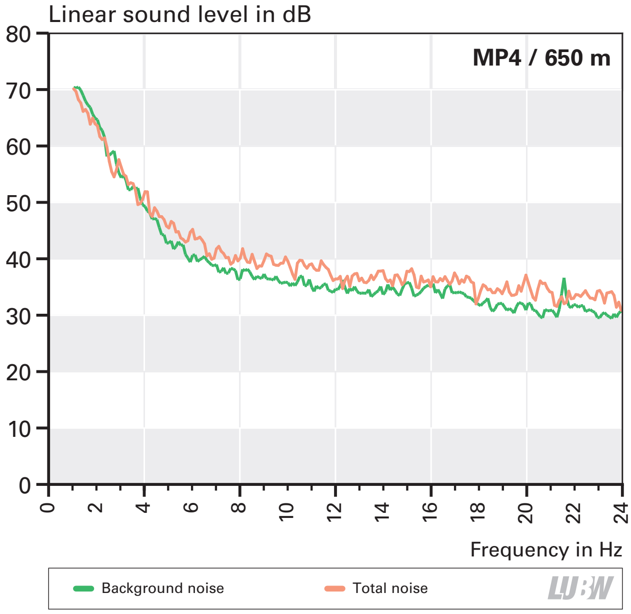


__Figure 4.6-3__: Narrow band spectra of background noise and total noise in the far range of wind turbine WT 5 for the frequency range of infrasound

of measurement point MP1 with the wind turbine switched on can no longer be distinguished. Between the states "turbine on" and "turbine off" there were only minor differences in infrasound for this measurement at a distance of 650 m. The infrasound here was primarily due to the sounds of wind and from the surroundings. The comparison of the narrowband spectra for the two measurement points MP3 (hole in the ground) and MP4 (reverberant plate) at a distance of 650 meters in ***Figures 4.6-4 to 4.6-5*** illustrates that in the infrasound range there is generally no significant difference between the two measurement points. Only at frequencies between 2 Hz and 8 Hz did the measurements in the hole in the ground show slightly higher levels. Neither the absorption of the secondary wind screen nor the ground influence appear to be of significance below 20 Hz. The increase in level towards lower

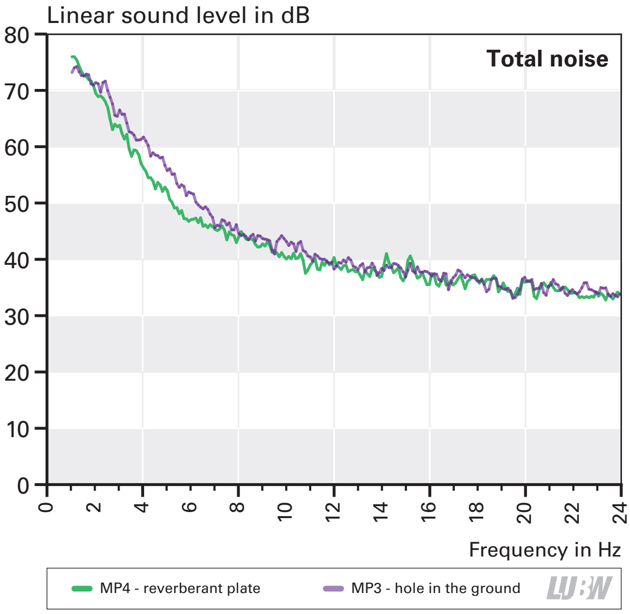


__Figure 4.6-4__: Narrowband spectra of the total noise at the measurement points MP4 (reverberant plate) and MP3 (hole in the ground) of the wind turbine WT 5 for the range of infrasound. The distance from the turbine was 650 m.

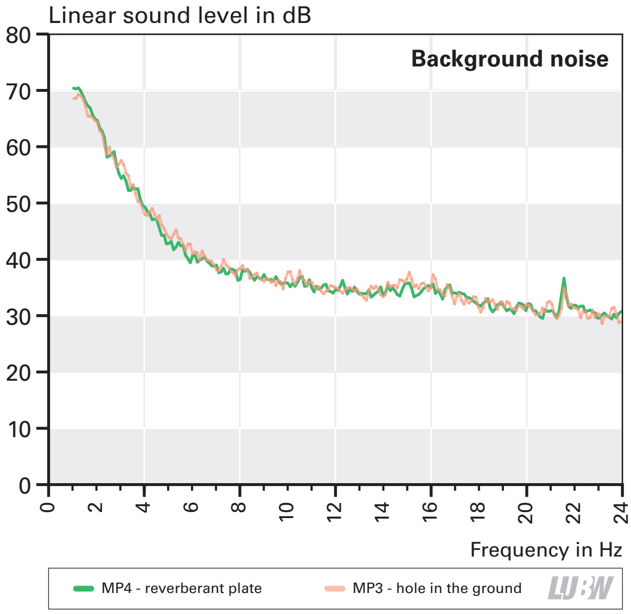
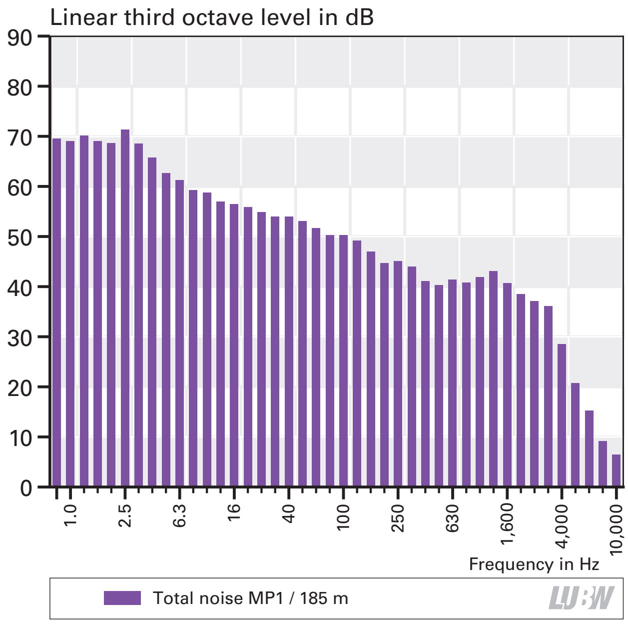


__Figure 4.6-5__: Narrowband spectra of the background noise at the measurement points MP4 (reverberant plate) and MP3 (hole in the ground) of the wind turbine WT 5 for the range of infrasound. The distance from the turbine was 650 m.



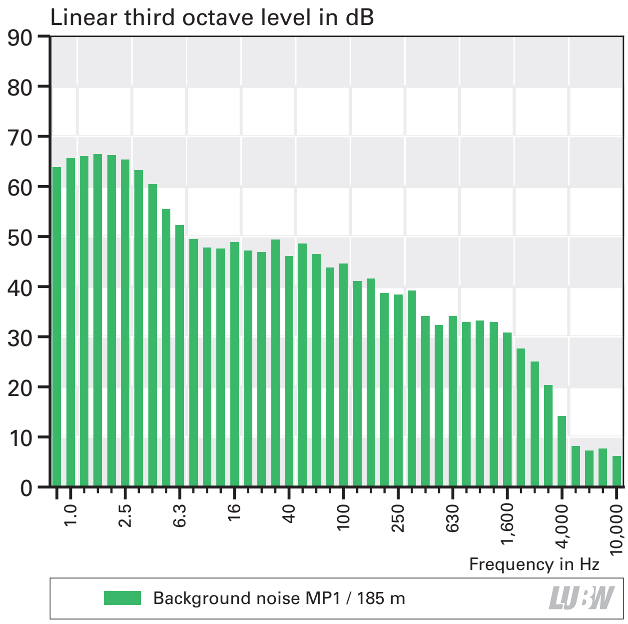


Figure 4.6-6: *Third octave spectra of total noise and background noise in the vicinity of wind turbine WT 5*

frequencies was present during this measurement with and without the hole in the ground. The expected reduction in the wind-induced background noise in the infrasound range cannot be observed in a direct comparison between the two measurement points (see also Section 4.5).

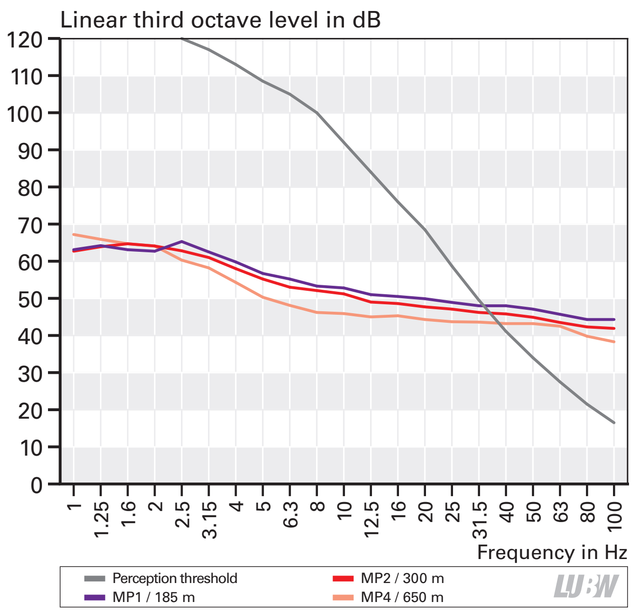


Figure 4.6-7: *Third octave spectra of total noise at the measurement points MP1 (185 m), MP2 (300 m) and MP4 (650 m) of WT 5, with the perception threshold according to Table A3-1 in comparison. The measured values were corrected according to Section 4.1.*

RESULTS: THIRD OCTAVE LEVEL

Figure 4.6-6 shows the third octave spectra of background noise and overall noise at the measurement point MP1 at a distance of 185 m for the frequency range from 0.8 Hz to 10,000 Hz. The wind speed was 5.5 m/s. The influence of the turbine in a much broader spectral range can be recognised here.

COMPARISON WITH THE PERCEPTION THRESHOLD

Figure 4.6-7 shows the third octave spectra of the total noise at the measurement points MP1, MP2 and MP4 for the frequency range from 1 Hz to 100 Hz along with the perception threshold in comparison. The wind speed was 7 m/s. It must be kept in mind that the background noise (wind, vegetation) is also included. This may vary at the respective measurement points. The measurement points MP2 and MP4 were further away from the turbine than measurement point MP1 (300 m and 650 m compared to 185 m). As expected, somewhat lower values were measured there, which becomes more apparent with increasing frequency. In the range of infrasound, the curves are well below the perception threshold.

INFLUENCE OF WIND SPEED

In order to investigate the dependency of low-frequency emissions on wind speed, numerous readings were recorded and graphically depicted in ***Figure 4.6-8***. The three

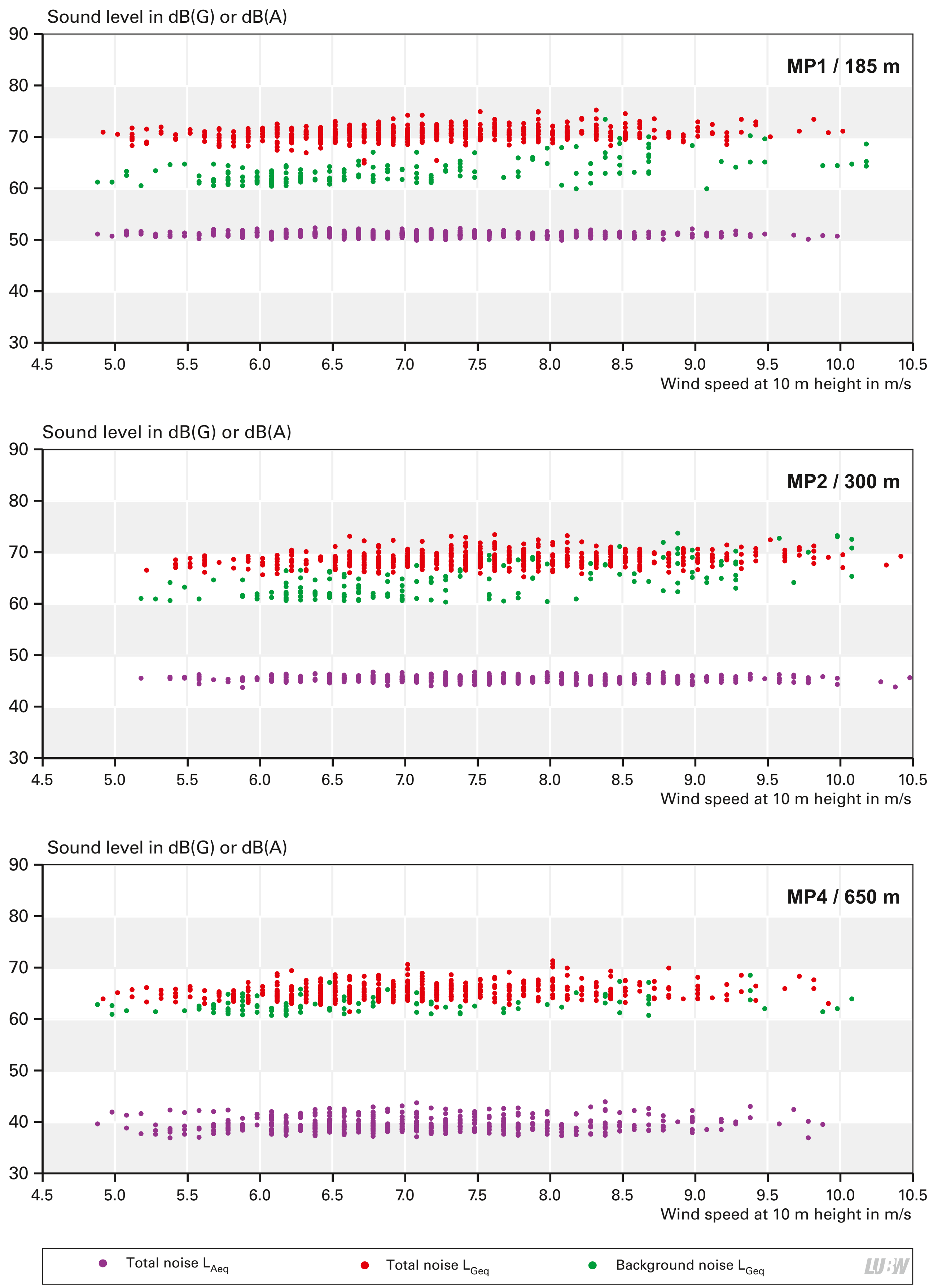


***Figure 4.6-8**: Audible sound level (A level) and infrasound level (G level) depending on the wind speed for the wind turbine WT 5. The G levels when the turbine is switched on (red dots) and when the turbine is switched off (green dots) are shown, as are the A levels with the turbine switched on (violet dots).*

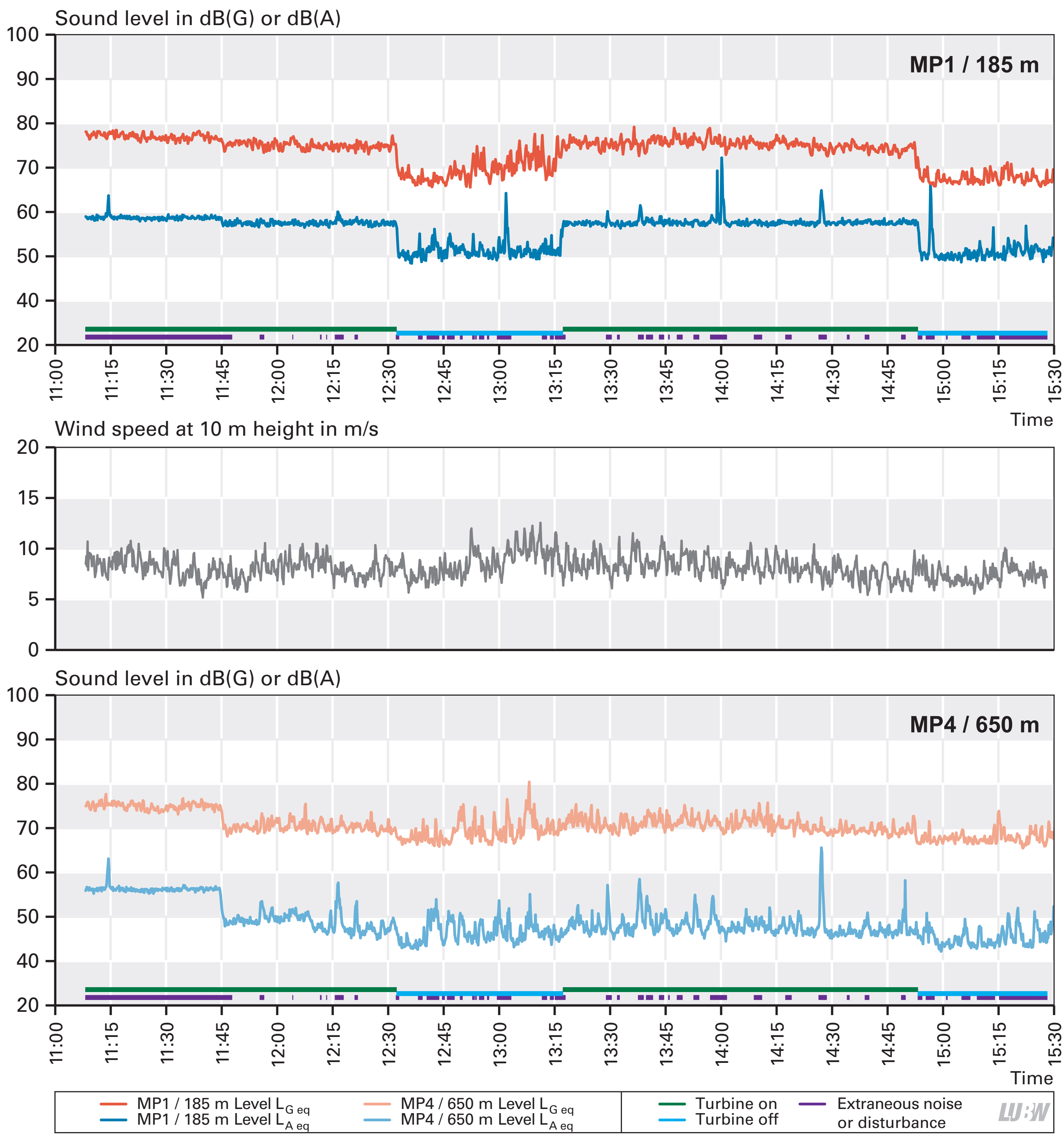


***Figure 4.6-9**: Chronological sequence of audible sound level (A level), infrasound level (G level), as well as the wind speed during the measurements of the wind turbine WT 5*

charts represent the relationships at the measurement points MP1 (185 m), MP2 (300 m) and MP4 (650 m).

The violet dots represent audible sound, expressed in dB(A). It is clearly visible that the measured A levels are higher close to the turbine than at the measurement points that are further away. The red dots represent the G-weighted sound level when the turbine is switched on, the green dots when the turbine is switched off. The figure shows that the G-weighted sound pressure levels at the measurement points examined during operation and standstill of the WT have no significant connection with the increase in wind speed. This fairly constant level curve can also be seen in the A-weighted level development. At measurement point MP1, a significantly increased mean G level can be seen during operation of the wind turbine compared to turbine standstill. As expected, the level difference between the states "turbine on" and "turbine off" decreases

Figure 4.7-1: Wind turbine WT 6 in surroundings used for agricultural purposes. The measurement point MP1 with reverberant plate and dual wind screen can be seen in the foreground. Photo: Wölfel company

with increasing distance. The A level also drops from values greater than 50 dB(A) at measurement point MP1 to values of around 40 dB(A) at measurement point MP4.

LEVEL DEVELOPMENT DURING THE MEASUREMENT

Figure 4.6-9 shows the A and G-weighted level developments between 11:00 a.m. and 5:30 p.m. for distances of 185 m and 650 m. In addition, the operating conditions of the wind power plant (green = turbine on, light blue = turbine off) as well as periods of extraneous noise (violet) are shown. For the two level developments of measurement point MP1, the operational phase "turbine off" is recognisable through the considerably declining level developments. At measurement point MP4, a level drop with the turbine switched off due to the fluctuating background noise is only slightly recognisable.

4.7 Noise at wind turbine 6: Enercon E-101 – 3.05 MW

BASIC CONDITIONS

The wind turbine 6 (WT 6) is a unit by the company Enercon, type E-101 (***Figure 4-6***) with a nominal generator capacity of 3.05 MW. The rotor diameter is 101 m, the hub height above ground is 135.4 m.

The measured turbine is part of a wind farm with several wind turbines. The adjacent turbines were completely turned off during the measurement period in order to prevent extraneous noise. The nearest other turbine that was in operation during the measurement period was located at a distance of approx. 850 m and was subjectively not perceptible over the entire measuring period. The vicinity of the turbine consists primarily of agricultural land. A dirt road is located in the immediate vicinity of the turbine, which is used only very seldom by agricultural and forestry vehicles. A state road is located at a distance of approx. 480 m eastward of the examined wind power plant. During the measurement, only occasionally traffic noise was perceptible. The measurements were carried out on 15.01.2015 between 12:00 p.m. and 3:00 p.m. The position of the microphone at the measurement point MP1 was located at a distance of 192 m from the turbine; the measurement point MP2 at a distance of 305 m and the measurement point MP3 at a distance of 705 m. The measurement points were each in a downwind direction in order to take into account the generally most unfavourable situation (promotion of sound propagation through the wind). The measurement point MP1 and the measured turbine can be seen in ***Figure 4.7-1***.

The measurement was performed in a wind speed range of 2.8 mm/s to 9.9 m/s (measured at 10 m height), a temperature range of 6 °C to 7 °C, an air pressure range of 954 hPa to 956 hPa and in a power range of 0 to 3,050 kW. The turbulence intensity (see Appendix A3) during the measurement was 14 %.

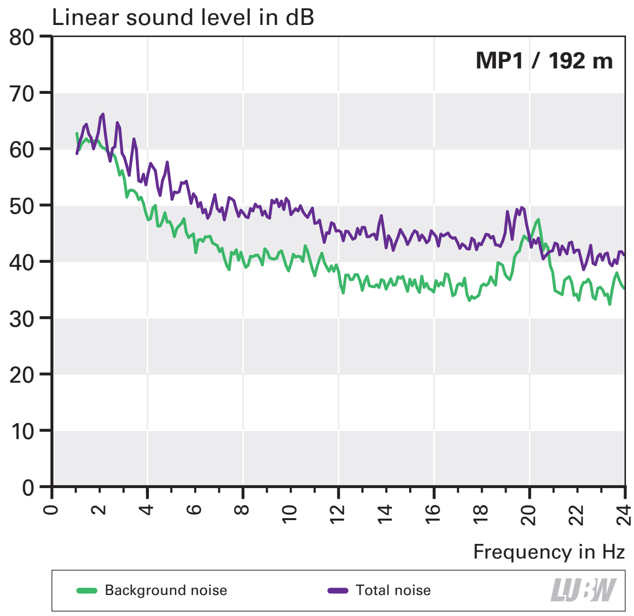


Figure 4.7-2: Narrow band spectra of background noise and total noise in the vicinity of wind turbine WT 6 for the frequency range of infrasound

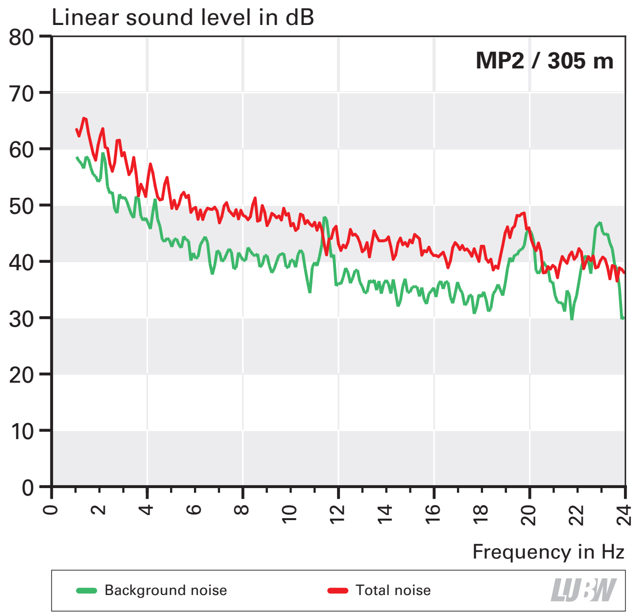


Figure 4.7-3: Narrow band spectra of background noise and total noise in the far range of wind turbine WT 6 for the frequency range of infrasound

RESULTS: NARROW BAND LEVEL

Figures 4.7-2 to 4.7-3 show the established narrow band spectra for the operation of WT 6 with a mean wind speed of approximately 5.6 m/s at a height of 10 m. Clearly visible maxima can be seen at the measurement points MP1 and MP2. The measured frequencies correspond to the passage frequency of a rotor blade (here approx. 0.7 Hz) and the harmonic overtones at 1.4 Hz, 2.1 Hz und 2.8 Hz. This concerns infrasound generated by the rotor due to its motion. The peaks disappear when the turbine is switched off. At the measurement point MP3 at a distance of 705 m (not pictured), the mentioned maxima no longer occur so clearly. The level maximum at approx. 20 Hz is striking, which is clearly visible at all measurement points. However, it is highly likely that this is not attributable to the wind turbine, as it is also evident in the background noise.

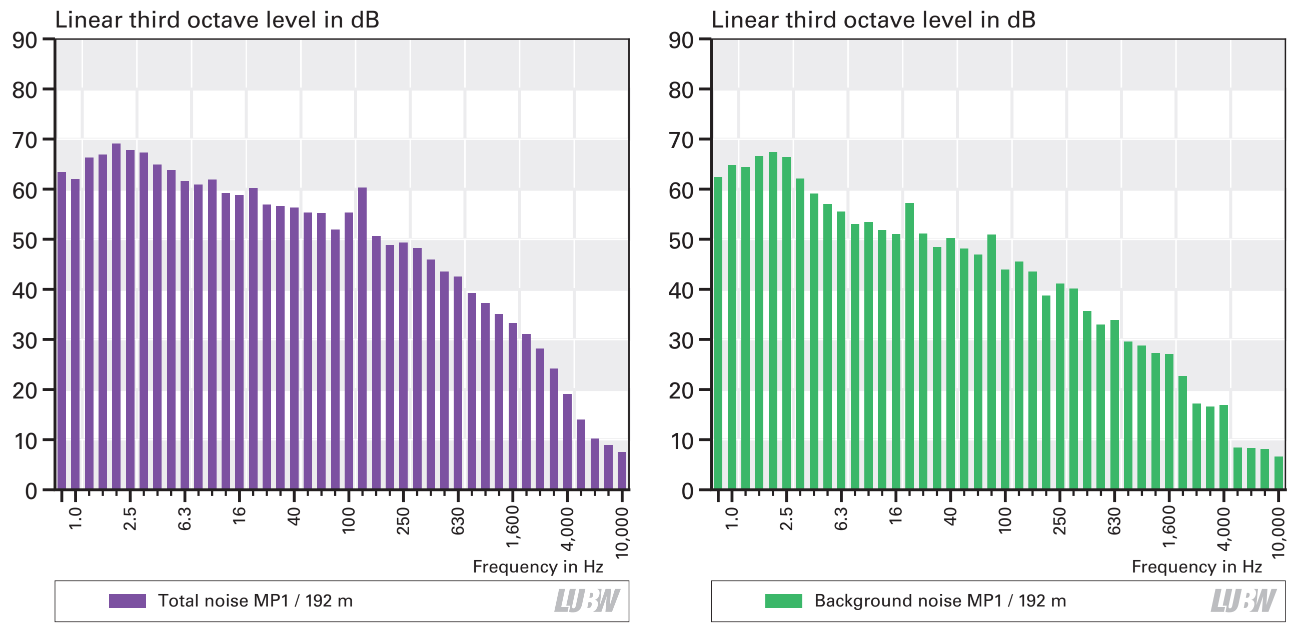


Figure 4.7-4: Third octave spectra of total noise and background noise in the vicinity of wind turbine WT 6

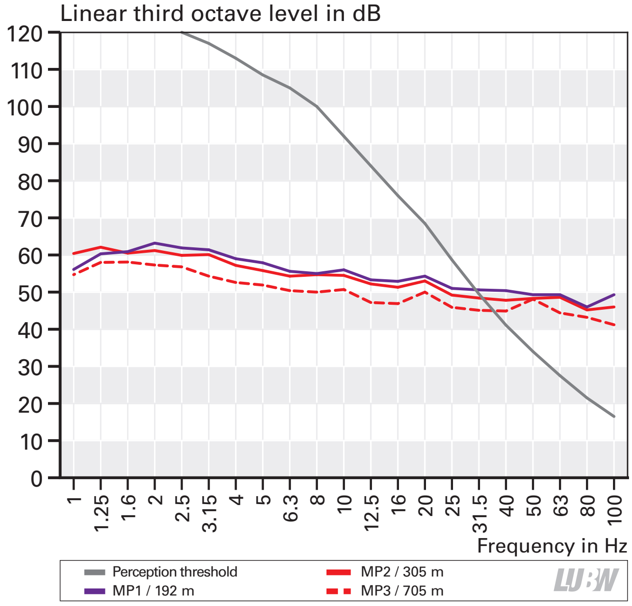


***Figure 4.7-5**: Third octave spectra of total noise at the measurement points MP1 (192 m), MP2 (305 m) and MP3 (705 m) of WT 6, with the perception threshold according to Table A3-1 in comparison. The measured values were corrected according to Section 4.1.*

RESULTS: THIRD OCTAVE LEVEL

Figure 4.7-4 shows the third octave spectra of background noise and overall noise at the measurement point MP1 at a distance of 192 m for the frequency range from 0.8 Hz to 10,000 Hz. The wind speed was 5.6 m/s. The level reduction through switching off the turbine in a clearly broader spectral range can be seen.

COMPARISON WITH THE PERCEPTION THRESHOLD

Figure 4.7-5 shows a comparison of the three measurement points for the low-frequency range from 1 Hz to 100 Hz. It must be noted that the background noise (wind, vegetation) is also included. This may vary at the respective measurement point. The wind speed at 10 m height during the averaging period was on average 5.6 m/s. At all measurement points, the ascertained levels were below the perception threshold at frequencies lower than 30 Hz. The levels in the area of infrasound fell clearly below the perception threshold.

INFLUENCE OF WIND SPEED

In order to investigate the dependency of low-frequency emissions on wind speed, numerous readings were recorded and graphically depicted in ***Figure 4.7-6***. The three charts represent the relationships at the measurement points at the distances 192 m, 305 m and 705 m.

The violet dots, which depict the lower value area, represent audible sound, expressed in dB(A). It can be seen clearly that the measured A levels are higher at a distance of 192 m (upper image) than at the measurement points further away. The A level at first increases with increasing wind speed.

The red dots represent the G-weighted sound level when the wind turbine is switched on, the green dots when the turbine is switched off. Similarly to the A level, it can also be seen for the G level that – despite higher scattering – it somewhat increases with increasing wind speed, and then remains constant (measurement point MP1).

The image above shows that at MP1, i.e. in the near field at a distance of 192 m from the turbine, the G-weighted sound pressure level during operation of WT 6 is significantly higher than the background noise when the turbine is off. This is much less pronounced at a distance of 305 m (centre image).

LEVEL DEVELOPMENT DURING THE MEASUREMENT

Figure 4.7-7 shows the A and G-weighted level development between 12:40 p.m. and 2:40 p.m. for the distances of 192 m and 705 m. In addition, the operating conditions of the wind power plant (green = turbine on, light blue = turbine off) as well as periods of extraneous noise (violet) are shown. For the two level developments of measurement point MP1, the operational phase "turbine off" is easily recognisable through the considerably declining level developments. At measurement point MP3, a level drop with the turbine switched off due to the fluctuating background noise is hardly recognisable.

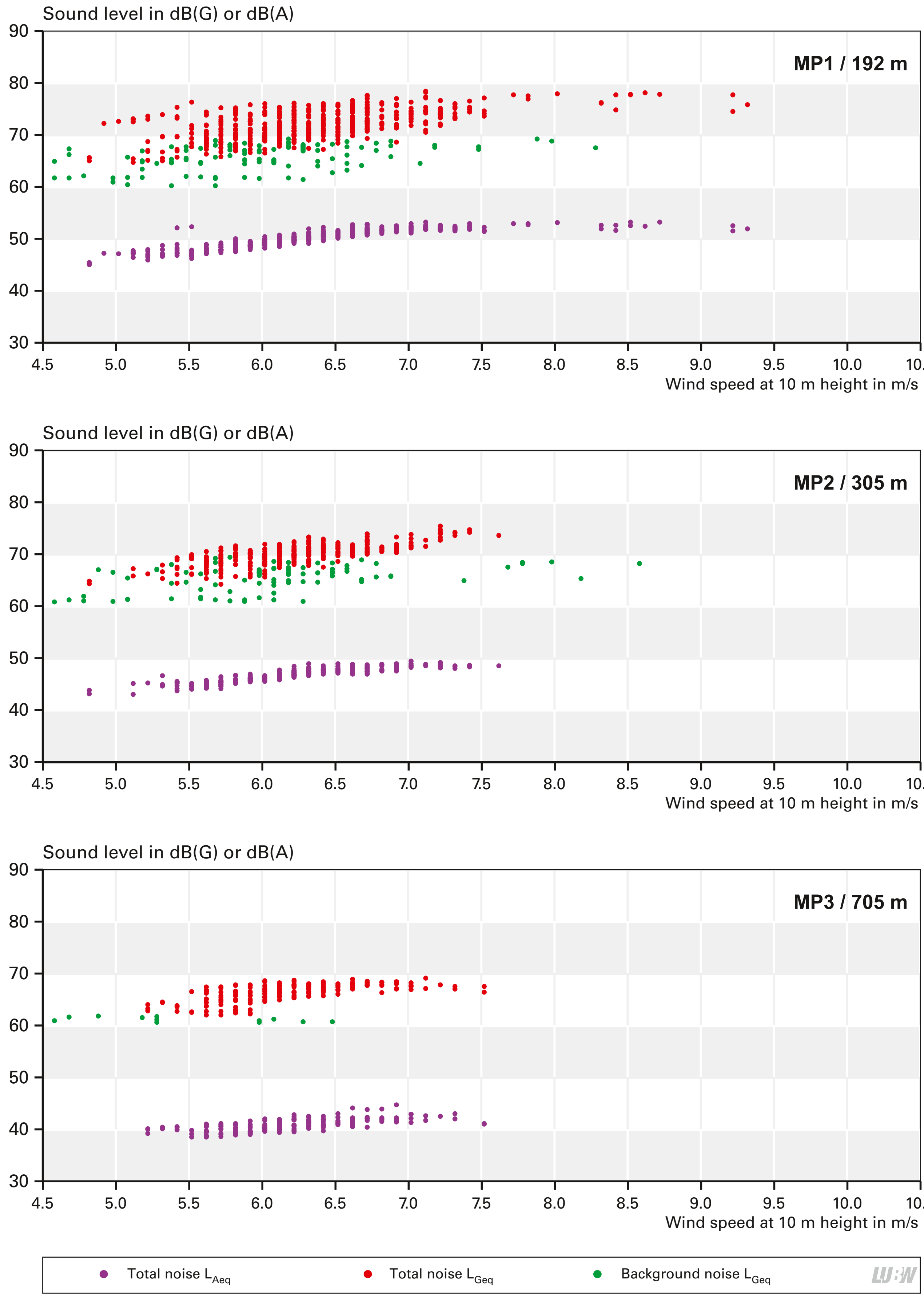


__Figure 4.7-6__: Audible sound level (A level) and infrasound level (G level) depending on the wind speed for the wind turbine WT 6. The G levels when the turbine is switched on (red dots) and when the turbine is switched off (green dots) are shown, as are the A levels with the turbine switched on (violet dots).

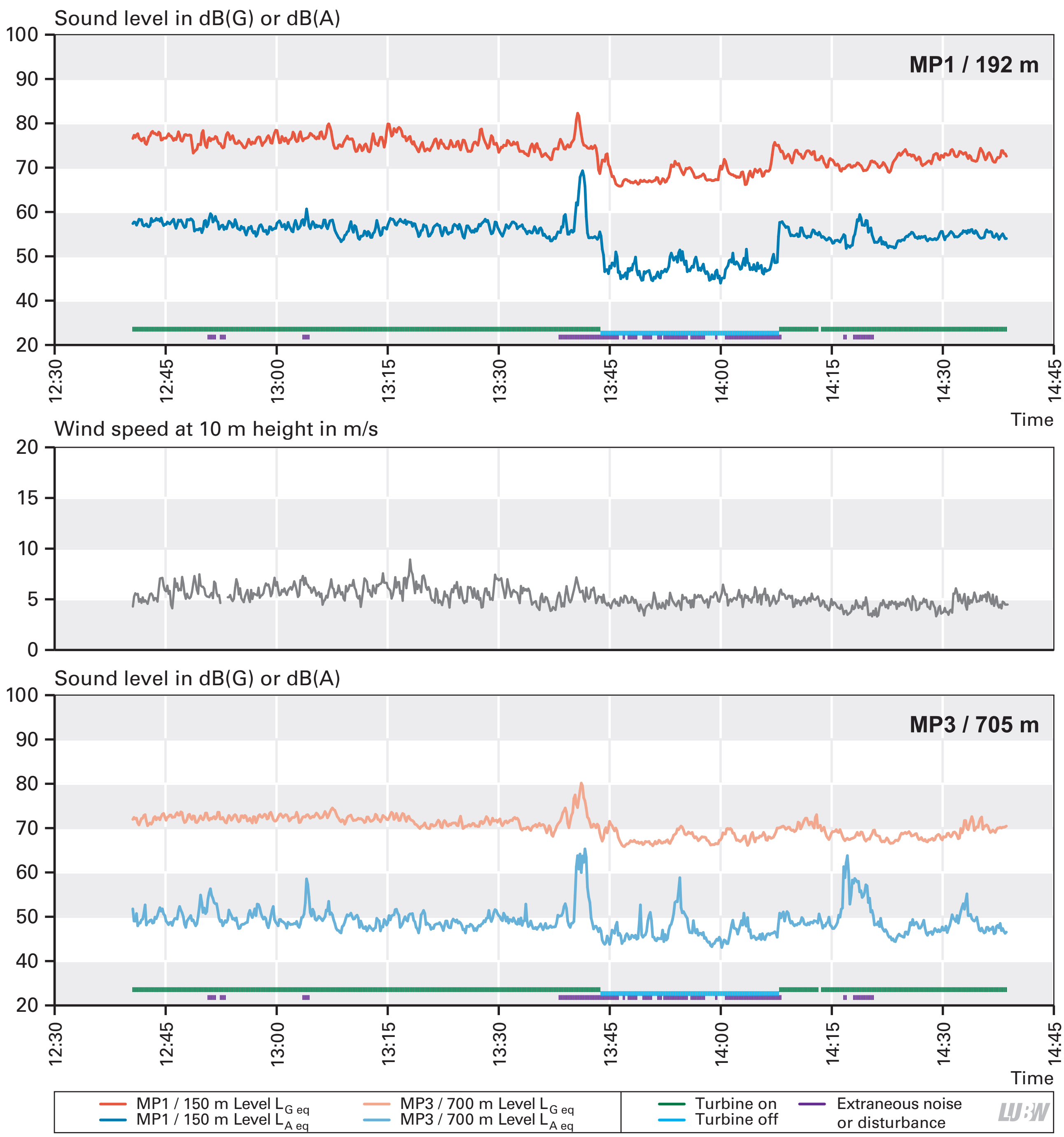


***Figure 4.7-7**: Chronological sequence of audible sound level (A level), infrasound level (G level), as well as the wind speed during the measurements of the wind turbine WT 6*

4.8 Vibrations at wind turbine 5: Nordex N117 – 2.4 MW

In order to determine a possible influence of the wind power plant on the surrounding area through vibration emissions, tremor measurements were carried out in addition to the sound assessments in the surrounding areas of wind turbine 5 (WT 5). The execution and analysis of the measurements was carried out in accordance with DIN 45669 [12] and DIN 4150 [13].

Figure 4.8-1: *Vibration measurement point MP A at the tower foundation of WT 5. Photo: Wölfel company*

BASIC CONDITIONS

Wind turbine 5 (WT 5) is a unit by the company Nordex, type N117/2400, with a nominal generator capacity of 2.4 MW (see ***Figure 4.6-1***). The rotor diameter is 117 m, the hub height above ground is 140.6 m. The following is known about the building ground of the power plant: Up to a depth of 7 m there is cohesive ground (loam, weathering clay), which is judged to be not stable enough for the foundation of the power plant. Only after a depth of approx. 7 m is there Keuper rock, meaning that the foundation of the building structure or the load transfer has to be in this layer. It is not known whether this was accomplished with a pile foundation or a different procedure.

Figure 4.8-2: *Vibration measurement point MP D on ground spike at a distance of 285 m from WT 5. Photo: Wölfel company*

The vibration measurement was carried out in all three spatial directions with the help of vibration sensors. The x axis was radially aligned to the tower, the y axis tangentially and z axis vertically aligned. Measurements were taken at the same time at the following locations:

- MP A directly at the tower near the outer wall of the wind turbine on concrete, see ***Figure 4.8-1***
- MP B at a distance of 32 m from the WT's exterior wall on a ground spike
- MP C at a distance of 64 m from the WT's exterior wall on a ground spike
- MP D at a distance of approx. 285 m from the WT's exterior wall on a ground spike, see ***Figure 4.8-2***

For the connection of the sensors by means of ground spikes to the ground, holes with a diameter of approximately 50 cm and a depth of 20 cm to 40 cm were dug into the ground.

The following operational states were registered during the measuring time:

- Operation of a wind turbine at wind speeds between approx. 6 and 12 m/s at a height of 10 m
- Switching off and subsequent restarting of the turbine
- Standstill of all wind power plants in the wind farm

During the measurement the wind turbine reached the maximum possible speeds starting from wind speeds of 6.6 m/s. Even at higher wind speeds no higher rotational speeds of the turbine are to be expected.

RESULTS

During the operation of the wind turbine, fluctuations in the signals were repeatedly seen, in particular at measurement point MP A directly by the tower. These can be attributed to individual gusts of wind. At the measurement points located farther away, these effects are less pronounced. A direct link between the changes in wind speed in the range of 6 to a maximum of 12 m/s and the vibrations in the ground cannot be seen. ***Table 4.8-1*** shows the ascer-

Table 4.8-1: *Maximum values of the unweighted vibration velocities v in mm/s at the measurement points. The wind speeds measured at 10 m above ground level were between about 6 and 12 m/s.*

	MP A, at the tower		**MP B**, 32 m distance		**MP C**, 64 m distance		**MP D**, 285 m distance	
	z	x, y	z	x, y	z	x, y	z	x, y
Turbine on	0.5 - 1.0	0.30	0.03	0.08	0.02	0.04	< 0.01	0.01
Turbine off	0.04	0.03	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01

tained maximum values of the unweighted vibration velocities v in mm/s for the different measurement points with uniform full load operation of the turbine. In the horizontal measurement directions the one with the highest value is stated; this was usually the x direction (radial, towards the tower).

Decreasing vibration velocity over the distance is shown graphically in ***Figure 4.8-3***. At the measurement point MP D at a distance of 285 m, the influence of the wind turbines is barely perceptible. For comparison, the spread calculated in accordance with [13] is also shown. When shutting down or restarting the turbine, the vibration level changes only slightly, see ***Figure 4.8-4***.

The evaluation of vibrational immissions with respect to possible exposure of people in buildings is carried out on the basis of DIN 4150 Part 2 [13]. The essential base parameter of this standard is the weighted vibration severity $KB_F(t)$. This is also an indication of the ability to sense vibrational effects. The perception threshold for most people lies in the area between $KB_F = 0.1$ and $KB_F = 0.2$. The KB_F value of 0.1 corresponds to an unweighted vibration velocity of approx. 0.15 to 0.30 mm/s. During the transition of tremors from the ground to building foundations there is usually a reduction of the vibration amplitudes. According to DIN 4150 Part 1, a factor of 0.5 should be taken. In the building itself, there may be an amplification, particularly if the excitation frequency is in the range of the ceiling's natural frequency. However, it is not expected that the effects established at the measurement point MP D could actually reach the level of the reference values according to DIN 4150 Part 2 in a building, since this would require an amplification by more than a factor of 20 within the building. At measurement point MP D at a distance of 285 m, mainly frequencies below 10 Hz were established, as shown in ***Figure 4.8-5***. In contrast, the natural frequencies for concrete ceilings in residential buildings are normally approx. 15 Hz to 35 Hz. For beamed ceilings, the natural frequencies are lower and can drop to approx. 10 Hz. Resonance excitation of the building ceilings can therefore not be expected.

CONCLUSION

The ground vibrations emanating from wind turbines can be detected by measurement. Already at a distance of less than 300 m from the turbine, they have dropped so far that they can no longer be differentiated from the permanently present background noise. No relevant vibrational effects can be expected at residential buildings.

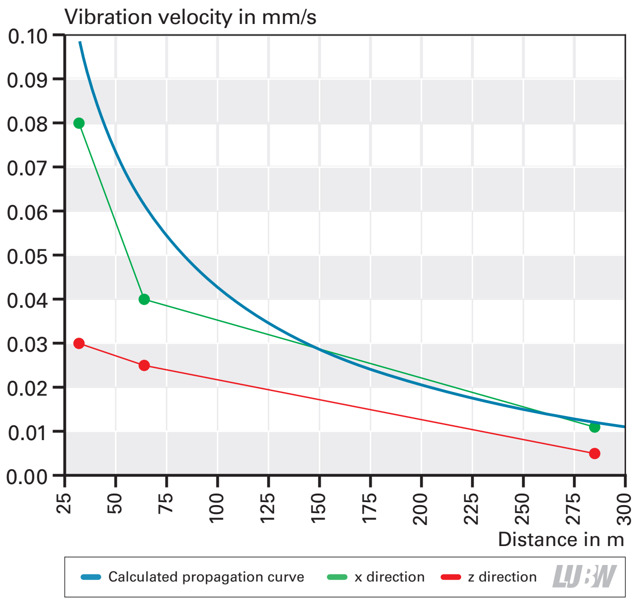


Figure 4.8-3: *Comparison of prediction formula for [13] with the measured values*

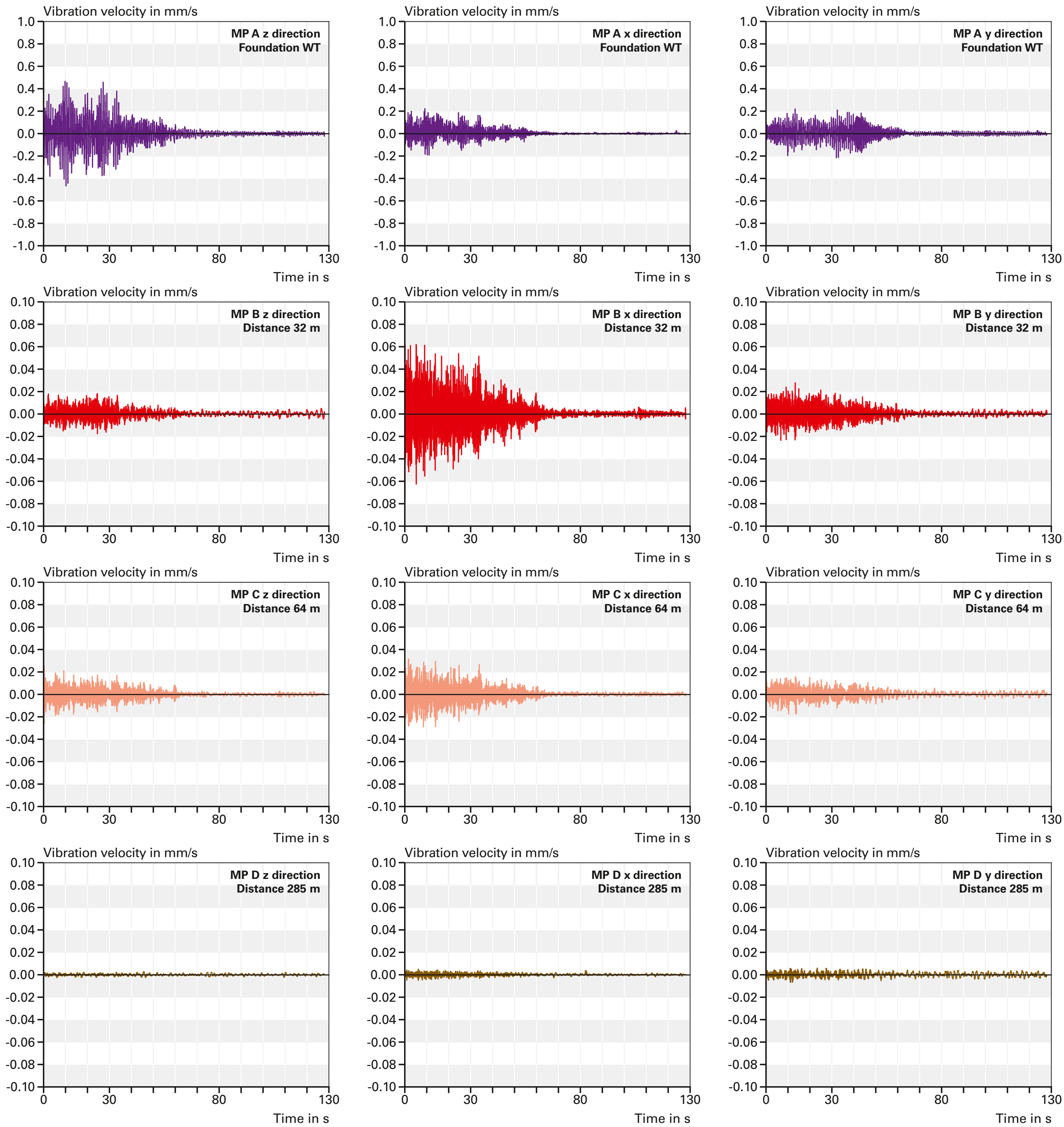


Figure 4.8-4*: Representation of the decreasing vibration after shutdown of the wind turbine 5 for all measurement points and directions. From top to bottom: Measurement points MP A to MP D; left to right: Spatial directions z, x and y. The shutdown of the turbine followed at 12:32 p.m. – Note the different scale of the vibration velocity at the measurement point MP A (foundation, top row).*

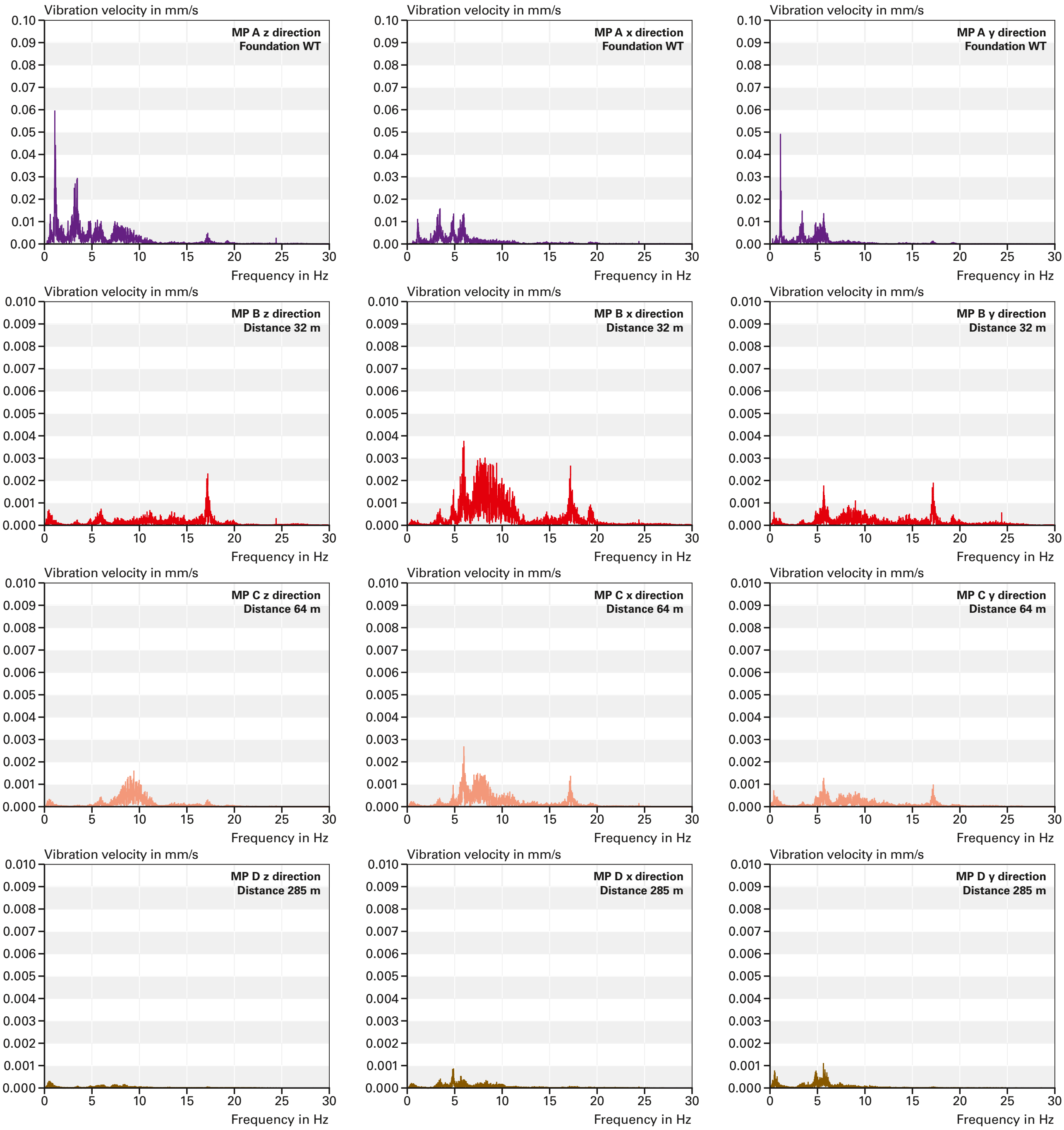


__Figure 4.8-5__: Representation of the frequency spectrum of the vibrations with uniform operation of the wind turbine 5 for all measurement points and directions. The measurement was taken at 11:12 a.m. at a wind speed of approx. 8 m/s at a height of 10 m. From top to bottom: Measurement points MP A to MP D; left to right: Spatial directions z, x and y. – Note the different scale of the vibration velocity at the measurement point MP A (foundation, top row).

4.9 Measurement results from literature

In the following a few previously available, publicly accessible measurement results about infrasound and low-frequency noise at wind turbines shall be briefly discussed. Overall, the amount of available worldwide publications on this issue is modest but not low. The publications presented here partially refer to many other references. In this selection we have aimed to introduce German-speaking publications (Mecklenburg-Western Pomerania, Bavaria) as well as important European (Denmark) and international (Australia) studies and measurement programmes. However, the report at hand is no literature study, meaning that a restriction is necessary.

MECKLENBURG-WESTERN POMERANIA

The company Kötter Consulting, Rheine, carried out emissions and immissions measurements in 2005 and 2009 on behalf of the Federal State of Mecklenburg-Western Pomerania, State Office for the Environment, Nature Conservation and Geotechnology (LUNG) at a wind farm that contained a total of 14 turbines. The report is publicly available [14]. In summary, the authors come to the following conclusions:

- "The results of the emission measurement [...] show that at frequencies in the infrasound range at f < 10 Hz, the individual operating states cannot be distinguished from one another. Moreover, the dispersion of the sound pressure level is high." See ***Figure 4.9-1***.
- "In terms of emissions, however, the different operating states in the low-frequency range (16 Hz < f < 60 Hz) are metrologically detectable, whereas at the immission location, the turbine noise is indistinguishable from background noise."
- "The results of immission measurements show [...] that the reference values for the evaluation of low-frequency noise according to Supplement 1 of DIN 45680 [4] [...] are also complied with."
- "In terms of immissions, no noteworthy difference is perceivable between the operating state ‚all WT on' and background noise. The readings are clearly below the hearing threshold level curve in the infrasound range." See ***Figure 4.9-2***.

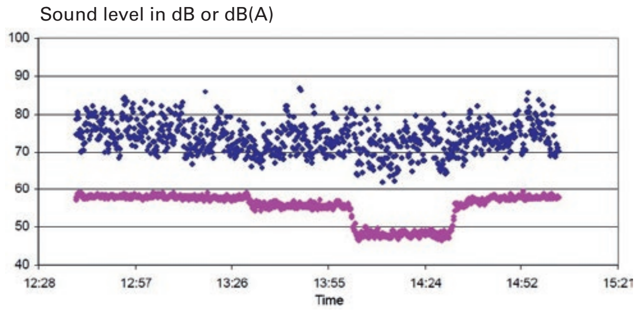


Figure 4.9-1: *Chronological sequence of level at the emission location (outside) near the turbine. The lower, magenta curve represents the sequence of the A-weighted audible noise level. The clearly identifiable gradual decrease in the sound level correlates with the various operating states (far left all turbines on, then two turbines off, then all turbines off). At the end, the A-weighted sound level increases again when all turbines are turned on (far right). Remarkably, the 8 Hz infrasound level hardly changes at all (blue, greater scattering of dots). The measurement report also includes illustrations for 20 Hz and 63 Hz; with these low frequencies, the operating conditions could be registered in the near field. Source: [14], Figure 9, page 24, details added.*

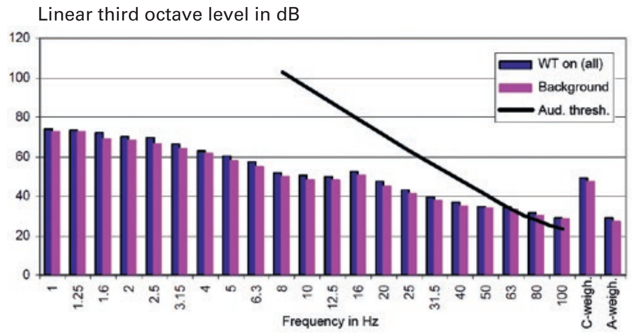


Figure 4.9-2: *Immission: Display of lower frequency levels subject to third octave frequency within a residential building at a distance of 600 m. No significant difference can be seen between the operating states "all WT on" and the background noise. The readings are clearly below the hearing threshold curve in the infrasound range. Source: [14], Figure 21, page 33*

BAVARIA

The Bavarian State Office for the Environment (LfU) carried out a long-term noise immission measurement from 1998 to 1999 at a 1 MW wind turbine of the type Nordex N54 in Wiggensbach near Kempten. ***Table 4.9-1*** and ***Figure 4.9-3*** show the main results. The study concludes that "the noise emissions of the wind turbine in the infrasound range are well below the perception threshold of humans and therefore lead to no burden". Furthermore, it was found that the infrasound caused by the wind is significantly stronger than the infrasound generated by the wind turbine alone [15] [16].

DENMARK

A Danish study from 2010 [17], in which data from almost 50 wind turbines with outputs between 80 kW and 3.6 MW was evaluated, comes to the following conclusion: "Wind power plants do certainly emit infrasound, but the levels are low when taking into account the human sensitivity to such frequencies. Even close up to the wind power plants, the sound pressure level is far below the normal auditory threshold, and the infrasound is therefore not seen as a problem for wind power plants of the same type and size as the ones examined" [15]. Further international publications on the issue are quoted in the study.

AUSTRALIA

In 2013 the Enviroment Protection Authorithy South Australia and the engineering company Resonate Acoustics published the study "Infrasound levels near windfarms and in other environments" [18]. The study includes results of measurements taken both outside as well as indoors. The measurement points were in close proximity to windparks and in regions without wind power plants.

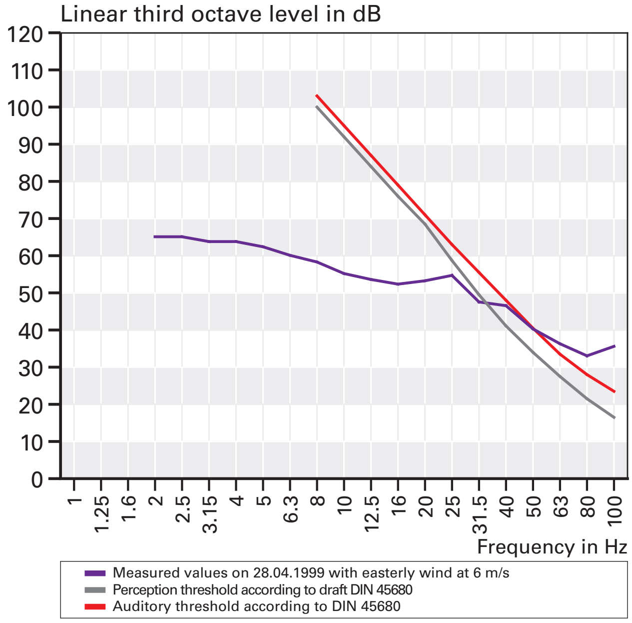


***Figure 4.9-3**: The examined wind turbine causes sound waves that can be heard only above 40 Hz by a person standing on a balcony at a distance of 250 m. The infrasound range is not perceptible, since it lies clearly below the perception threshold. Source: [15]*

In summary, it was stated that the measured infrasound expositions, which were measured in close proximity to windfarms in residential buildings, correspond to the levels determined in comparable regions without wind power plants. The lowest infrasound levels determined in the measuring project were registered in a house standing in the proximity of a wind park.

The infrasound levels in close proximity to wind power plants are not higher than in other urban and rural regions, in which the contribution of wind power plants is negligible, compared to the background level of infrasound in those areas.

***Table 4.9-1**: Infrasound level at a distance of 250 m from a 1 MW wind turbine with different wind velocities. Source: [15]*

Wind velocity		Linear third octave level in dB with a third octave centre frequency of				
		8 Hz	10 Hz	12.5 Hz	16 Hz	20 Hz
6 m/s	Breeze, the measured sound comes primarily from the wind turbine	58	55	54	52	53
15 m/s	Strong to stormy wind, the measured sound comes primarily from the wind	75	74	73	72	70

Quotation: "It is clear from the results that the infrasound levels measured at the two residential locations near wind farms (Location 8 near the Bluff Wind Farm and Location 9 near Clements Gap Wind Farm) are within the range of infrasound levels measured at comparable locations away from wind farms. Of particular note, the results at one of the houses near a wind farm (Location 8) are the lowest infrasound levels measured at any of the 11 locations included in this study. This study concludes that the level of infrasound at houses near the wind turbines assessed is no greater than that experienced in other urban and rural environments, and that the contribution of wind turbines to the measured infrasound levels is insignificant in comparison with the background level of infrasound in the environment". [18]

4.10 Conclusion of the measurements at wind turbines

- The low-frequency noise including infrasound measured in the vicinity of wind turbines consists of three parts: 1. Turbine noise; 2. Noise that results from the wind in the surrounding area; 3. Noise that is induced at the microphone by the wind. Wind always has to be considered as an interference factor (extraneous noise) when determining the turbine noise. The measured values are subject to a wide spread.

- The infrasound being emanated from wind turbines can generally be measured well in the direct vicinity. Below 8 Hz discrete lines appear in the frequency spectrum as expected, which are attributable to the constant movement of the individual rotor blades.

- At a distance of 700 m from the wind turbines, it was observed that when the turbine is switched on, the measured infrasound level did not increase notably or only increase to a limited extent. The infrasound was generated mainly by the wind and not by the wind turbines.

- The measured infrasound levels (G levels) at a distance of approx. 150 m from the turbine were between 55 and 80 dB(G) with the turbine running. With the turbine switched off, they were between 50 and 75 dB(G). At distances of 650 to 700 m, the G levels were between 55 and 75 dB(G) with the turbine switched on as well as off. A cause for the spread of the values is the strongly varying proportions of noise, which are caused by the wind (***Table 2-1***).

- For the measurements carried out even at close range, the infrasound levels in the vicinity of wind turbines – at distances between 150 and 300 m – were well below the threshold of what humans can perceive in accordance with DIN 45680 (2013 Draft) [5] or ***Table A3-1***.

- The vibrations caused by the wind turbine being examined were already minimal at a distance of less than 300 m. At distances as prescribed for reasons of noise pollution protection, no exposures that exceed the pervasive background noise are to be expected at residential buildings.

- The results of this measurement project comply with the results of similar investigations on a national and international level.

Table 4-11: *Tabular representation summing up the first measured values (infrasound and low-frequency noise) at wind turbines. The measured values were frequently subject to substantial fluctuations and always also contain wind noises. Since the measurements were carried out with a reverberant plate, a correction took place (see. Section 4.1).*

Wind turbine (WT)		Section	G-weighted level in dB(G) WT on / off	Infrasound third octave level ≤ 20 Hz in dB * WT on	Low-frequency third octave level 25-80 Hz in dB * WT on
WT 1	– 700 m	4.2	55-75 / 50-75	–	–
	– 150 m		65-75 / 50-70	55-70	50-55
WT 2	– 240 m	4.3	60-75 / 60-75	–	–
	– 120 m		60-80 / 60-75	60-75	50-55
WT 3	– 300 m	4.4	55-80 / 50-75	–	–
	– 180 m		55-75 / 50-75	50-70	45-50
WT 4	– 650 m	4.5	50-65 / 50-65	–	–
	– 180 m		55-65 / 50-65	45-55	40-45
WT 5	– 650 m	4.6	60-70 / 55-65	–	–
	– 185 m		60-70 / 55-65	50-65	45-50
WT 6	– 705 m	4.7	55-65 / 55-60	–	–
	– 192 m		60-75 / 55-65	55-65	45-50

* Linear third octave level in dB(Z)

5 Traffic

Within the context of the measurement project, not only wind turbines but also other sources of low-frequency sound incl. infrasound were to be examined. An obvious choice was to investigate the pretty-much ubiquitous road traffic. For this purpose, measurements was carried out at a road in Würzburg (by the company Wölfel) as well as at the federal motorway A5 south of Karlsruhe (by the LUBW). In addition, data from the inner-city continuous traffic noise measuring stations of the LUBW in Karlsruhe and Reutlingen was used, in order to assess the recorded data with respect to low-frequency noise incl. infrasound. The conditions were selected in such a way that neither wind noises in the vicinity nor wind-induced noises at the microphones arose, which can cause problems during the measurements at the wind turbines (see Section 4). The results represented in the following are therefore to be causally attributed to road traffic.

5.1 Inner-city roads – measurement in Würzburg

At the immission location of Rottendorfer Strasse in Würzburg it was possible to carry out the noise level measurements with a special focus on low-frequency noise and infrasound inside as well as outside of a residential building. The measurement point is predominantly in the direct sphere of influence of Rottendorfer Strasse, but also within the sphere of the federal road B 19, which leads from Bad Mergentheim to Würzburg, as well as the railway line Würzburg-Lauda (***Figure 5.1-1***). However, at the immission location, the noise from the road traffic on the Rottendorfer Strasse dominates (***Figure 5.1-2***), with an average traffic volume of 13,971 motor vehicles in 24 hours with a proportion of heavy goods traffic of approx. 3 % (data from the 2012 traffic survey).

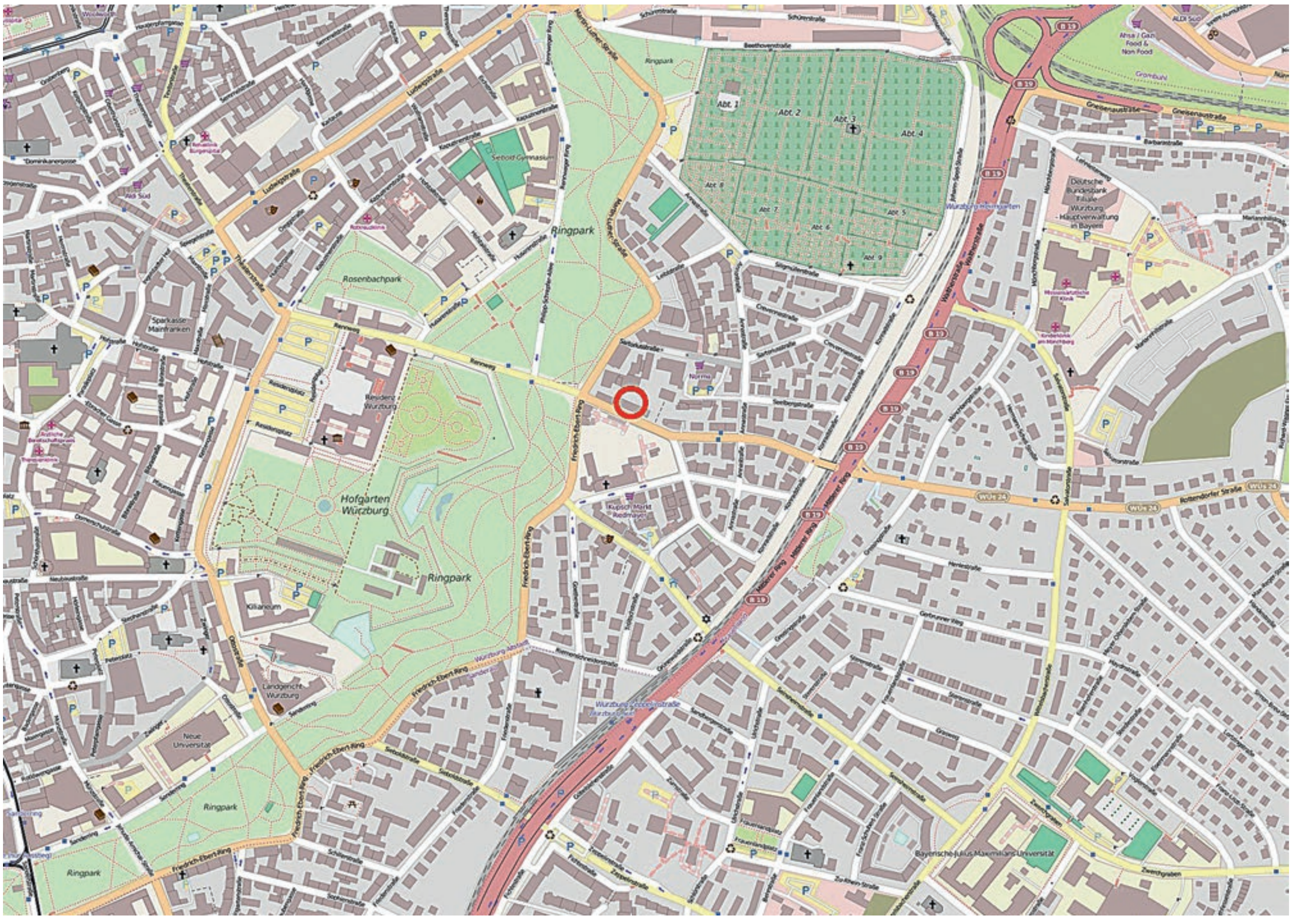


Figure 5.1-1*: Layout plan showing the immission location at Rottendorfer Strasse, Würzburg. Source: www.openstreetmap.org*

Figure 5.1-2 a/b*: View along Rottendorfer Strasse in Würzburg. Photo: Wölfel company*

A situation as can be found in many places was specifically selected. At measurement points with very high volumes of traffic and the thus associated traffic noise, the audible noise level is prioritised; this can already lead to situations that are a nuisance and possibly also harmful environmental effects. The low-frequency noise, incl. its share of infrasound, eminating from the road traffic could be measured without any disturbing wind noises. The measured levels are characteristic for the noise situation in the residential area.

The sound pressure level up to a lower threshold frequency of 1 Hz was measured at one measurement point in the open and one measurement point in a residential building. For the evaluation of the low-frequency effects, evaluations according to DIN 45680 (2013 draft) [5] were carried out for the measurement point within the building.

The execution of the measurement took place at two measuring locations. Measurement point MP1 was selected in accordance with DIN 45645 (1996) [8] and – in the same manner as the measurements at the wind turbines – with reverberant plate on the ground of the balcony facing the road. A second measurement point MP2 was located within the building in accordance with DIN 45680 (March 1997) [4]. The measurement was carried out as an observed measurement. The fully furnished and inhabited flat was not used during the measuring time. The size of the room was approx. 7.6 m x 4.3 m x 2.5 m. An informatively comparative measurement was carried out at a third measurement point located directly on the façade at the height of the windows. The third octave levels on the façade in the range below 25 Hz are between 0 and 3 dB lower than the third octave level on the floor of the balcony. Within the range between 25 Hz and 80 Hz, the third octave levels directly at the façade are up to 6 dB lower than the third octave levels on the floor of the balcony. In the frequency range above 100 Hz, on the other hand, they are 0 to 3 dB higher than the third octave levels on the floor of the balcony. The measuring data presented here for the floor of the balcony was not subjected to level corrections according to Section 4.1.

The measurement period extended from Thursday afternoon, 04.07.2013, 3:00 p.m., to the early morning of the following Friday, 05.07.2013, 6:00 a.m. The measuring period was not during the school holidays and is representative for the burden of the immission location on a working day. The traffic volume is estimated as being comparable to the data of the traffic survey. During the measurement of traffic noise, the periods with significant external noise exposure (e.g. flight noise, animal sounds and noises by the measuring engineer) were marked and excluded from the analysis. The measurements were performed in a wind speed range of 0 to 4 m/s (a mean value of 0.5 m/s), a temperature range of 16.3 to 22.5 °C, and an air pressure range of 999 to 1,003 hPa.

RESULTS AT OUTDOOR MEASUREMENT POINT

As an example, third octave spectra for the time periods 4:00 p.m. - 5:00 p.m., 10:00 p.m. - 11:00 p.m. and 12:00 a.m. - 1:00 a.m. are presented in ***Figure 5.1-3*** for the measurement point MP1 (outside the building). The outside daytime levels in the low-frequency range were up to 100 Hz above the hearing or perception threshold. A significant peak in the frequency range 25 Hz to 80 Hz can be seen in the third octave spectra, which is due to vehicle traffic. In the area of 25 Hz to 63 Hz, the levels exceed 70 dB, partially up to 75 dB. At night, values of up to 65 dB are reached. For the infrasound up to 20 Hz, the outdoor daytime levels were below the hearing or perception threshold between 45 and 65 dB. The specified frequencies refer to the third octave centre frequency.

Figure 5.1-4 shows the one hour average linear third octave level for the low-frequency range below 100 Hz compared to the perception threshold in accordance with DIN 45680 (2013 draft) [5]. For values below 8 Hz, this was amended [11], see also ***Table A3-1***. The correlation of the values with the traffic situation is clearly recognisable: The heavier road traffic between 4:00 p.m. to 5:00 p.m. leads to higher values both in the infrasound range as well as in the other low-frequency ranges. Depending on the traffic volume, the perception threshold is exceeded between 20 Hz and 32 Hz (third octave centre frequency).

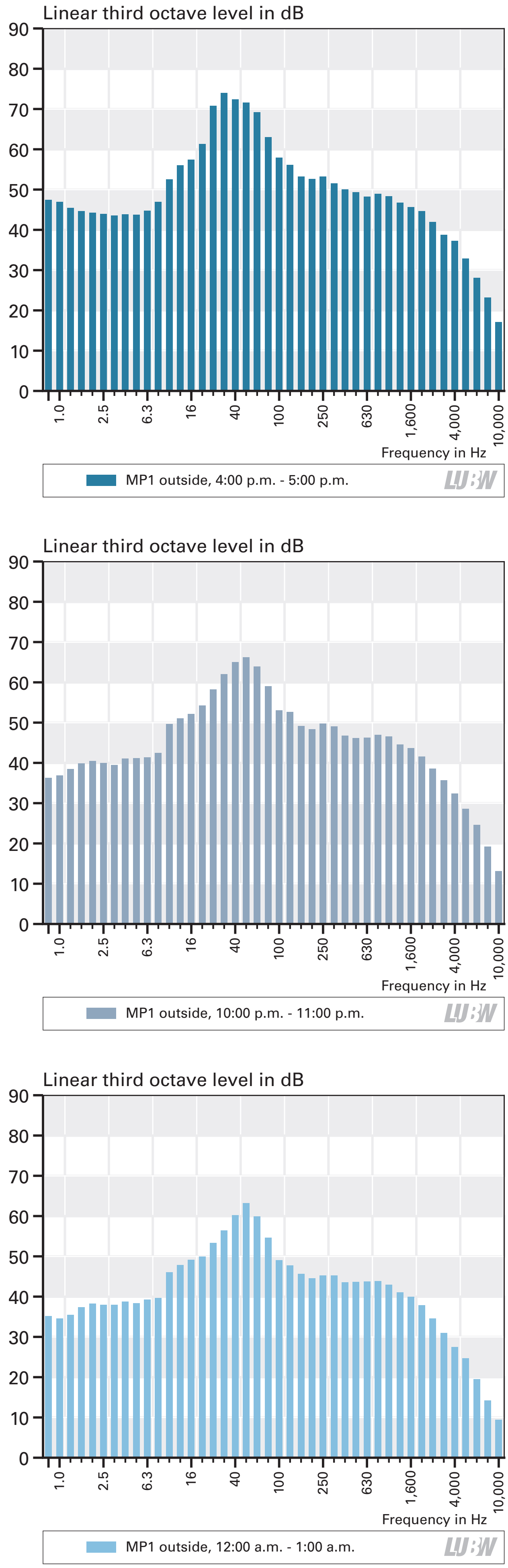


Figure 5.1-3*: Linear third octave spectra for the periods 4:00 p.m. - 5:00 p.m. (top), 10:00 p.m. - 11:00 p.m. (centre) and 12:00 a.m. - 1:00 a.m. (below) at the outside measurement point MP1. A significant peak in the frequency range 25 Hz to 80 Hz can be seen for the spectra, which is due to vehicle traffic.*

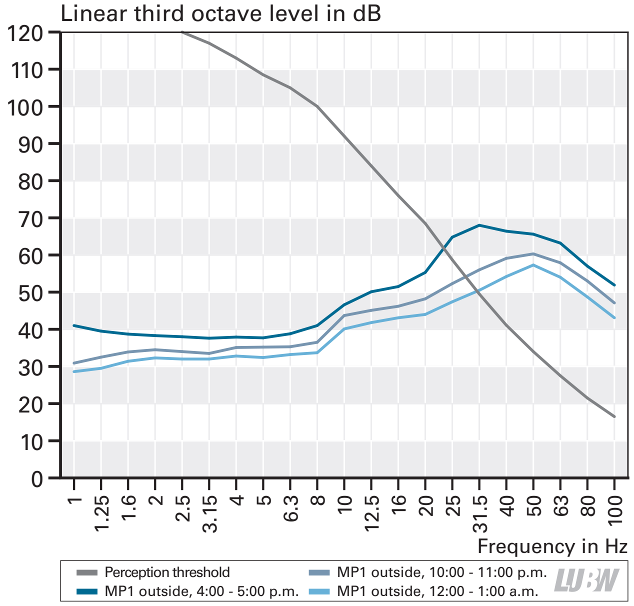


***Figure 5.1-4**: Comparison of the corrected linear third octave levels, determined at the measurement point MP1 (outside the building) for the averaging periods 4:00 - 5:00 p.m., 10:00 - 11:00 p.m., and 12:00 - 1:00 a.m. Furthermore, the perception threshold is also shown (see Section 4.1).*

The A and G-weighted sum level LAeq(t) and LGeq(t) recorded during the entire measuring period are shown in ***Figure 5.1-5***. While the A-weighting shows the audible sound as a single number value, the valuation focus of the G level is in the infrasound range. The curves show a significant bandwidth that is created by the variations of the sound influences. These variations are less pronounced for the G level. The relationship of the courses of the A and G levels can also be clearly seen. Both levels are significantly reduced at night, when there is less traffic. The G level reaches values of up to 80 dB (G) at daytime and minimum values of around 55 dB (G) at night, with strong fluctuations.

RESULTS AT INDOOR MEASUREMENT POINT

The third octave spectra for the time periods 4:00 p.m. - 5:00 p.m., 10:00 p.m. - 11:00 p.m. and 12:00 a.m. - 1:00 a.m. are presented in ***Figure 5.1-6*** for the measurement point MP2 inside the building. The interior levels for infrasound up to 20 Hz are below the hearing or perception threshold (< 55 dB) at day and night. Above 32 Hz to 40 Hz (third octave centre frequency), the values of the linear third octave level are above the hearing or perception threshold (up to 55 dB). In narrowband spectra (not shown here) a number of discrete, prominent maxima were detected, which were attributable to natural frequencies of the room and excited natural frequencies of the building.

Figure 5.1-7 shows the one hour average linear third octave level for the low-frequency range below 100 Hz compared to the perception threshold in accordance with DIN 45680 [5]. This was amended for values below 8 Hz [11]. In general, a decrease in the level can be seen the later it gets. Why

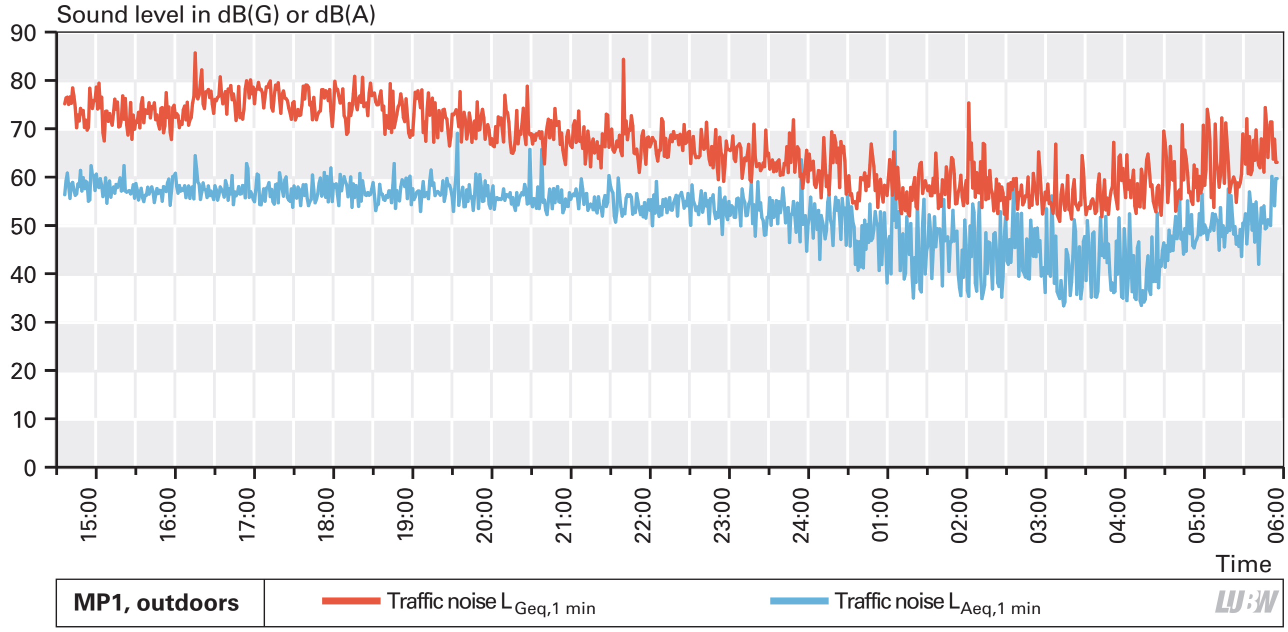
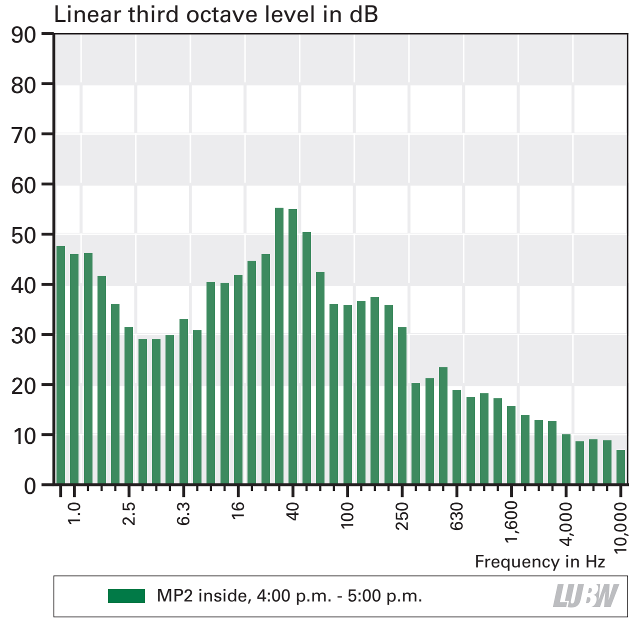
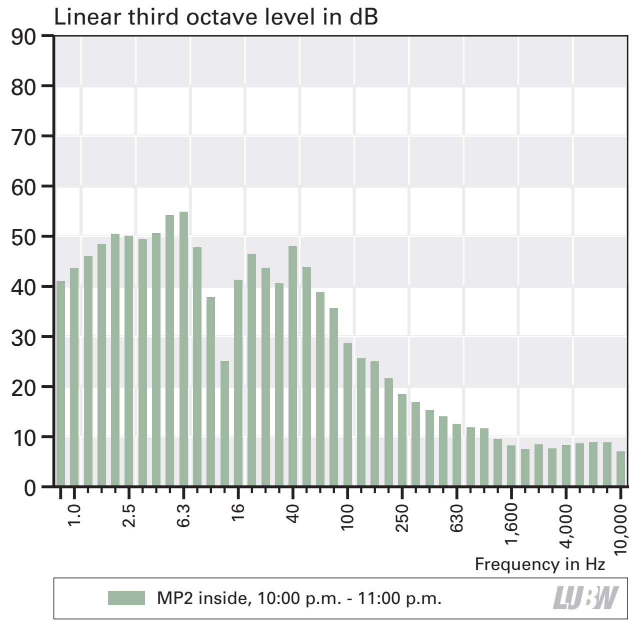
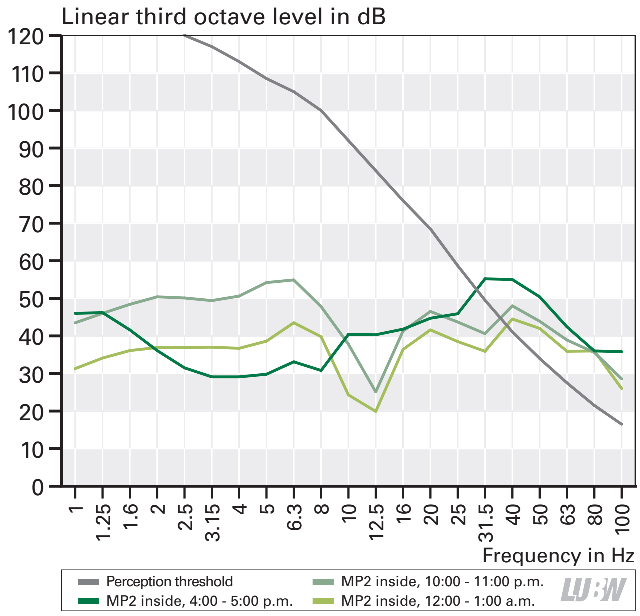


***Figure 5.1-5**: Distribution of the A-weighted sum level $L_{Aeq(t)}$ (blue) and the G-weighted sum level $L_{Geq(t)}$ (red) over the entire measurement period at the outdoor measurement point MP1*



the infrasound levels between 2 Hz and 8 Hz are higher at night is unclear. The G-weighted level during the time elapsed was between 40 dB(G) at night and 65 dB(G) at day.





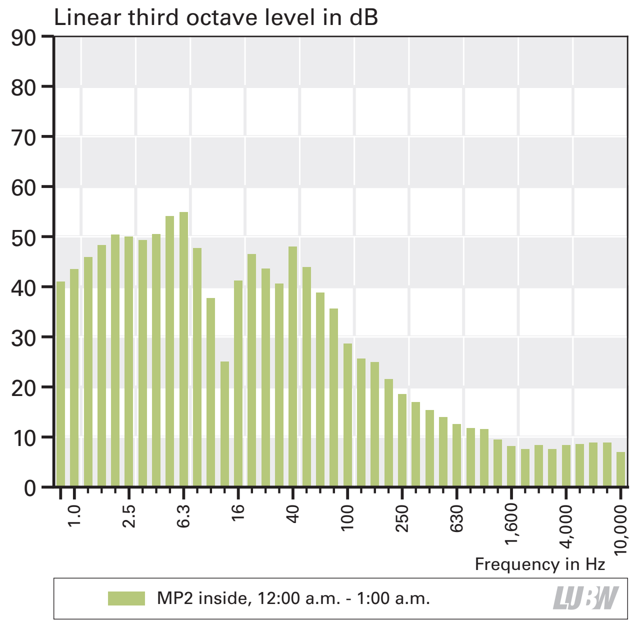


Figure 5.1-7 *(top): Comparison of the third octave levels at the measurement point MP2 (indoors) for the averaging periods 4:00 - 5:00 p.m., 10:00 - 11:00 p.m. and 12:00 - 1:00 a.m. The perception threshold according to Table A3-1 is also shown.*

Figure 5.1-6 *(left column): Linear third octave spectra for the time periods 4:00 - 5:00 p.m. (top), 10:00 - 11:00 p.m. (centre) and 12:00 - 1:00 a.m. (bottom) at the indoor measurement point MP2.*

5.2 Inner-city roads – permanent measuring stations Karlsruhe and Reutlingen

Since November 2012, the LUBW has been running a stationary road traffic noise monitoring station in Karlsruhe (Reinhold-Frank Strasse), and a further one in Reutlingen (Lederstrasse-Ost) since March 2013. This is where average and maximum levels of total noise are measured with the use of high-quality sound level measurement devices, as well as meteorological parameters such as temperature, wind speed and precipitation. In addition, the traffic data (vehicle type, quantity and speed) are recorded. Both stations are in areas with relatively high volumes of traffic: In Karlsruhe, approximately 24,000 vehicles/24h, however with a partial standstill of traffic, and in Reutlingen approximately 50,000 vehicles/24h (as of 2011).

In Karlsruhe, the microphone is positioned close to the road, meaning that the recorded levels do not directly depict the concerns of the population living somewhat further away. The distance to residential buildings is less than 10 m (***Figure 5.2-1***). The location of the measuring station in Reutlingen allows immediate statements to be made about the noise pollution for the people affected (***Figure 5.2-2***). Further information is available on the website www.lubw.de/aktuelle-messwerte (home page). The annual reports by the LUBW for the traffic noise monitoring stations can be found under the heading "Auswertungen" (Reports).

Based on the measurement data of the road traffic noise measuring stations in Karlsruhe and Reutlingen, evaluations were made by us with regards to low-frequency noise (incl. infrasound). In the following ***Figures 5.2-3 and 5.2-4*** frequency-selective representations of the noise level from 6.3 Hz to 125 Hz (third octave centre frequency) can be found for the two stations. Averaging was carried out over 30 minutes and summarized. Here only those time periods have been considered in which the wind speeds were less than one meter per second. These were approx. 2,000 half-hour averages for Karlsruhe and about 1,900 for Reutlingen, including many night hours. This avoided the occurrence and subsequent measurement of noise in the vicinity caused by the wind, and also ensured that no sound induced by the wind occurred directly at the microphone. Both

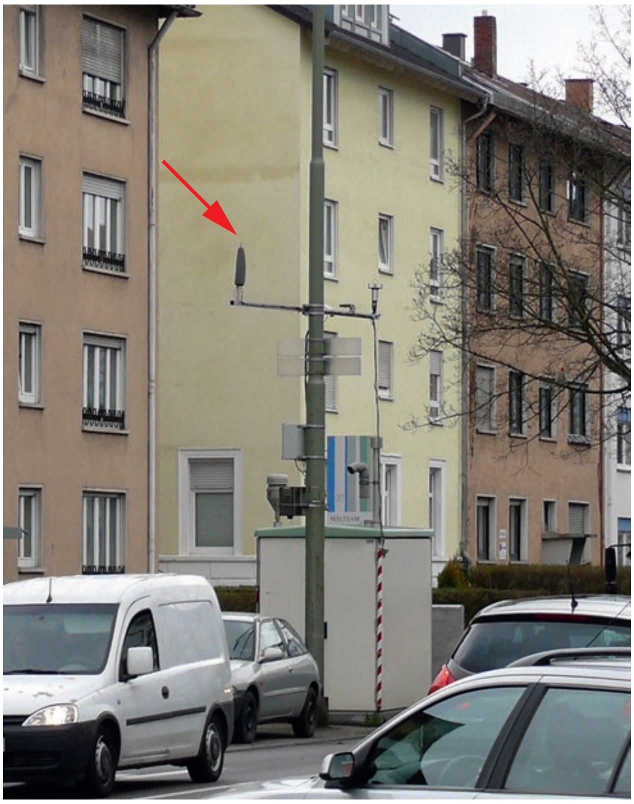


Figure 5.2-1: *LUBW measuring station for detecting road traffic noise in Karlsruhe, Reinhold-Frank-Strasse. The arrow shows the location of the microphone. Residential buildings visible in the background. Photo: LUBW*

Figure 5.2-2: *LUBW measuring station for detecting road traffic noise in Reutlingen, Lederstrasse. The arrow shows the location of the microphone. Photo: LUBW*

effects would have led to an increase in the level values at low frequencies and infrasound, as was the case during the measurements at the wind turbines.

To show the influence of traffic density, illustrations for higher and lower traffic volumes as well as for an average amount of traffic have been added (the exact data is given from the legend of ***Figure 5.2-3 and 5.2-4***). The proportion of heavy-goods traffic, based on the evaluated overall data, was 5 % in Karlsruhe and 11 % in Reutlingen.

Both evaluations show a striking increase between 31.5 Hz and 80 Hz above the perception threshold, which is attributable to motor vehicle traffic. Depending on traffic intensity, mean values of 72 dB (Karlsruhe) or 75 dB (Reutlingen) are reached. In the infrasound range (below 20 Hz) and below, the results of the measurements differ: This is where in Karlsruhe lower values are measured than in Reutlingen, which is probably due to different amounts of heavy-goods traffic, traffic volumes and speeds. In both cases, the third octave levels already exceed the perception threshold with a higher traffic volume between the 20 Hz and 25 Hz third. A similar result was at hand for the road measurement in Würzburg (Section 5.1, ***Figure 5.1-4***). The G-weighted sound levels were between 65 and 75 dB(G) in Karlsruhe and between 70 to 80 dB(G) in Reutlingen, see ***Table 5.2-1***.

5.3 Motorway – measurement near Malsch

The LUBW undertook sound measurements at the A5 (E52) motorway south of Karlsruhe near the town of Malsch on 26.06.2013 during the daytime between 1:00 p.m. and 3:00 p.m. The weather was sunny and practically windless. Wind-induced interfering noise at the microphone can therefore be ruled out. The distances of the microphone position to the middle of the centre strip of the motorway were 80 m, 260 m and 500 m (***Figure 5.3-1***). The measurement values at the measurement point at a distance of 500 m later had to be rejected due to the interference of the B3 main road and other interfering noise. Information on the used metrology can be found in Appendix A4.

The measurement results for the distances of 80 m and 260 m are graphically presented in ***Figure 5.3-2*** as a third

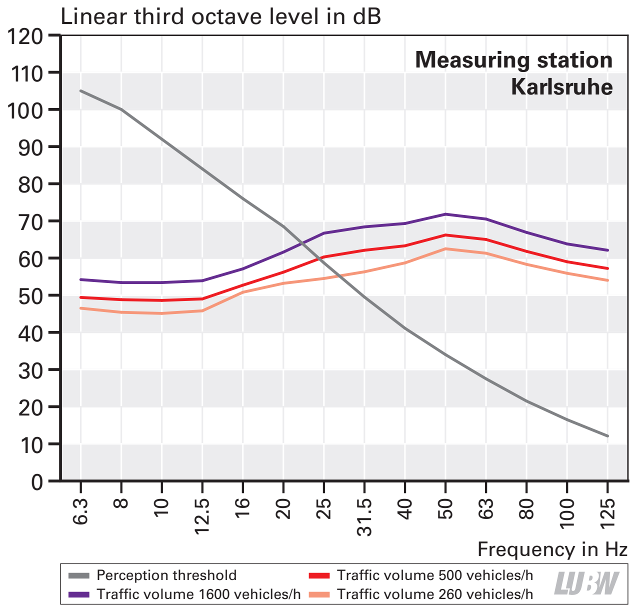


Figure 5.2-3: *Third octave spectra, measuring station Karlsruhe*

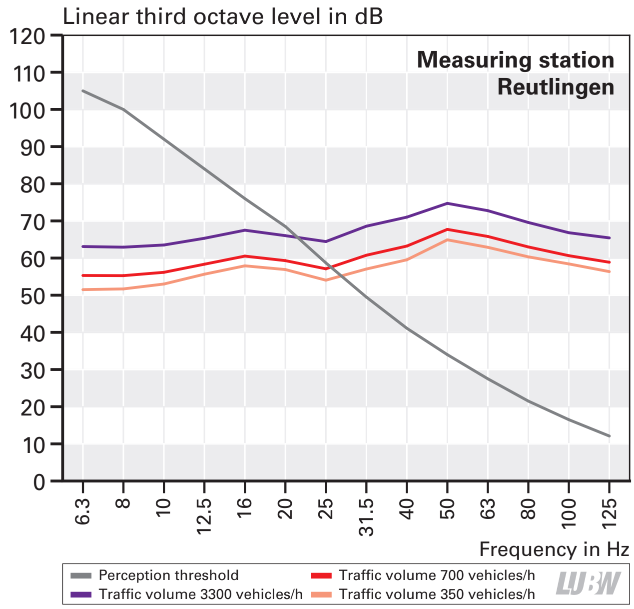


Figure 5.2-4: *Third octave spectra, measuring station Reutlingen*

Periods with zero wind or wind velocities below 1 m/s in the year 2013 were evaluated. Averages over 30 minutes each were formed and aggregated. The increased level in the range between the 31.5 Hz and 80 Hz thirds is caused by road traffic. The curves show the differences at various traffic volumes. Note: The representation begins at a frequency of 6.3 Hz (in other illustrations partly from 1 Hz.); this is due to the measuring technology. For comparison, the perception threshold according to Table A3-1 is shown.

***Table 5.2-1**: Summary of the measurement results for low-frequency noise (including parts of infrasound) at the traffic noise monitoring stations Reutlingen and Karlsruhe*

Source/situation	G-weighted level in dB(G)	Infrasound third octave level ≤ 20 Hz in dB *	Low-frequency third octave levels 25-80 Hz in dB *
Traffic noise measuring station Karlsruhe traffic volume >1600 vehicles/h	75	53 to 62	67 to 72
Traffic noise measuring station Karlsruhe average traffic volume: 500 vehicles/h	65	48 to 57	60 to 67
Traffic noise measuring station Karlsruhe traffic volume < 260 vehicles/h	69	45 to 54	55 to 63
Traffic noise measuring station Reutlingen traffic volume > 3300 vehicles/h	80	63 to 68	64 to 75
Traffic noise measuring station Reutlingen average traffic volume: 700 vehicles/h	70	55 to 61	57 to 68
Traffic noise measuring station Reutlingen traffic volume < 350 vehicles/h	73	52 to 57	54 to 61

* Linear third octave level in dB(Z)

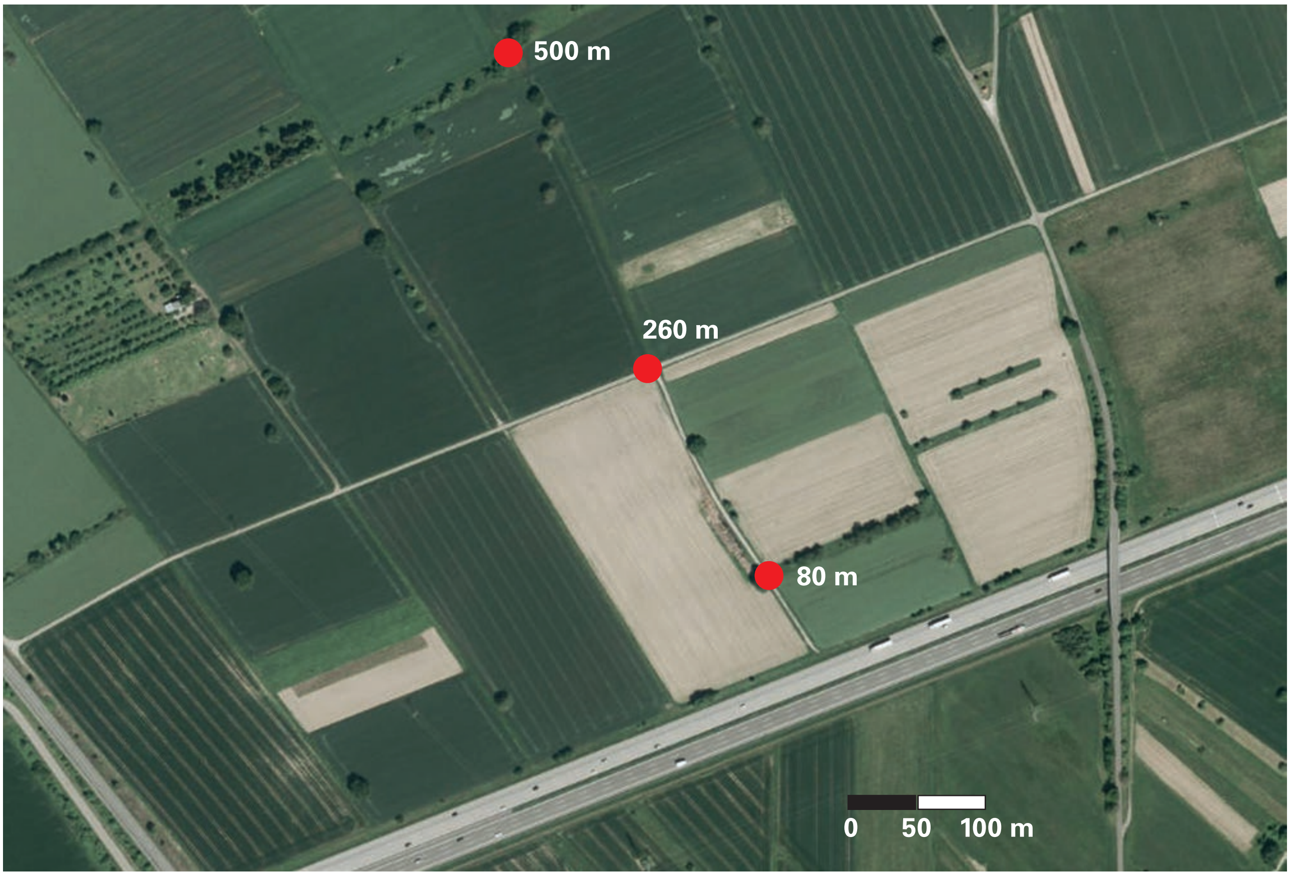


***Figure 5.3-1**: Location of the measurement points at the A5 motorway south of Karlsruhe near Malsch, indicating the distances between the microphone positions and the centre of the motorway. The town of Malsch is located outside of the picture at the bottom left. The B3 main road is located above the picture. Picture source: LUBW, LGL*

octave representation. The third octave levels in the infrasound range are at levels of around 60 dB and slightly below. In the low-frequency range, approximately between 40 Hz and 80 Hz, a slight peak can be seen. Here the measured values are significantly above the hearing threshold. The average traffic intensity is approximately 3,000 vehicles/h with a share of heavy-goods traffic of around 15 %. The G-weighted infrasound levels were around 75 dB(G) at a distance of 80 m and around 71 dB(G) at a distance of 260 m. Additional information concerning the G level can be found in Appendix A3.

5.4 Noise inside car while driving

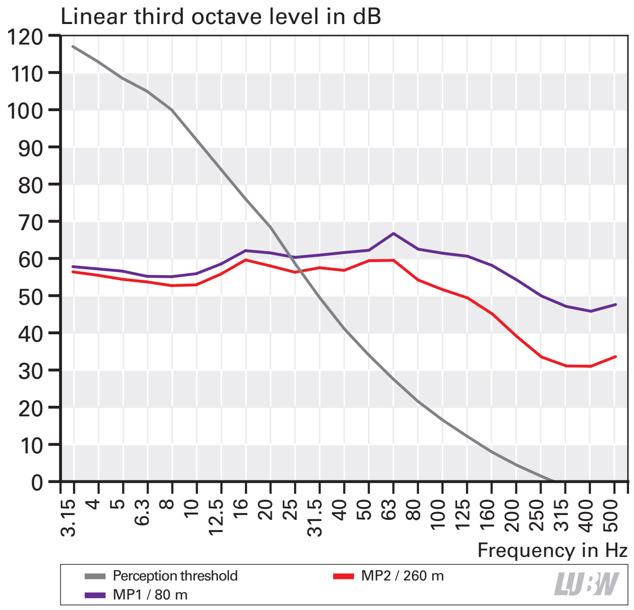
Below are the results of noise measurements carried out by the LUBW inside a moving car and a minibus on 06.09.2012. This is in fact no sound that occurs in the vicinity, i.e. no ambient noise or environmental noise in the strict sense. However, a lot of people are exposed to these sounds often and for longer periods of time, meaning that it surely makes sense to include such measurement values here. It became evident that relatively high levels in the infrasound range up to 20 Hz, as well as in the other low-frequency frequency range above 20 Hz occurred (***Firgure 5.4***, ***Table 5.4***). It must be noted that, with windows open, the levels that arise in the area of low frequencies incl. infrasound are so high that they are subjectively perceived as being painful. The values measured by us correspond to the respective specifications in literature (e.g. [19] [20]).

5.5 Conclusion of the road traffic measurements

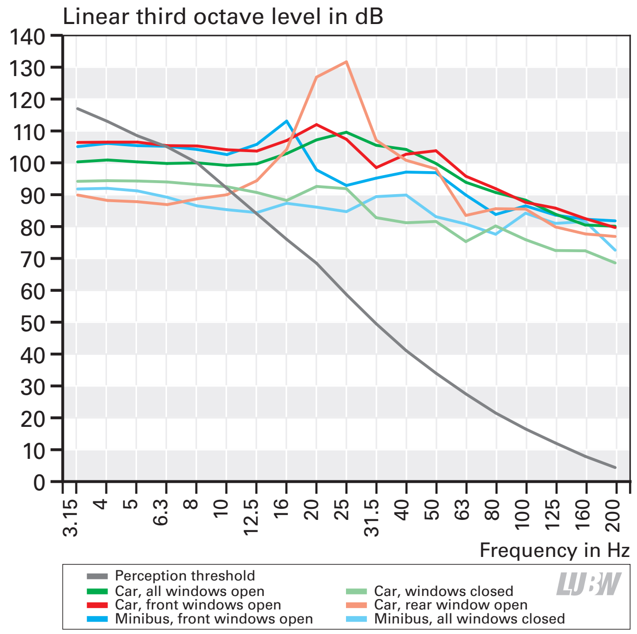
- It was possible to carry out the measurements for the low-frequency noise incl. infrasound resulting from road traffic without interfering wind noise. Unlike in the case of wind turbines, the recorded levels occur in the direct vicinity of residential buildings.

- As expected, it could be observed that the level of low-frequency noise including infrasound dropped at night. A good correlation with the traffic volume was also determined: The more the traffic, the higher the sound levels of low-frequency noise including infrasound.

- The Infrasound levels of traffic reach a maximum of 70 dB (unweighted) in individual thirds with respect to residential buildings in the vicinity. The G-weighted level



Firgure 5.3-2*: Frequency-dependent representation (linear third octave level) of a measurement at the motorway A5. As a comparison, the perception threshold according to Table A3-1 was also included. Note: The representation begins at a frequency of 3.15 Hz (in other illustrations partly from 1 Hz or 6.3 Hz). This is due to the measuring technology used.*



Firgure 5.4*: Low-frequency sound (averaging level) in the inside of car and minibus driving at approx. 130 km/h in comparison to the perception threshold according to Table A3-1*

***Table 5.4**: Infrasound level inside a passenger car or minibus while driving at 130 km/h*

Source	G-weighted level in dB(G)	Infrasound third octave level between 3.2 und 20 Hz in dB *
Interior noise in passenger car, all windows closed	105	88 to 94
Interior noise in passenger car, rear window open	139	87 to 127
Interior noise in minibus, all windows closed	100	85 to 93
Interior noise in minibus, side windows open	122	98 to 113

* Linear third octave level in dB(Z)

LUBW

is in the range between 55 and 80 dB(G). This roughly corresponds to values found in literature for sea surf (***Table 2-1***).

- For road traffic, increased levels were detected in the frequency spectra in the range of between roughly 30 Hz and 80 Hz. Low-frequency noise in this area lies significantly above the hearing threshold and seems to be more relevant for an assessment than the infrasound level up to 20 Hz. The values in this low-frequency frequency range are significantly higher for the observed situations of road traffic than in the areas surrounding wind turbines (***Table 2-1***).

- The highest levels in the context of the measurement project were measured in the interior of a car travelling at 130 km/h. Even though these are not immission levels that occur in the free environment, they are an everyday situation that many people are frequently subjected to for a longer period of time. The measured values for both the infrasound as well as the other low-frequency areas are higher by several orders of magnitude than the values usually measured in road traffic or at wind turbines.

6 Urban background

The Friedrichsplatz in Karlsruhe was chose for the measurement of infrasound and low-frequency noise at day and night in an urban background. It is located in the heart of the city. The Friedrichsplatz is a rather quiet square located directly by the natural history museum. Benches, landscaped flower beds and a fountain invite passersby to linger and stop for a short break (***Figure 6-1***). The square extends for about 125 m from north to south and 100 m from east to west. The Erbprinzenstrasse crosses the Friedrichsplatz as a bicycle road. In a westerly and easterly direction are the Ritterstrasse and Lammstrasse respectively, with very slowly driving traffic. In the south, the square is limited by the natural history museum of Karlsruhe. To the west lies the Church of St. Stephan with forecourt. Apart from that, the Friedrichsplatz is surrounded by offices and commercial buildings, as well as a number of individual apartments. The next somewhat busier road is situated about 250 m to the south, shielded behind the natural history museum and the Nymphengarten (Kriegstrasse, B 10). Tram lines are located at a distance of several hundred metres, partially behind several blocks of buildings (***Figure 6-2***), and a construction site is located in a north-westerly direction.

The measurements were carried out simultaneously at three measurement points. The location of the measurement points is shown in the aerial view in ***Figure 6-3***. Measurement point MP1 was chosen in the inside of a building adjacent to the Friedrichsplatz (meeting room of the education authority of Karlsruhe). A second measurement point MP2 was placed on the ground of the Friedrichsplatz, a third measurement point MP3 on the roof of the museum of natural history (***Figures 6-4 to 6-6***). MP2 and MP3 were positioned on a reverberant plate.

The measurements were carried out from Friday, 20.09.2013, 3:00 p.m. to Saturday, 21.09.2013, 2:00 a.m. Preliminary

Figure 6-1: *Friedrichsplatz in Karlsruhe, looking south at the natural history museum. Photo: LUBW*

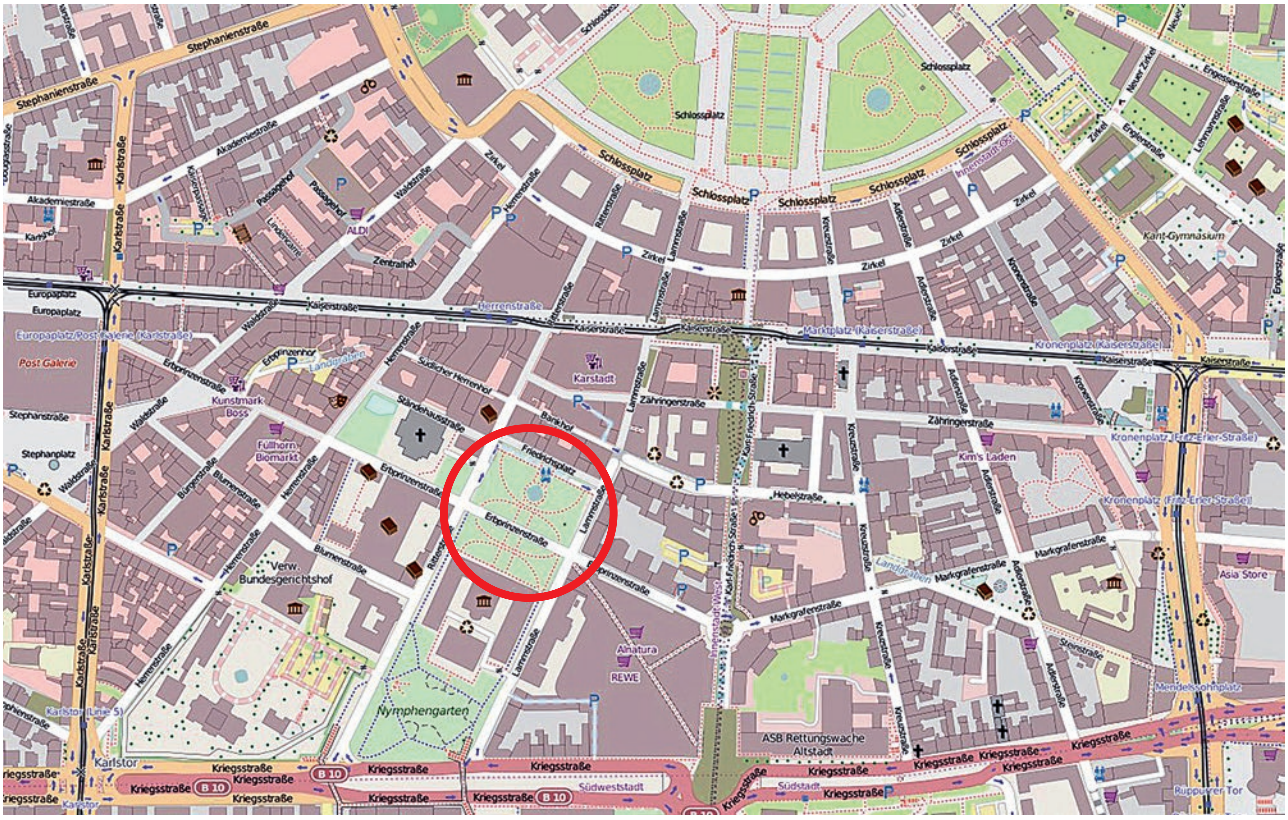


***Figure 6-2**: City map of Karlsruhe with Friedrichsplatz (red circle) and the tram lines in the vicinity (dark and dashed lines). Source: www.OpenStreetMap.org*

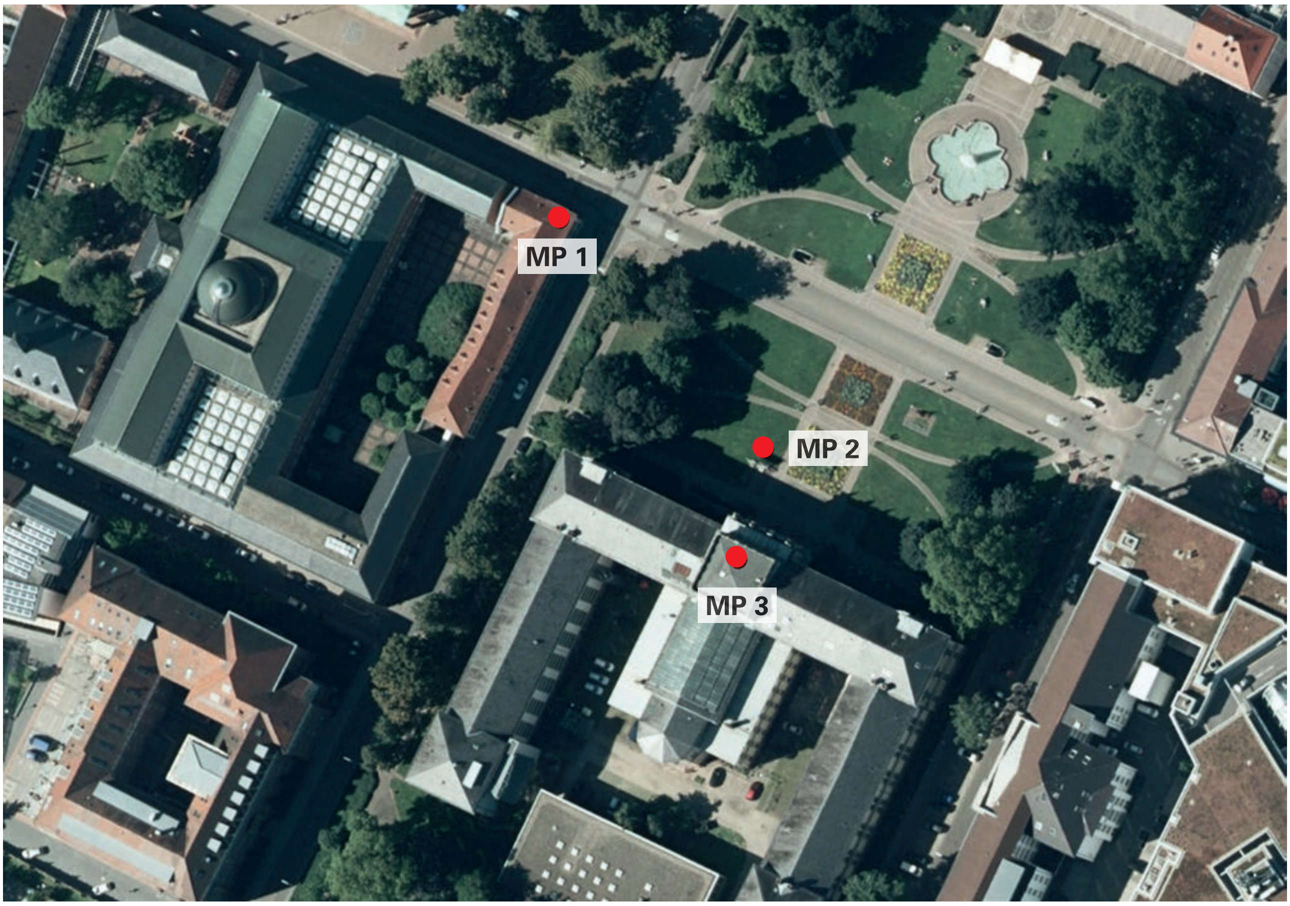


***Figure 6-3**: Oriented aerial view of Karlsruhe Friedrichsplatz. Location of the three measurement points MP1 (meeting room of education authority), MP2 (on Friedrichsplatz) and MP3 (roof of museum of natural history). Source: LUBW, LGL*

measurements were taken by the LUBW on 26.06.2013. The measurements should enable conclusions to be made about the situation at day and at night. The volume of traffic (cars, pedestrians, cyclists) was typical for this site in the given weather conditions. In summer nights or during events, higher volumes will surely be the case.

Note: While the infrasound and low-frequency noise measured in the vicinity of operating wind turbines always contains a proportion of wind (and possibly also a share that is induced by the wind at the microphone), the conditions are much more favourable for the measurement of inner city noise. Here these effects related to the wind play virtually no role. The infrasound and low-frequency noise could be measured largely without any disturbing wind noise. Only on the roof of the museum of natural history did wind noise occur from time to time. For more information see page 73.

RESULTS

The measured third octave spectra for the three measurement points, each for the time periods 4:00 p.m. - 5:00 p.m., 10:00 p.m. - 11:00 p.m. and 12:00 a.m. - 1:00 a.m. are shown in ***Figure 6-8*** and are explained in the following:

At the measurement point MP1 (education authority, indoor measurement), third octave levels between just under 20 dB to 45 dB were measured in the infrasound area below 20 Hz. The values are all below the perception threshold. It is clearly visible that the infrasound levels drop at night by about 10 dB. In the further low frequency range a significant rise from 25 Hz to 63 Hz can be found, which is probably due to traffic noise and electrically powered equipment (the building was not without electrical power). All in all, the lowest levels are found at the indoor measurement at MP1 as a result of the absorption through the building envelope. The results of the indoor measurement were evaluated according to DIN 45680 (1997) [4],

Figure 6-4*: Setup of the measurement point MP1, indoor measurement at the education authority of Karlsruhe. Photo: LUBW*

Figure 6-5*: Measurement point MP2 on the Friedrichsplatz in front of the natural history museum Karlsruhe. Photo: LUBW*

Figure 6-6*: Microphone position at measurement point MP3 (roof of museum) with view over Karlsruhe. The meteorology was also determined at MP3. Photo: LUBW*

Figure 6-7*: View from measurement point MP3 (roof of museum) looking north over Karlsruhe. The floodlights of the KSC stadium in the Wildpark can be seen. Photo: LUBW*

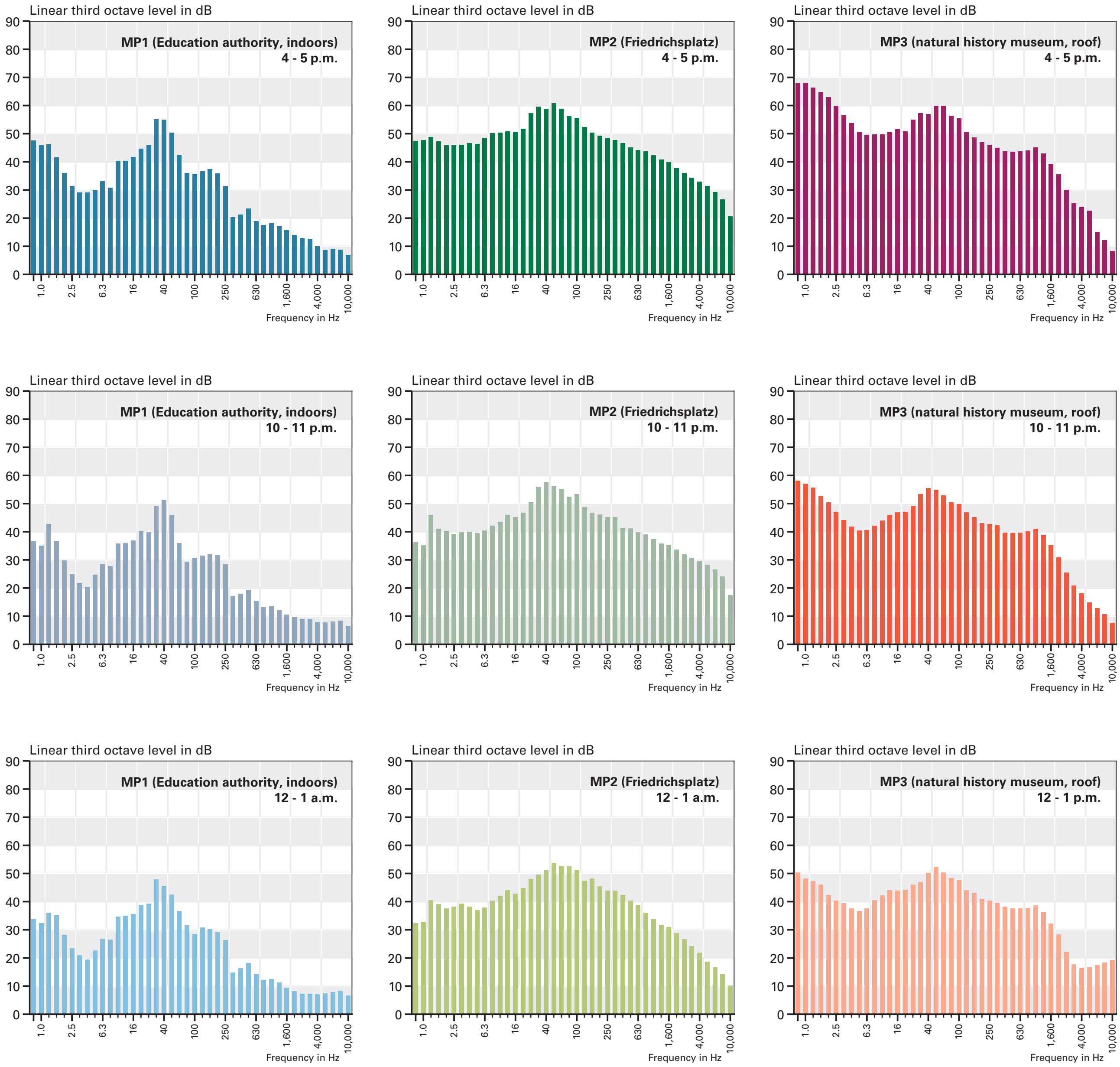


***Figure 6-8**: Measured third octave spectra for the three measurement points at different times of the day and at night. Left column: Measurement point MP1 (education authority, indoors); centre column: Measurement point MP2 (Friedrichsplatz); right column: Measurement point MP3 (natural history museum, roof). For explanations see text.*

even if the scope of this standard does not cover road traffic noise. Time periods with substantial influence of background noise at measurement point MP1 were excluded from the evaluation. The following periods of time were chosen: For the night period (10:00 p.m. - 11:00 p.m., loudest hour), as well as in accordance with the procedure of DIN 45680 (1997) [4] for the day period (4:00 p.m. - 5:00 p.m., loudest hour) as well as informatively for the night hour from 12:00 a.m. - 1:00 a.m. The reference values taken from the supplement sheet "Beiblatt 1" for above-stated norm (these are formally only valid for the operation of industrial plants) were exceeded in the daytime as well as night time periods. There were no clearly protruding single tones. For informative purposes, the measurement data was also evaluated according to the revised draft of DIN 45680 (2013) [5]. The reference values taken as a comparison (these are formally only valid for the operation of industrial plants) were exceeded in the daytime as well as night time periods.

The data of the measurement points MP2 and MP3 was respectively corrected according to Section 4.1 (reverberant plate). At the measurement point MP2 (Friedrichsplatz in front of the museum), third octave levels between

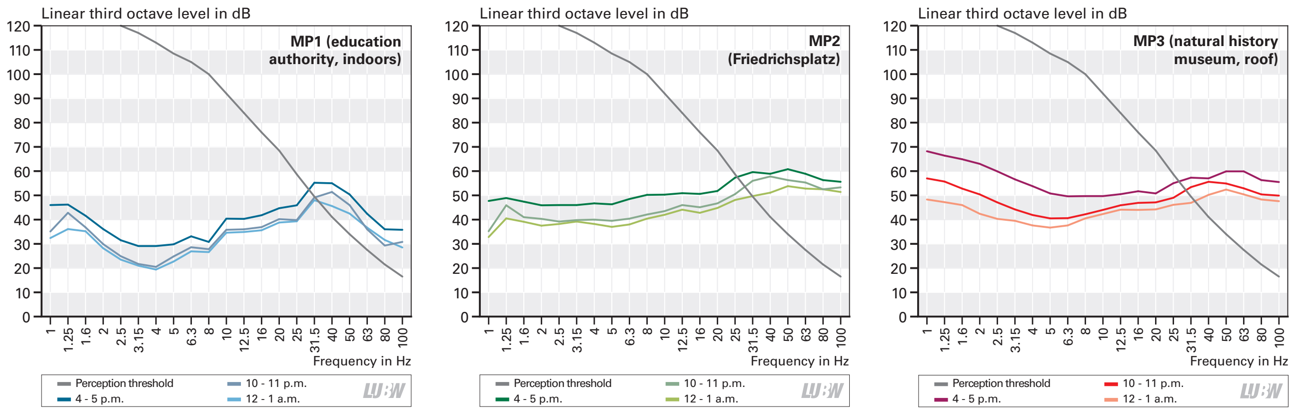


***Figure 6-9**: Comparative frequency-dependent representation of the third octave sound level for the three measurement points at different times of the day and at night. The results for MP2 and MP3 have been corrected (reverberant plate, see Section 4.1). The perception threshold was also shown as a means of orientation. Left: measurement point MP1 (education authority, indoors); Centre: measurement point MP2 (Friedrichsplatz); right: measurement point MP3 (natural history museum, roof).*

just under 35 dB and a little over 50 dB were measured in the infrasound range up to 20 Hz. Here too, a decrease of the infrasound can be recognised later at night. In the low-frequency range, an excessive increase can also be seen, which can be attributed to the road traffic. This is where levels above 55 dB are also reached at night in the range of 32 Hz to 80 Hz, which is above the perception or hearing threshold. An interesting effect can be seen for the 1.25 Hz third, which, for example, clearly stands out in the third octave spectrum for MP2 between 10:00 p.m. and 11:00 p.m. This concerns a natural frequency of the Friedrichsplatz, which is largely surrounded by buildings (half a wavelength corresponds to merely the extent of the square). This effect can be analysed further in the narrow band spectrum (not shown here).

At the measurement point MP3 (museum roof), similar conditions as for MP2 can be seen – with two differences: For the infrasound below 5 Hz, an excessive increase can be seen, which here is attributed to the somewhat increased wind speed on the roof and the corresponding wind effects. An increase arising in the range above 500 Hz can at least partially be attributed to the rolling noises of cars on roads located further away, such as the B 10 (Kriegstrasse). These were noticeable on the roof, but were otherwise screened off. In the evening, it was possible to get a direct view of the KSC football club's Wildpark stadium, where a match was taking place (***Figure 6-7***).

In a further analysis of the narrow band spectra (not listed here), some individually protruding lines could be detected at some frequencies. However, these could not all be associated with specific sources.

In ***Figure 6-9*** the developments of the linear third octave levels in the range from 1 Hz to 100 Hz are presented for the measurement points MP1 to MP3 in comparison to the perception threshold (according to draft of DIN 45 680 [5]; below 8 Hz supplemented by literature values [11]). See also ***Table A3-1***. The results for MP2 and MP3 were corrected, as shown in Section 4.1, due to the use of a reverberant plate.

Figure 6-10 shows the course of the A-weighted and G-weighted sound level during the measurement at the measurement point MP2 (Friedrichsplatz). It can be clearly seen that the G level, which represents the low-frequency noise including infrasound, slowly and steadily decreases in the evening hours. The G levels at the measurement point MP1 (indoors) were mostly between 45 dB(G) and 60 dB(G) during the measuring period, and at times even above that. At the measurement points MP2 (Friedrichsplatz) and MP3 (roof), the values were mostly between 55 dB(G) and 65 dB(G), and partially reached levels above 70 dB(G).

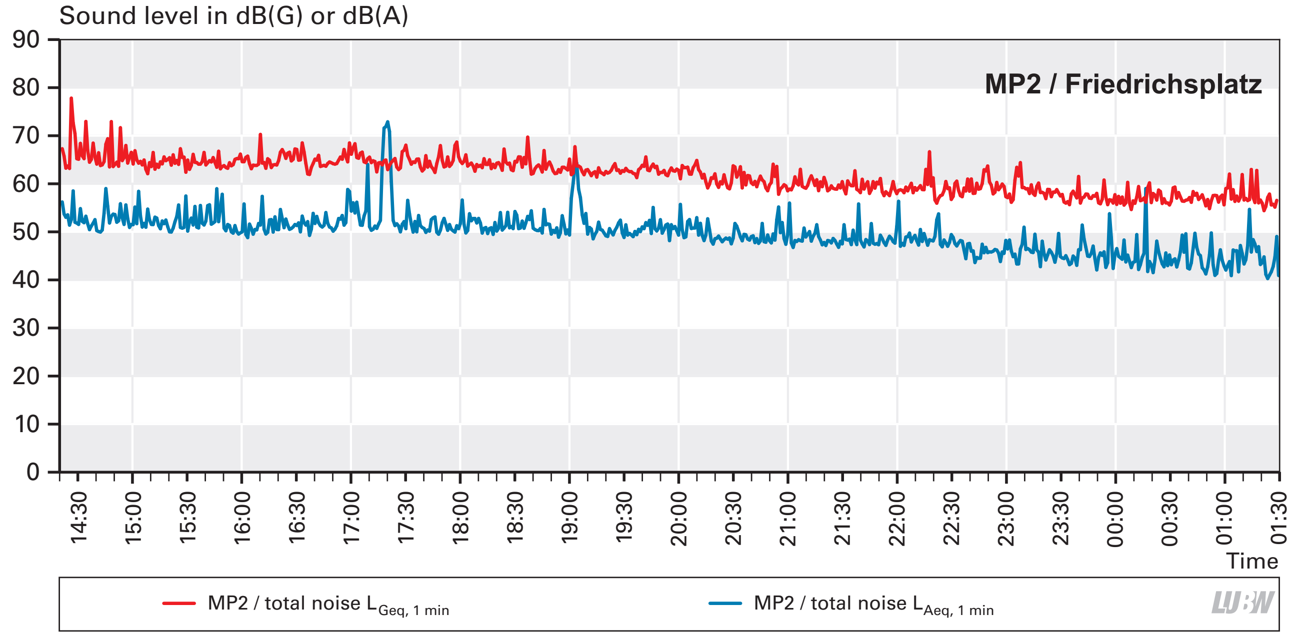


Figure 6-10: *Course of the A and G-weighted sum level L_{Aeq}(t) und L_{Geq}(t) at the measurement point MP2 (Friedrichsplatz) in the time period 20.09.2013, approx. 2:30 p.m. to 21.09.2013, 1:30 a.m.*

7 Sources of noise in residential buildings

Life in the modern household is characterized by the use of technical devices, which are used to facilitate everyday life. The locations of the devices are normally chosen on the basis of the existing supply connections for electricity, water or gas. When doing so, people also generally pay attention to ensuring a preferably trouble-free use of the living quarters. Devices such as fridges or ventilation systems are permanently or intermittently in operation, while other devices such as vacuum cleaners or electronic tools are used only briefly. During operation, every technical device emits characteristic sounds. Depending on the source, different sound patterns can also be caused by different operating modes.

With the help of manufacturer‘s instructions, buyers can inform themselves about the expected noise levels prior to the acquisition of technical devices. However, the data sheets often only specify the A-weighted levels. These provide no indications of how the sound spreads across different frequencies.

In order to also be able to present low-frequency noise that may occur in a living environment in a comparative manner, the LUBW carried out sound level measurements in a residential building in the city centre of Tübingen. The apartment building in half-timbered construction style dates from the second half of the 19th century. The compartments of the walls are made of sandstone and the wood-beamed ceilings are filled with clay. The ceilings and walls are additionally covered with a 3-4 cm thick layer of lime plaster. In the course of renovation work during the last few years, the worksite sandstone slabs or tiles were moved onto a layer of reinforced cement screed in some areas, such as in the bathrooms. The building is located in a restricted traffic area; the next multilane roads are about 150 m away. Any traffic noise emanating from there is largely shielded by the building density of Tübingen city centre. The acoustic situation around the building is significantly characterized by the communication noise of passers-by.

The measurements on 04.08.2015 registered two washing machines from various manufacturers, one refrigerator, one oil heating and one gas heating. For detailed information on the used measuring instrumentation please refer to Appendix A4.

7.1 Washing machine

The washing machines were located in two apartments on the 1st and 2nd floor of the house. The measurements were each taken at a measurement point MP1 at close range within the room of the installation itself, as well as at a measurement point MP2 in a separate room. When measuring washing machine 1 on the 1st floor, the measurement point MP1 in the middle of the room was approx. 0.5 m from the washing machine. Measurement point MP2 was located approx. 3 m vertically above MP1 on the 2nd floor. Washing machine 2 was located on the 2nd floor. Here measurement point MP1 was also positioned in the middle of the room approx. 0.5 m from the washing machine, while measurement point MP2 in the adjoining room – separated by a wall – was positioned approx. 5 m away.

RESULTS

The measurements of the two washing machines took place in the period from 10:50 a.m. to 11:30 a.m. Periods with extraneous noise effects were excluded from the evaluation.

With washing machine 1 in operation, third octave levels between 44 dB and 76 dB in the infrasound range under 20 Hz were measured at measurement point MP1 (***Figure 7.1-1***). The highest levels occurred during the spin cycle and the lowest ones during the wash cycle. At measurement point MP2, third octave levels of 29 dB to 60 dB occurred below 20 Hz during the measurement of washing machine 1. Here, too, the higher levels were registered during the spin cycle.

At washing machine 2, the third octave levels at measurement point MP1 in the infrasound range below 20 Hz were between 35 dB and 70 dB (***Figure 7.1-2***). Here too, the highest third octave levels were registered in the spin cycle. The measurements at measurement point MP2 showed third octave levels between 26 dB and 71 dB in the same frequency range.

The curves for the individual modes of operation of the two measured washing machines are almost parallel for the measurement points MP1 and MP2 in the infrasound range below 20 Hz. In contrast, it can be seen that above 20 Hz the difference between the third octave levels measured at both measurement points increases with increasing frequency. This can be attributed to the sound insulation effect of the building components (ceiling or wall). The building components reduce the higher-frequency sound to a significantly higher degree than is the case in the infrasound range.

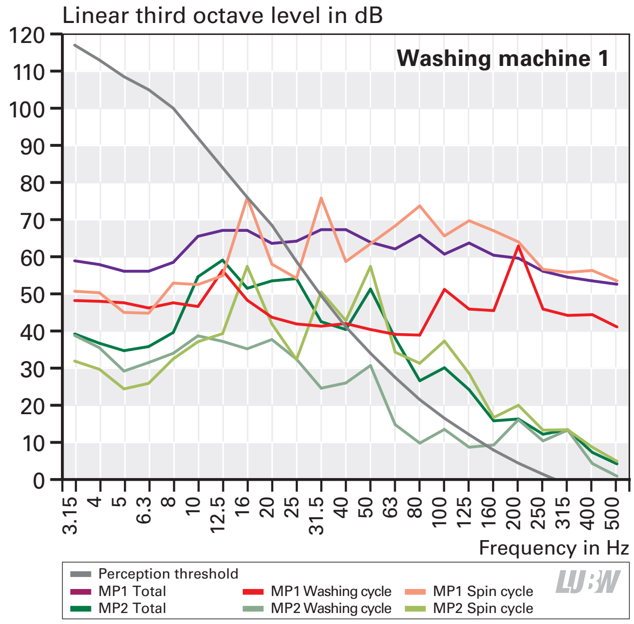


***Figure 7.1-1**: Third octave noise level of washing machine 1 at measurement points MP1 and MP2 for different operating states, with perception threshold according to Table A3-1 for comparison. "Total": Average level over the entire wash cycle.*

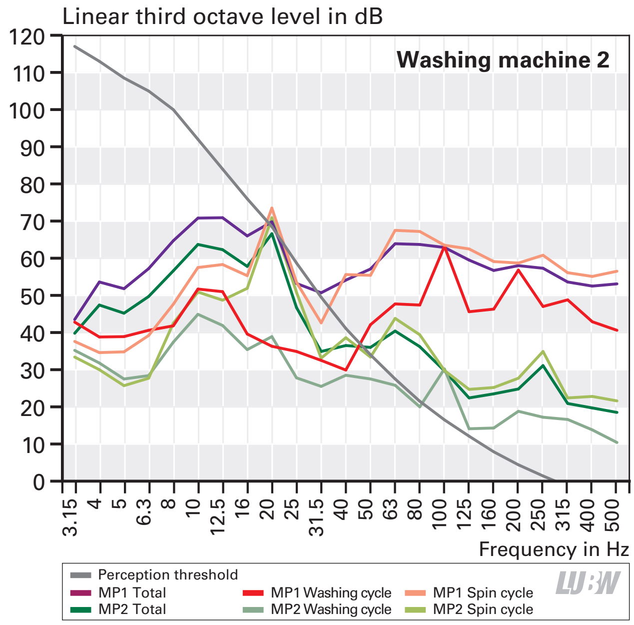


***Figure 7.1-2**: Third octave noise level of washing machine 2 at measurement points MP1 and MP2 for different operating states, with perception threshold according to Table A3-1 for comparison. "Total": Average level over the entire wash cycle.*

The single tone at 16 Hz (washing machine 1) as well as 20 Hz (washing machine 2) are caused by the respective rotational speed during the spin cycle. The 16 Hz third octave correlates with 960 rpm, the 20 Hz third octave with 1,200 rpm. The additionally emerging single tone at washing machine 1 at about 31.5 Hz is a harmonic overtone of the 16 Hz third octave. Depending on the operating mode, single third octave levels can reach the perception threshold according to ***Table A3-1*** between roughly 16 Hz and 20 Hz; above 50 Hz the third octave levels are generally in the audible range.

7.2 Heating and refrigerator

The two heating units measured were an oil boiler in the basement with pressurised atomiser burner on the one hand, and a gas water heater installed on a wall in the bathroom of the 2nd floor on the other. The fridge was located on the 2nd floor in a corner of the kitchen. The measurements of these noise sources were each carried out at a measurement point at a distance of about 0.5 m.

RESULTS

The third octave spectra during operation of the two heating systems as well as the refrigerator in the period from 11:40 a.m. to 1:30 p.m. were measured using technical measuring equipment. The results of the measurements are shown in ***Figure 7.2-1***. As was the case for the other measurements, extraneous noise, e.g. caused by measuring staff or passers-by outside, was excluded from the assessment.

Levels of approx. 55 dB to 70 dB were measured at the oil heating in the infrasound range below the 20 Hz third octave. In the low-frequency range between 20 Hz and 80 Hz, the third octave levels are between 55 dB and 60 dB. A single tone with a third level of 74 dB is recognisable at 100 Hz. Levels between 40 dB and 50 dB were measured at the gas water heater in the infrasound range below 20 Hz. In the low-frequency range between 20 Hz and 80 Hz, the third octave levels measured at the gas heating are between 40 dB and 50 dB. The difference between the levels measured at the oil heating and the gas water heater in the low-frequency range is between 10 dB and 40 dB.

The fridge measured in the kitchen of the 2nd floor delivered third octave levels of between 32 dB and 50 dB in the infrasound range. Third octave levels between 17 dB and 50 dB were measured at the refrigerator between 20 Hz and 80 Hz. While the third octave spectrum of the oil heating clearly sets itself apart from the other measured units through higher levels, the third octave spectra of the gas water heater and the refrigerator are very similar.

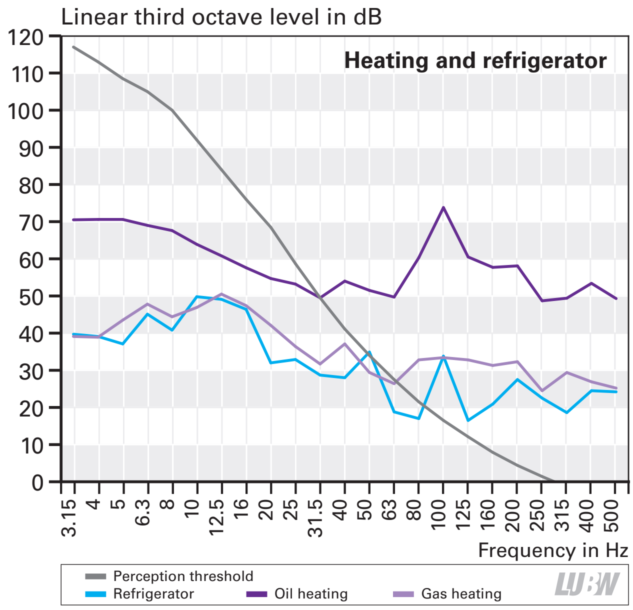


Figure 7.2-1*: Third octave sound level of the noise from oil heating, gas heating and refrigerator at a distance of 0.5 m from the unit, with perception threshold according to Table A3-1 for comparison*

SUMMARY

During the measurements in the residential building, the highest levels at washing machines were recorded during the spin cycle. Tonalities in individual third octaves correlate with the rotational speed of the drum of the washing machine during the spin cycle. As expected, building components dampen higher frequency noise components more than at low frequencies. The perceptual threshold according to ***Table A3-1*** was reached for the washing machines in the frequency range above 16 Hz and 20 Hz respectively. With the other devices, the infrasound level did not reach this threshold.

8 Natural sources

8.1 Rural environment

In order to make statements about how much infrasound is caused by wind in the great outdoors, sound level measurements were carried out within the framework of the measuring programme on 09.05.2015 with strong winds in an open field (measurement point MP1), on the edge of a forest (measurement point MP2) and in a forest (measurement point MP3). The three points were aligned downwind of each other, starting with MP1. As with the wind power plants, the sound level measurements were carried out on a reverberant plate with a primary and secondary wind screen. At the same time, the wind speed was measured at 10 m height (open field) at the measurement point MP1. ***Figures 8.1-1 to 8.1-3*** provide an impression of the positioning of the measurement points. The measurement point MP1 lies approx. 130 m from the edge of forest.

The evaluation was carried out for the frequency range between 1 Hz and 10 kHz. The procedure corresponded to the analysis of the measurements at wind power plants, as described in Section 4. Two time periods were examined per measurement point at different wind speeds (6 m/s and 10 m/s at the measurement point MP1, open field), within which the wind blew evenly if possible. As a result, two situations with widely differing environmental conditions were recorded. Due to the spatial situation at the measurement points MP2 (edge of forest) and MP3 (forest) it can be assumed that at the same given point in time the wind speed is lower there than at the measurement point MP1 (open field).

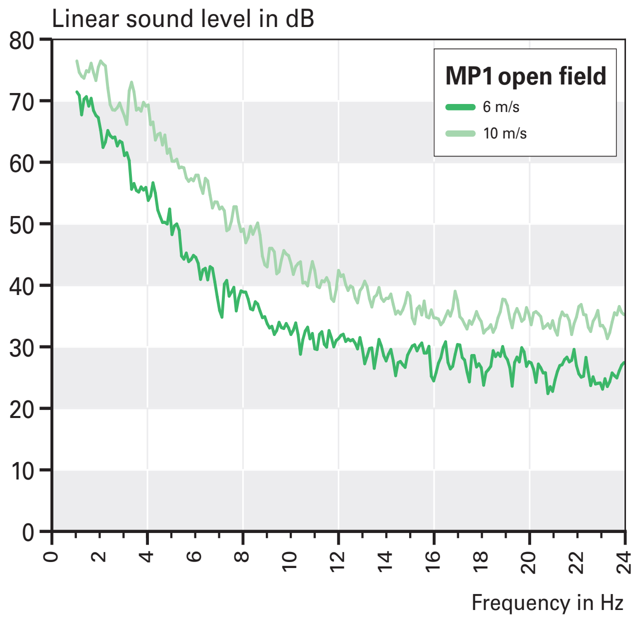
RESULTS: NARROW BAND LEVEL

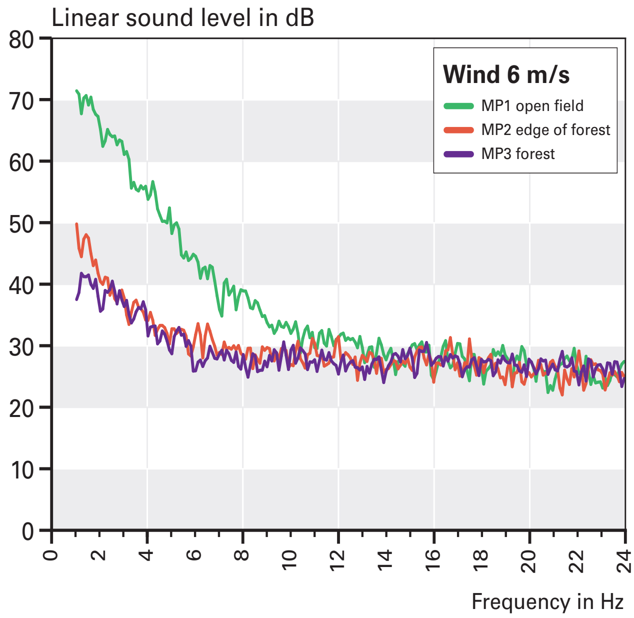
Figure 8.1-4 shows the narrow-band spectra determined from the audio signals at an average wind speed of approx. 6 m/s and 10 m/s at a height of 10 m (measured at the measurement point MP1). The three charts in the left column enable a comparison of measurement results for the two wind speeds at each measurement point. The two graphs in the right column show the sound levels that were recorded at the three measurement points for each of the wind speeds 6 m/s and 10 m/s. It can be seen clearly how the le-

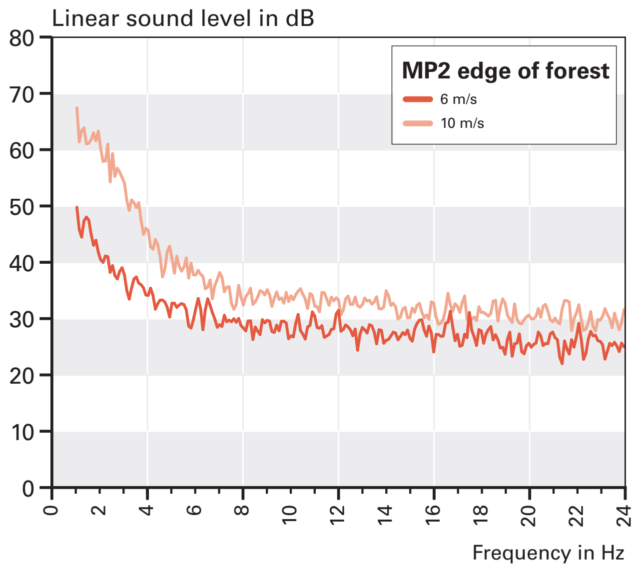
Figure 8.1-1*: Measurement point MP1 on open field (left) and meteorology mast (right), looking in direction of forest. Photo: Wölfel company*

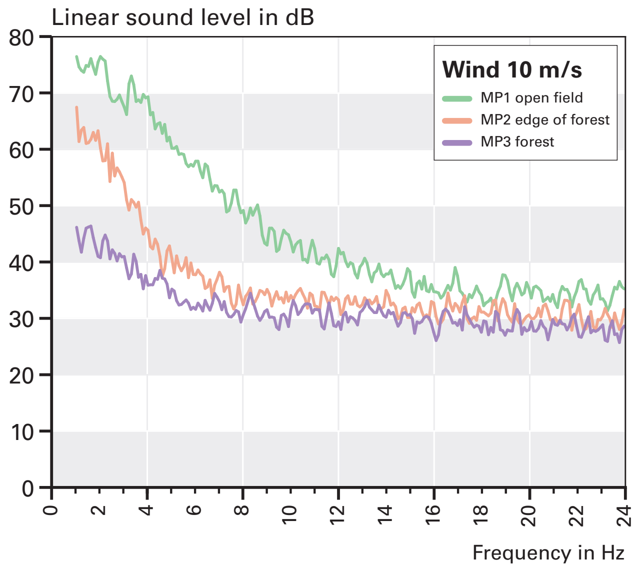
Figure 8.1-2*: Measurement point MP2, edge of the forest. Photo: Wölfel company*

Figure 8.1-3*: Measurement point MP3 in the forest, approx. 90 m from measurement point MP2. Photo: Wölfel company*









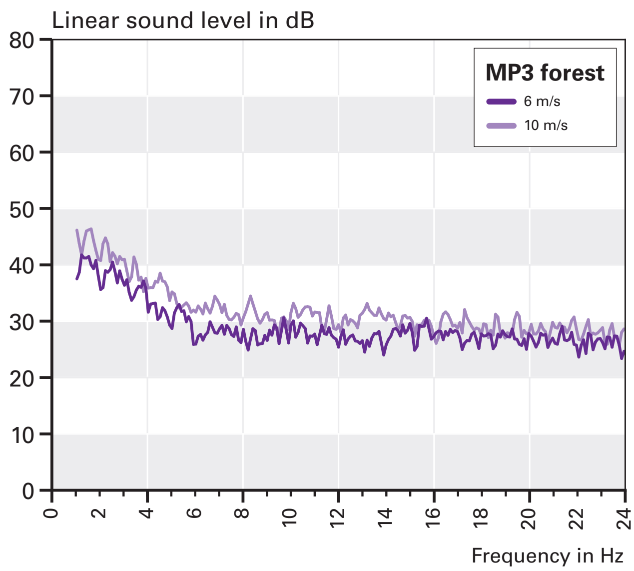


***Figure 8.1-4**: Narrow band spectra of noise at the measurement point MP1 (open field), MP2 (edge of forest) and MP3 (forest) for the frequency range of infrasound at different wind speeds. The wind measurement was always carried out at the measurement point MP1 (open field).*

Left column: Comparison of narrow band levels for the various wind speeds, separately presented for the measurement points MP1 (open field), MP2 (edge of forest) and MP3 (forest).

Right column: Comparison of the narrow band level at the three measurement points, represented separately for the wind speed 6 m/s (above) and 10 m/s (below)

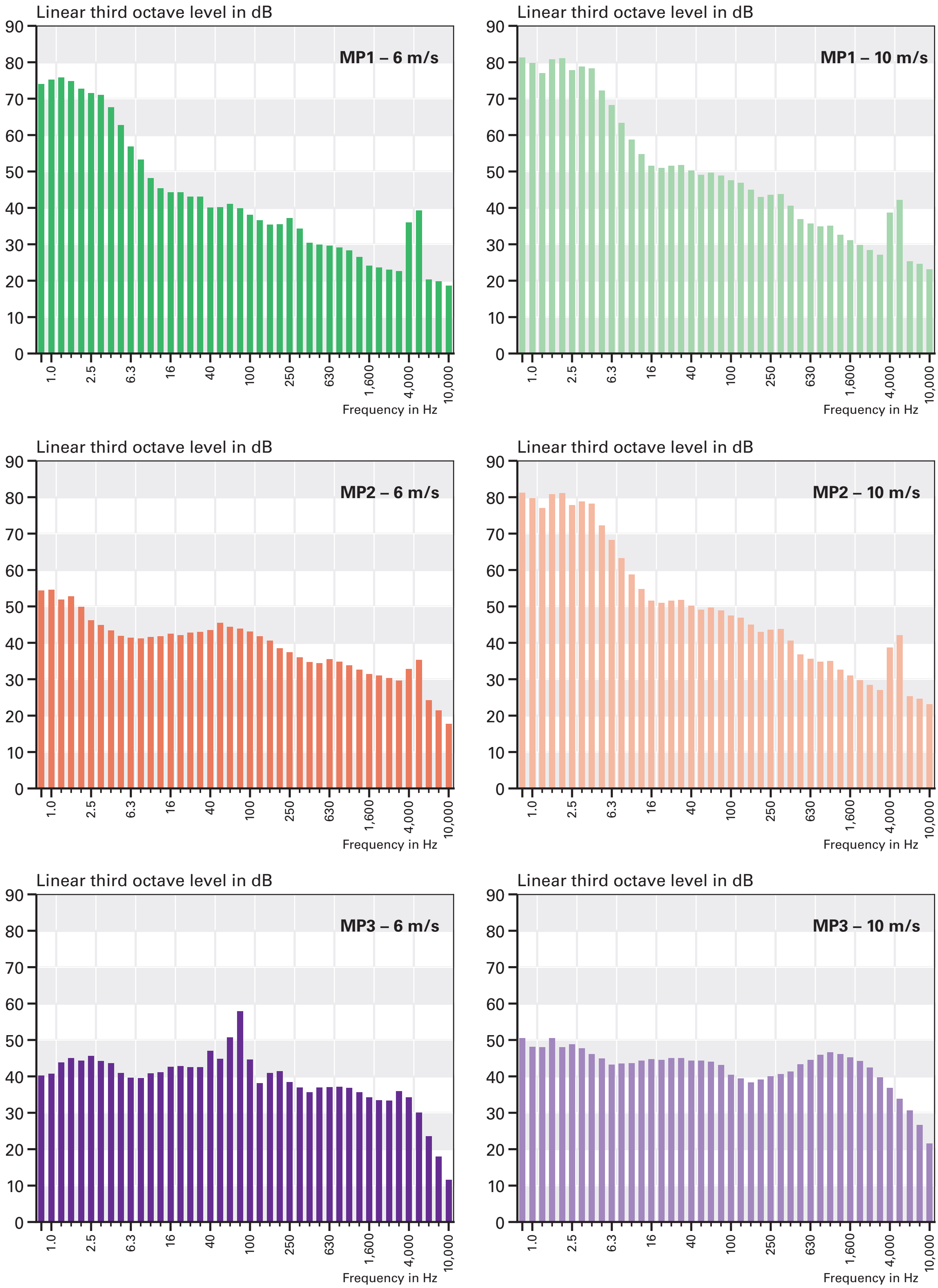


Figure 8.1-5: *Third octave spectra of the background noise at the measurement point MP1 (open field), MP2 (edge of forest), and MP3 (forest). Left column: Wind speed 6 m/s; right column: Wind speed 10 m/s. The wind measurement was always carried out at the measurement point MP1 (open field).*

vels depend on the measuring position and the wind speed. On an open field, the levels are about 10 to 15 dB higher at a wind speed of 10 m/s than at a wind speed of 6 m/s. At the edge of the forest, this difference is somewhat weaker for frequencies above roughly 5 Hz. The difference is only 5 to 10 dB. In the forest, the difference is 5 dB or less. The spread of the measured values between the three measurement points falls from roughly 30 dB at the lowest end of the spectrum to 0 to 5 dB at the upper end, depending on the wind speed. Noteworthy level differences between the edge of the forest and the forest occur only below 10 Hz. The differences in level between open field and forest, on the other hand, become less only above 20 Hz.

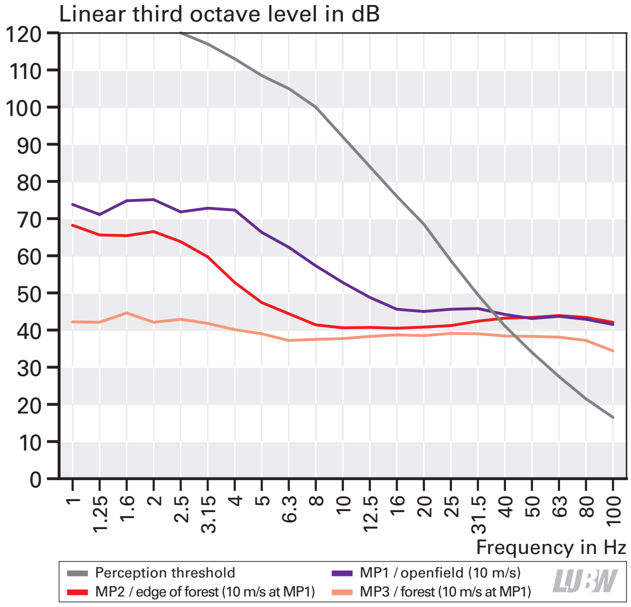


Figure 8.1-6: *Comparison of the third octave spectra of the total noise at the measurement points MP1 (open field), MP2 (edge of forest) and MP3 (forest) with the perception threshold according to Table A3-1. The measured values were corrected in accordance with Section 4.1.*

RESULTS: THIRD OCTAVE LEVEL

The third octave spectra of the background noise at all three measurement points for the frequency range from 0.8 Hz to 10,000 Hz are presented in ***Figure 8.1-5***. The wind speed was 6 m/s (left column) and 10 m/s (right column). On the open field, the low frequencies are predominant in the spectrum; at the edge of the forest and even more so in the forest, however, a shift to higher frequencies can be seen. While the wind becomes less the closer it gets to the forest, and less wind noise is therefore induced at the microphone, the noise from the leaves in the forest increases considerably. The peak values at about 4,000 Hz are due to the chirring of crickets and chirping of birds.

COMPARISON WITH THE PERCEPTION THRESHOLD

Figure 8.1-6 shows the third octave spectra of the total noise at the measurement points field, edge of forest and forest for the frequency range from 1 Hz to 100 Hz along with the perception threshold for comparison. The wind speed was 10 m/s. In the range of infrasound, the curves are well below the perception threshold.

INFLUENCE OF WIND SPEED

The data in ***Figure 8.1-7*** shows that both the audible sound level (A level) and the infrasound level (G level) increase with increasing wind speed. Worth noting is the decrease in level of the G-weighted level from the measurement point MP1 (open field) in the direction of the measurement point MP3 (forest). This correlates with the decreasing wind speed when moving from the open field towards the forest. Wind-induced effects on the microphone can be generally ruled out (see Section 4.5 and 4.6, measurement in hole in the ground). The A-weighted level increases the closer you get to the forest, which can be attributed to the rustling of leaves, which is reflected in the A level.

Table 8.1-1: *Infra sound in a rural location at the three measurement points at different wind speeds*

Measurement point	G-weighted level in dB(G) Wind 6 / 10 m/s	Infrasound third octave level ≤ 20 Hz in dB * Wind 6 / 10 m/s
MP1 open field, 130 m from forest	50-65 / 55-65	40-70 / 45-75
MP2 edge of forest	50-60 / 50-60	35-50 / 45-75
MP3 forest	50-60 / 50-60	35-40 / 40-45

* Linear third octave level in dB(Z)

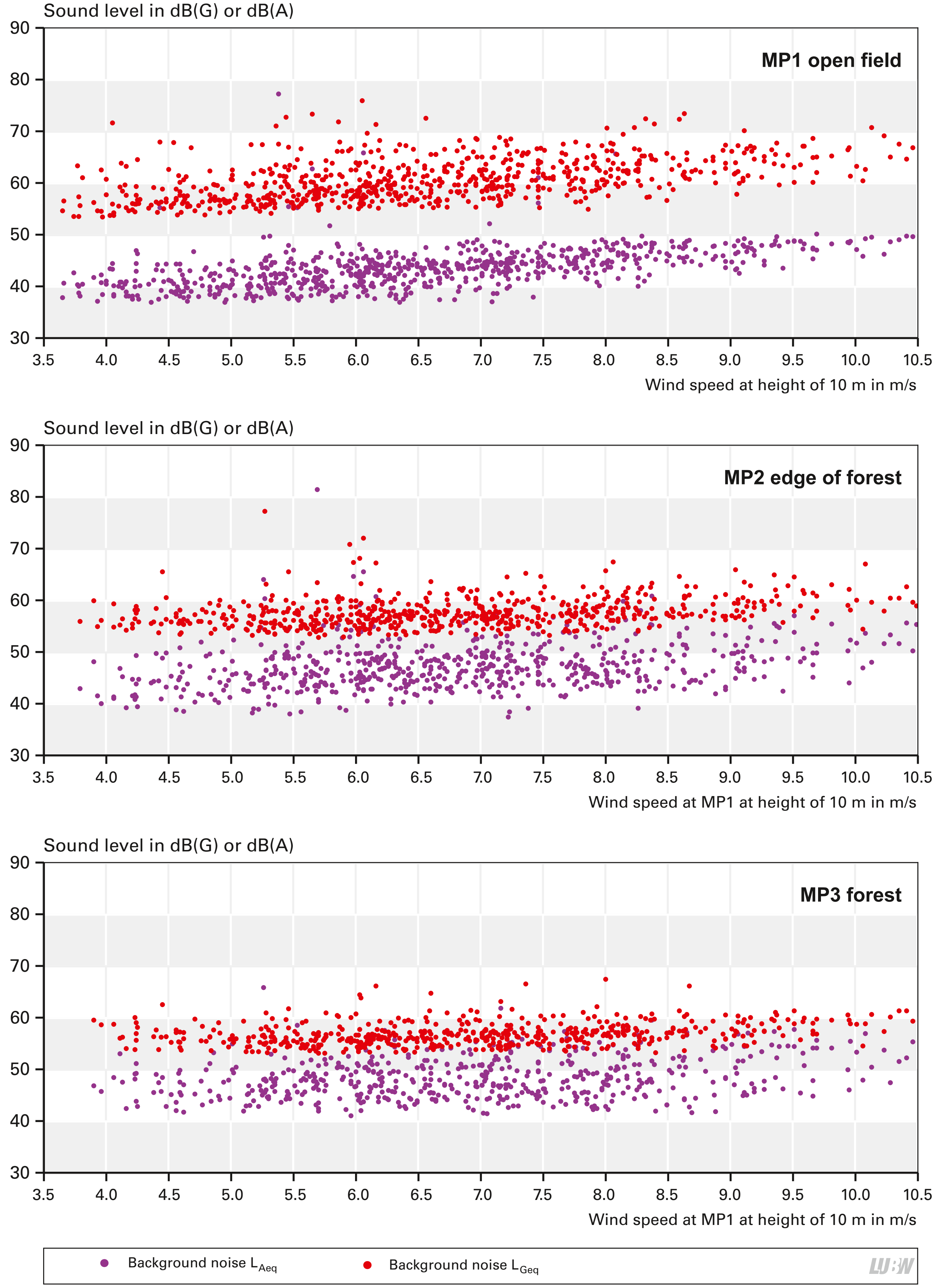


***Figure 8.1-7**: Audible sound level (A level) and infrasound level (G level) depending on the wind speed for the three measurement points MP1 (open field), MP2 (edge of forest) and MP3 (forest). The G levels (red dots) and the A levels (violet dots) are shown. The wind measurement was always carried out at the measurement point MP1 (open field).*

CONCLUSION

The infrasound shows a strong dependence on the measuring position. The linear levels in the narrow-band spectrum measured in the open field were up to 30 dB higher than the levels measured in the forest (***Table 8.1-1***). The differences are not as pronounced above 16 Hz, but a tendency towards higher levels can be seen in the open field compared to the forest at low frequencies. Higher levels were measured for A-weighted audible sound in the forest, which is attributable to the rustling of leaves.

8.2 Sea surf

In addition to wind noise, sea surf is a widespread natural source of low-frequency noise and infrasound. The LUBW was not able to take its own measurements at the coast within the framework of this project. Therefore, currently published values shall be drawn upon in order to provide an order of magnitude. In 2012 TURNBULL, TURNER and WALSH published metrics for sea surf as a natural source of infrasound [21]. Accordingly, the G-weighted infrasound level on a beach was 75 dB(G) at a distance of 25 m from the waterline, 69 dB(G) at a distance of 250 m from a cliff, and 57 dB(G) at a distance of 8 km from the coast (***Table 8.2-1***). Near the coast, the third octave levels at different frequencies below 20 Hz were in the range of 53 dB to 70 dB (***Figure 8.2-1***).

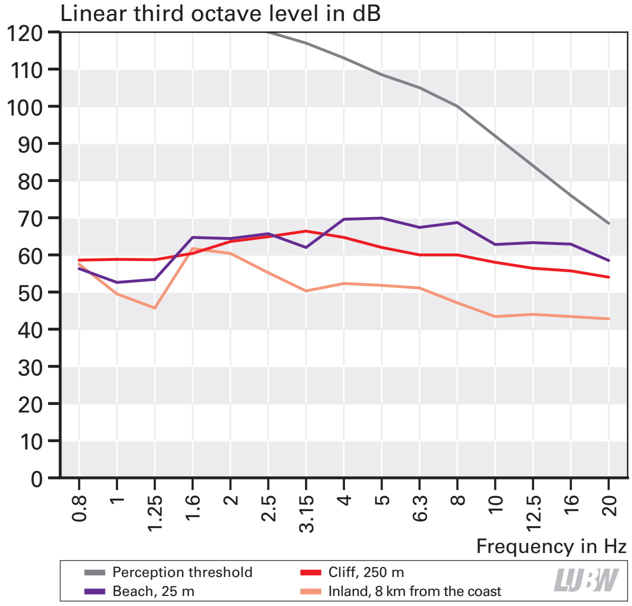


Figure 8.2-1: *Third octave spectra of the total noise of surf, different boundary conditions according to [21], perception threshold according to Table A3-1 for comparison*

Table 8.2-1: *Infrasound levels of sea surf for different boundary conditions*

Source	G-weighted level in dB(G)	Infrasound third octave level ≤ 20 Hz in dB *
Beach, 25 m from the waterline	75	53 to 70
Cliff, at distance of 250 m	69	54 to 65
Inland, 8 km from the coast	57	43 to 63

* Linear third octave level in dB(Z)

9 Design of a long-term measuring station for low-frequency noise

9.1 Task

An integral part of the measurement project "Low-frequency noise incl. infrasound from wind turbines and other sources" was the setup of a feasibility concept for a self-sufficient long-term measuring station with which to measure and document the noise situation at wind turbines. In particular, low-frequency effects were to be taken into account. When designing the concept, it was assumed that such a measuring station is to be used primarily in the context of monitoring measurements or in connection with complaint cases. Furthermore, the long-term measuring station should also provide a possibility to carry out special studies, e.g. for the determination of infrasound or sound modulations or before/after analyses. The following specifications had to be taken into account:

- DIN EN 61400-11 "Windenergieanlagen – Teil 11: Schallmessverfahren" (2013) [6]
- Technical guidelines for wind turbines, part 1, revision 18 (as of 01.02.2008, issued by FGW Fördergesellschaft Windenergie e.V.) [7]
- Technical instructions on noise abatement – "TA Lärm" (1998) [10]
- DIN 45680 "Messung von Bewertung tieffrequenter Geräuscheinwirkungen in der Nachbarschaft" (1997) [4] as well as DIN 45680 "Messung und Beurteilung tieffrequenter Geräuschimmissionen" (2013 draft) [5].

In addition, a mains voltage-independent operation of the measuring station should be ensured for a period of two to four weeks.

9.2 Concept

The design of the measuring station was to include in particular the technical equipment, the evaluation of the measured data as well as the evaluation of the results in the context of immission protection. In principle, the projected long-term measuring station is divided into the following functional modules:

- Unit for detecting the operating parameters of the wind turbine
- Meteorology measuring unit
- Noise measuring unit
- Device monitoring (remote control unit)
- Data centre (database and data analysis)

If the task requires it, the long-term measuring station could contain several similar measurement units. The basic design of a possible long-term measuring station is shown in ***Figure 9.2-1*** dargestellt.

9.3 Individual modules for data acquisition

FACILITY AND OPERATING PARAMETERS

Approximate statements regarding the operating state of a wind power plant can be derived from wind data determined near the measuring location. However, this does not apply for special operating modes of the system (e.g. low noise operation, system downtime in case of insufficient wind conditions).

Reliable results for the current performance of a wind turbine require the continuous determination of the actual turbine and operating parameters such as system power, rotor speed, nacelle angle, blade angle, wind speed and wind direction. Typically, the system operator already records these parameters as part of standard procedure. However, taking over such data from the operator into the collective of the data determined by the long-term measuring station is often difficult, if not impossible, in practice. It is therefore much more reliable, yet more bothersome, to record the turbine operation data on one's own measuring system. In order to do so, the turbine signals would have to be decoupled from the turbine control system of the wind

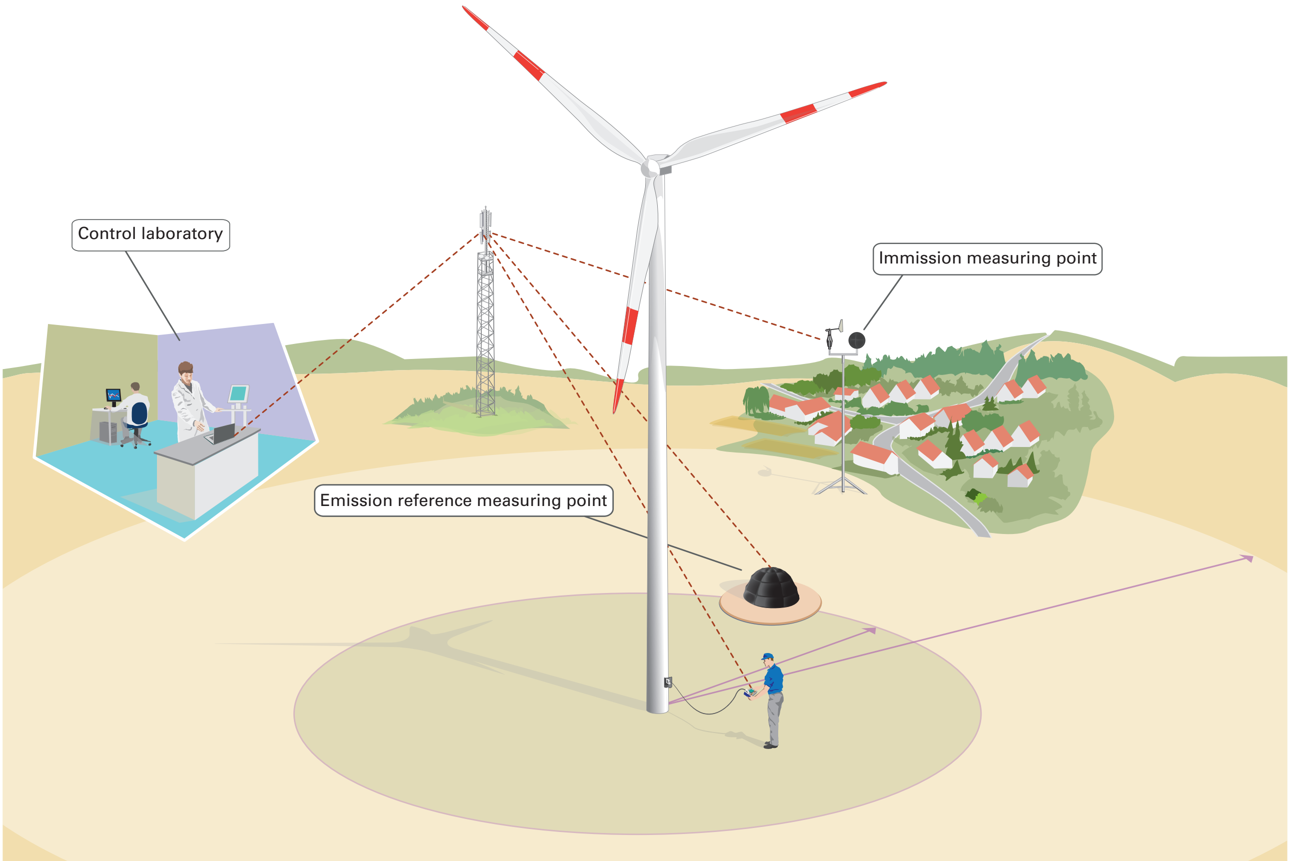


***Figure 9.2-1**: Basic design of a possible long-term monitoring station*

power plant via transducers or existing interfaces, and be registered by the appropriate data loggers. With this type of gathering of data, the data recording (sampling sequence, data formats, etc.) can be devised according to its own standard. Thus, optimal data integration into the overall system would be guaranteed. However, this would certainly require the support by trained personnel during the setup and connection of the measuring system to the turbine control.

WEATHER DATA

In addition to the noise measurement data, the meteorological variables – mean wind speed, mean wind direction (each in 10 s intervals) – as well as precipitation, air temperature and air pressure have to be determined. Commercially available weather stations (sensors and data loggers) equipped with sufficient data storage could be used for this purpose. The collected meteorological parameters are then linked with the other metrics in the data centre. If technically possible, the recording of meteorological data could already be carried out on location together with the noise measurement data in the sound level analyser. The wind data should be collected at a height of up to 10 m above ground. The respective masts that can also be used on rough terrain are provided by a number of manufacturers.

ACOUSTIC DATA

In order to measure the acoustic data, a combination of devices consisting of a standard sound level analyser and changeable microphone unit can be used. As far as necessary or appropriate, further functional units such as controller, monitoring system or meteorology recording can be included or attached. The noise measuring system is fundamentally suitable for determining emissions (DIN EN 61400-11 [6]), noise immissions (TA Lärm [10]) and low-frequency noise (DIN 45680 [4]). The following specifications must be met by the sound level analyser:

- Calibratable sound level meter according to DIN EN 61672-1:2003 [22] Class 1, with standard microphone and third octave filters according to DIN EN 61260:2003 [23] Class 1

- Usable range of levels: 18 dB(A) to 110 dB(A), usable frequency range: 1 Hz to 20 kHz
- Ongoing collection of different sound levels (L_{Aeq}, L_{AFmax}, L_{Ceq}, L_{CFmax}, $L_{TerzAeq}$, $L_{TerzAFmax}$) in periodic times of 0.1 s to 10 s
- Continuous recording of the audio signal and hourly storage as a WAV file. The data storage capacity must be sufficient for records of at least two weeks, or in the case of a restricted frequency range of the audio recording for recordings of at least four weeks
- Extensive trigger management (timed triggering and external trigger option)
- Alternatively usable infrasound microphone (lower limiting frequency ≤ 1 Hz, uncertainty at 1 Hz ≤ ± 3 dB)
- Additional weatherproof microphone plate with primary and secondary wind screens according to DIN EN 61400-11 [6]
- Additional primary and secondary wind screens for mounting on tripod or measuring mast for immission measurements according to TA Lärm [10]

DEVICE MONITORING

Ideally, the possibility should be given to monitor and control all measuring systems wirelessly via an Ethernet or GSM connection from the data centre. If permitted by the data connection, a transfer of the stored data to the data centre should also be possible.

In order to increase the transparency of the respective measuring project, a real-time display of measurement results on a publicly accessible website could also be enabled.

GENERAL REQUIREMENTS

In general, it must be possible to operate all devices of the long-term measuring station with 12 V direct voltage independently from the public power supply network. The measuring station should be equipped with the respective power supply units. A maintenance-free continuous operation of four weeks ought to be ensured. The long-term measuring station should generally be designed in a weatherproof manner. As far as necessary, all parts should be sufficiently protected from the weather (precipitation, sun, wind). Operation in an air temperature range of -5 °C to +30 °C must be made possible. The long-term measuring station must be fitted with safety features against damage by animals, against vandalism and against theft.

9.4 Central data evaluation

The evaluation of the data gathered on location and its compilation to measurement reports is generally carried out in the data centre after the end of the measurements. The nature and scope of the evaluation depends on the predefined task. The actual data evaluation can largely be carried out automatically. Analysis programmes for this purpose are commercially available. The following points should be considered for the evaluation:

- Data preparation: Individual data that is required but cannot be determined on location can be derived from the measured data or the audio recordings. (e.g. G-weighted noise levels, narrowband frequency analyses, tonalities, impulsiveness).
- Data synchronization: The individual values of the turbine data, the meteorological measurements and the acoustic measurements are to be consolidated for the same period lengths (e.g. 10 s) and to be synchronised to the same absolute points in time.
- Rectifying faults: If there is extraneous noise at the measurement point as well as noise from the wind power plant, this could lead to misinterpretations of the noise situation. The levels of the noise influenced by extraneous sources therefore must be excluded when determining the turbine noise levels. This requires a comprehensive plausibility check of all measured data for every individual case. Impulsive background noise can often be well recognized from the level curve, ongoing external noise interference can often be seen only on the basis of the level curves of individual frequency bands. When in doubt, the audio recordings will have to be referred to.

9.5 Applicability and benefits

The affected population is often rather sceptical when it comes to projected noise levels or measurements of wind turbines that are taken within a matter of hours. It is thus that the people affected often assume that the applied procedures do not take into account all facets of possible disturbances. Also, it is believed that the worst operating mode of the wind turbine is often not the basis for the noise measurements. In such cases, the use of a long-term measuring station is a good idea. In order to increase its acceptance, the general population could also be involved in the evaluation proceedings.

FIELDS OF APPLICATION

- Determination of the noise emissions and immissions caused by wind power plants subject to wind and plant operating conditions. Generation of different statistics on noise occurrence, plant parameters or wind conditions.
- Comparison of the results with the reference values and indicators in the TA Lärm and DIN 45680 [4, 5], as well as the level values used or specified in the approval procedure.
- Determination of the infrasound influencing a measurement point, possibly depending on the wind and plant operating conditions.
- Determination of noise exposure at a location before and after commissioning of wind turbines.
- Identification of specific or not regularly occurring noise or sound effects, for example implemented by complainants.
- Ultimately, the operation of such a long-term measuring station could be seen as a contribution towards the protection of the population against the harmful effects of noise, and in particular as a contribution to the pacification of the conflict situation on location.
- The use of a long-term measuring station is not suited as a means of carrying out acceptance tests. Such measurements require direct support through expert staff.

Appendix A1 – General information

The following sections provide information on infrasound and low-frequency noise in generally understandable form. This concerns the development, occurrence, spreading as well as the evaluation and perception of infrasound and low-frequency sound [15] [19] [24] [25] [26] [27] [28].

A1.1 LOW-FREQUENCY NOISE AND INFRASOUND

Put simply, sound consists of compressional waves. When such pressure fluctuations spread in the air, one refers to them as airborne noise. A human's sense of hearing is able to capture sound, the frequency (see Appendix A3) of which lies between approximately 20 Hz and 16,000 Hz (for children this value is about 20,000 Hz). Low frequencies correspond to low notes while high frequencies correspond to high notes. Sound below the audible range, i.e. with frequencies below 20 Hz, is called infrasound. Noise above the audible range, i.e. with frequencies above 20,000 Hz, is known as ultrasound. Low-frequency noise is defined as sound which is primarily within the frequency range below 100 Hz. Infrasound is thus a part of low-frequency sound.

Periodic air pressure fluctuations spread with a velocity of approximately 340 meters per second. Low-frequency vibrations have large wave lengths while high-frequency vibrations have small wave lengths. For example, the wavelength of a 20 Hz tone in air is about 17 m, while a frequency of 20,000 Hz has a wavelength of 1.7 cm (see ***Table A1-1***).

A1.2 SOUND PROPAGATION

The propagation of infrasound and low-frequency sound follows according to the same physical laws as all kinds of air-borne noise. A single sound source, such as a wind turbine generator, emits waves that spread in all directions in a spherical manner (***Figure A1-1***). As the sound energy is distributed across an ever growing area, the noise intensity decreases per square meter in an inverse proportion: With increasing distance it quickly becomes quieter (roughly 6 dB per doubling of distance). In addition, there is also the effect of absorption of sound through the air. A small part of the sound energy is converted into heat during the spread of the waves, resulting in additional absorption. This air absorption depends on the frequency: Low-frequency sound is only slightly absorbed while high-frequency is absorbed more. In comparison, the decrease of the sound level over distance significantly outweighs the decrease through air absorption. When spreading across flat surfaces, interference can occur, leading to highly fluctuating sound levels. A pressure build-up may occur in front of large obstacles leading to an increase in the sound pressure level. Standing waves may occur outdoors between the facades of buildings. Furthermore, a special feature of low-frequency sound waves is their low absorption through walls or windows, meaning that effects can also occur inside of buildings. Here too, the formation of standing waves may be the case. However, in the infrasound range these can arise only in large halls or churches; in common residential buildings the fundamental oscillations are at higher frequencies.

Table A1-1: *Relationship between frequency and wavelength for sound waves in the air*

Frequency	1 Hz	10 Hz	20 Hz	50 Hz	100 Hz	2,000 Hz
Wavelength	340 m	34 m	17 m	6.8 m	3.4 m	17 cm

LUBW

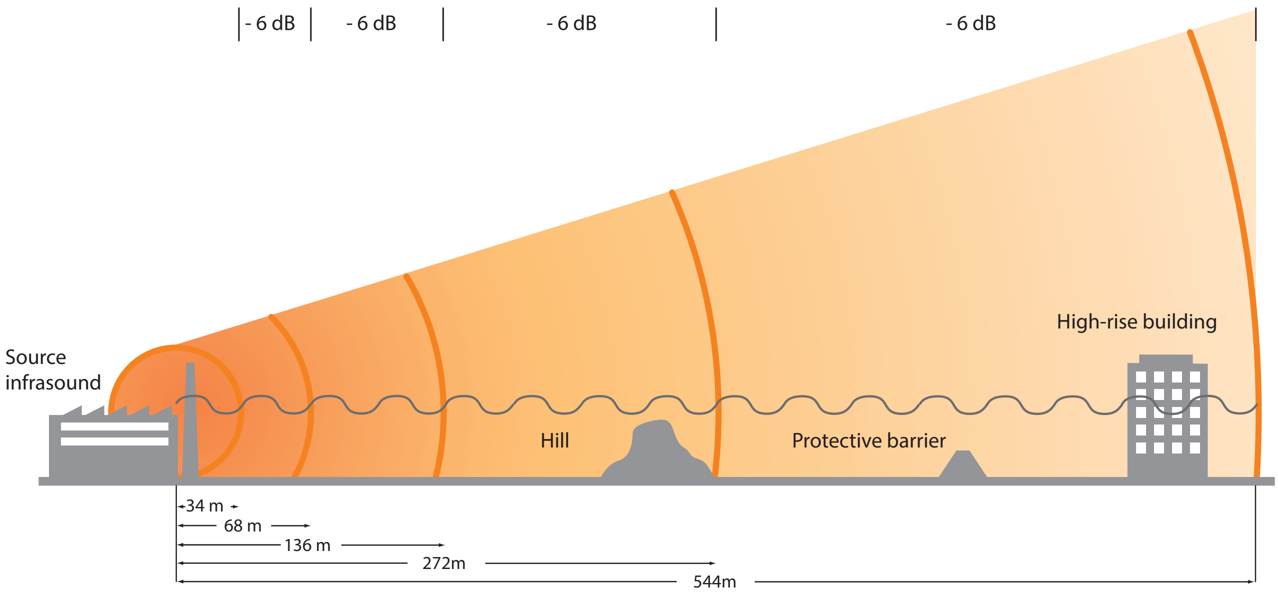


***Figure A1-1**: Exemplary presentation of spread of infrasound with a frequency of 10 Hz. The associated wavelength of 34 m is larger than the height of houses, trees and protective barriers. Therefore these hardly absorb the sound. However, the sound pressure level nevertheless decreases according to the same law as for audible sound: Each doubling of distance from the source results in a decrease in sound level of 6 dB. Image source: Bayerisches Landesamt für Umwelt [15]*

A1.3 INCIDENCE AND OCCURRENCE

Infrasound and low-frequency noise are everyday components of our environment. They are produced by a large number of different sources. These include natural sources, such as wind, waterfalls or sea surf, just as much as technical sources, such as heating and air conditioning systems, road and rail traffic, airplanes or speaker systems in nightclubs, etc.

A1.4 EVALUATION

The measurement and assessment of low-frequency noise are regulated in the technical instructions for the protection against noise (TA Lärm [10], please refer to Chapter 7.3 and Appendix A1. 5) as well as the standard DIN 45680 [4]. The impact of noise can be safely determined on the basis of these regulations. In this case the frequency range from 8 Hz to 100 Hz is considered. The crucial aspect when it comes to possible noise pollution is the human hearing threshold or perception threshold, which is outlined in the standard. See also the next section.

An own frequency weighting, the so-called G-weighting, exists for the area of infrasound. The relevantly weighted levels are specified as dB(G) – "decibel G". The A-weighting of noise dB(A) – "decibel A" – is more common, which is derived from human hearing. The G-weighting is focused at 20 Hz. Levels are amplified between 10 Hz and 25 Hz. Above and below that, the valuation curve quickly falls. The purpose of G-weighting is to characterise a situation regarding low frequencies or infrasound with only a single number. A disadvantage is that frequencies below 8 Hz and above 40 Hz hardly contribute at all. For more information please refer to "Frequency Evaluation" in Appendix A3, where you will also find an evaluation curve (***Figure A3-1***).

A1.5 PERCEPTION

In the area of low-frequency noise below 100 Hz there is a smooth transition from hearing, i.e. the sensations of volume and pitch, to feeling. Here the quality and nature of the perception changes. The pitch sensation decreases and does not apply at all for infrasound In general, the following applies: The lower the frequency, the higher the

***Table A1-2**: Hearing and perception threshold (in decibels) in the range of infrasound. The lower the frequency, the louder the noise or sound intensity has to be in order for a person to perceive something. At 8 Hz the sound pressure level has to be at 100 decibels. Humans can hear best in the area of 2,000 to 5,000 Hz. That is where the average hearing threshold is at 0 decibels and even below it (up to minus 5 decibels).*

Frequency (as a third octave centre frequency)	8 Hz	10 Hz	12.5 Hz	16 Hz	20 Hz
Hearing threshold according to DIN 45680 (1997) [4]	103 dB	95 dB	87 dB	79 dB	71 dB
Perception threshold according to draft DIN 45680 (2013) [5]	100 dB	92 dB	84 dB	76 dB	69 dB

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sound intensity has to be so that the noise is heard at all (see ***Table A1-2***). Low-frequency impact with high intensity is often perceived as ear pressure and vibrations. Permanent exposure to such high noise levels can lead to buzzing, vibrating sensations or a feeling of pressure in the head. In addition to the sense of hearing, other sensory organs can also register low-frequency sound. For example, the sensory cells of the skin convey pressure and vibration stimuli. Infrasound can also affect cavities in the body, such as lungs, sinuses and middle ear. Infrasound of very high intensity has a masking effect for the middle and lower acoustic range. That means: In the case of very strong infrasound, your hearing is unable to perceive quiet tones in frequencies above it.

But where are the limits between hearing, feeling and "no longer perceiving"? ***Table A1-2*** shows some levels of the hearing and perception thresholds for different frequencies. The hearing threshold of DIN 45680 (1997) [4] is defined in such a way that 50 % of the population will no longer perceive the respective frequency below the specified level. The perception threshold of DIN 45680 (2013) [5] is defined so that 90 % of people will no longer perceive the sound below this level. The limit from which low-frequency sound can be heard, varies from person to person. This is nothing unusual, as it is similar to what we are accustomed to regarding audible sound in everyday life. For almost 70 % of people, the hearing threshold lies in a range of ± 6 dB around the values shown in ***Table A1-2***. For particularly sensitive individuals, who make up around two to three percent of the total population, the hearing threshold is at least 12 dB lower. ***Figure A1-2*** provides a graphic depiction of the relationship of the two thresholds. The differences are relatively small.

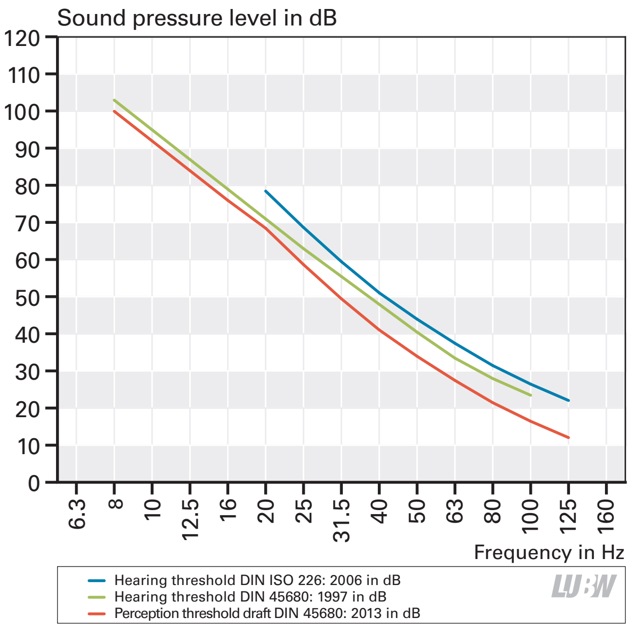

***Figure A1-2**: Representation of hearing and perception threshold according to ISO 226 [29], DIN 45680 (1997) [4] and draft DIN 45680 (2013) [5]. The perception threshold according to the draft of DIN 45680 is roughly 10 dB lower than the values of ISO 226.*

Laboratory tests on the impact of infrasound have shown that high intensities above the perception threshold are tiring and have an adverse effect on concentration, and can influence performance. The best proven reaction by the body is increasing fatigue after several hours of exposure. The balance system can also be affected. Some test persons had feelings of insecurity and anxiety, while others displayed a reduced respiratory rate. Furthermore, as is the case with audible sound, very high sound intensities can lead to a temporary hearing impediment – an effect often known by people who go to nightclubs. Long-term exposure to strong infrasound can also lead to permanent hearing loss. However, the infrasound levels that occur in the vicinity of wind power plants will hardly be able to cause any such effects, as they fall far short of the hearing or perception threshold. In scientific literature, any health effects could so far be shown only at sound levels above the hearing threshold. Below the hearing threshold, no effects on humans caused by infrasound could so far be proven [25].

Exhibit A38-6

Appendix A2 – Sources and literature

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Appendix A3 – Explanation of terms and parameters

A-weighting

Frequency-dependent alteration of a noise or sound signal by means of A filter according to DIN EN 61672-1:2003 [22]. See also frequency weighting and dB(A).

Averaging level

See sound pressure level

Background noise

Noise with the wind power plant switched off. It consists particularly of the sound caused by wind in the vicinity and of noise coming from other sources of noise in the vicinity. The background noise may also include sound induced by the wind at the microphone. Also referred to in the report as the operating condition "turbine off".

C-weighting

Frequency-dependent alteration of a noise or sound signal by means of C filter according to DIN EN 61672-1:2003 [22]. See also frequency weighting and dB(C).

dB

Decibel, unit of measurement for the identification of levels, in this case sound pressure level (quod vide).

dB(A)

Decibel A, unit of sound pressure level in A-weighting. See also sound pressure level and A-weighting.

dB(C)

Decibel C, unit of sound pressure level in C-weighting. See also sound pressure level and C-weighting.

dB(G)

Decibel G, unit of sound pressure level in G-weighting. Is used particular with low-frequency noise incl. infrasound. See also sound pressure level and G-weighting.

dB(Z)

Decibel Z, unit of sound pressure level in Z-weighting that corresponds to the linear sound pressure level unweighted in terms of frequency. Formerly also referred to as dB(lin).

Emission

See sound emission

Extraneous noise

Noise that is not caused by the turbine being measured and can temporarily lead to an increase of background noise. Disturbing extraneous noise is excluded from the evaluation by placing markers, and is therefore included neither in the represented total noise nor in the background noise.

Frequency

Number of oscillations per second; the unit is hertz (Hz). The total audible frequency range is divided into:

- Infrasound: Sound with frequencies below 20 Hz
- Audible sound: Sound in the range of 20 Hz to about 16,000 Hz (limit is age-dependent)
- Ultrasound: Sound above roughly 16,000 Hz
- Low-frequency sound: Sound at frequencies below 100 Hz, including infrasound

Frequency weighting (noise)

The frequency content of noise is weighted differently according to the specific objective. In addition to the generally usual A-weighted and C-weighted noise levels, G-weighted and Z-weighted noise levels are also determined and represented in this study.

By default, the frequency weighting A is used for the valuation of sound signals in the normal audible sound range. It approximately constitutes the hearing sensitivity of the human ear in the low and medium sound intensity level. The description and assessment of noise emission and immissions generally follows by means of A-weighted levels. The evaluation of low-frequency noise including infrasound requires separate restrictions of the frequency ranges; A-weighted sound levels that are determined across the entire frequency band are unsuitable for this.

The frequency weighting C approximately corresponds to the auditory sensation of the ear at high volumes. It is applied in particular when assessing noise level peaks in the scope of occupational safety and health. In addition, the

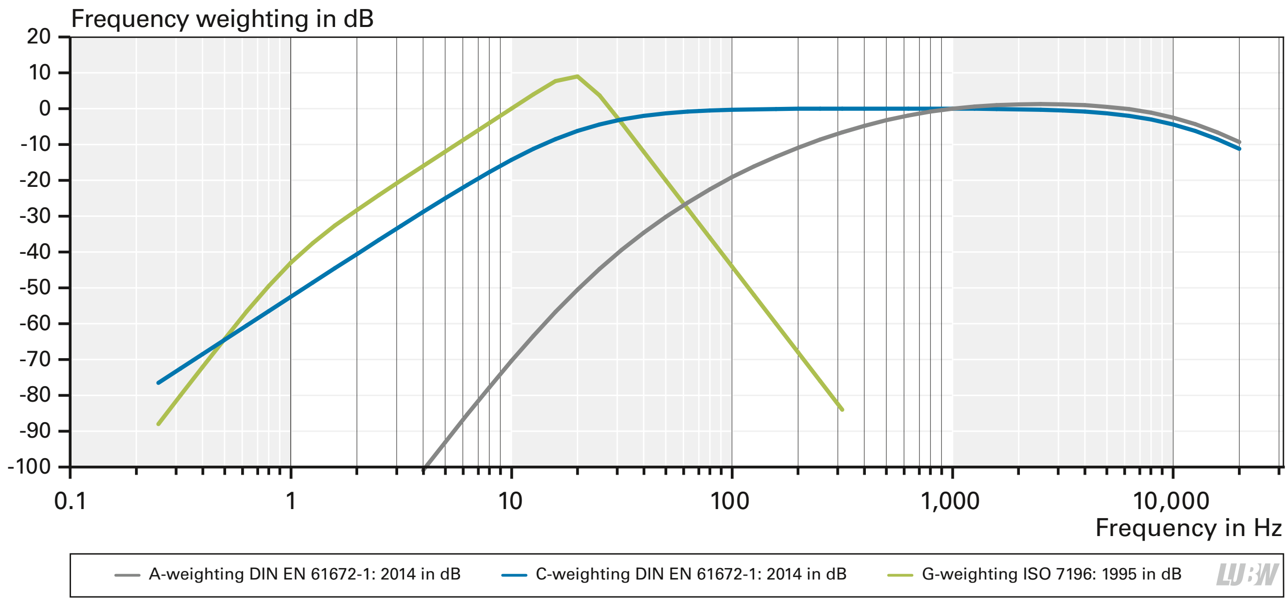

***Figure A3-1**: Course of the frequency weighting curves A, C and G in the range below 500 Hz according to ISO 7196 and DIN EN 61672-1 (2013) [22]*

level difference of measured C-weighted and A-weighted levels is seen as an indicator for possible low-frequency noise contamination in the area of immission control.

The frequency weighting G is a filter that was defined for the effect adaptation of infrasound. Its focus lies at 20 Hz (see Figure A3-1). However, no relevant reference or comparative values are known for the quantitative classification of any infrasound effects or determined G-weighted levels.

The frequency weighting Z (zero) describes a linear band pass filter without any effect on the frequency.

Frequency spectrum

See spectral analysis

G-weighting

Frequency-dependent change of noise or sound signal using G filter according to ISO 7196:1995 [30]. See frequency weighting and dB(G).

Hearing threshold

See Appendix A1.5

Immission

See sound immission

Infrasound

See Appendix A1.1

Level

Logarithm of the relationship of two identical sizes. For the sound pressure level, the ratio of sound pressure, which is caused by noise, to a fixed reference size (hearing threshold) is formed. See also sound pressure level.

L_{eq}

Energy equivalent average of the (time-varying) sound pressure level course within a reference period. See also sound pressure level.

L_{max}

Maximum sound pressure level in a measurement interval. See also sound pressure level.

Low-frequency sound

See Appendix A1.1

Narrowband spectrum

See spectral analysis

Noise

Noise can be considered unwanted, disturbing or harassing sound. While sound can be well-measured and characterized as a physical phenomenon, human feelings also play a part when it comes to noise.

Operating noise

Noise with wind turbine switched on, including background noise. Is referred to as total noise throughout the report.

Perception threshold

The perception threshold used in this report is composed of the perception threshold according to Table 2 in DIN 45680 (2013 draft) [5] and values from literature.

The values of the draft standard are based on DIN ISO 226 [29]; they are 10 dB below the hearing threshold specified therein. For frequencies of 8 Hz to 20 Hz they are supplemented by the values determined by WATANABE & MØLLER [34]. The course corresponds to the 90 % percentile of audible threshold distribution.

Since no standardized threshold levels exist in the frequency range below 8 Hz, the values of the hearing threshold proposed by MØLLER & PEDERSEN [11, Figure 10] were taken for the representations in this measurement report in the range of 1.6 Hz to 8 Hz (***Table A3-1***).

Sound

Put simply, sound consists of compressional waves. Airborne sound is the propagation of pressure fluctuations in the air as a wave motion. If this happens in solid materials, e.g. the floor or walls, it is called structure-borne sound. In order to characterize sound, variables such as sound level (characterizes the strength of the sound) or frequency (denotes the pitch) are used.

Sound emission

The noise coming from a turbine in accordance with § 3 para. 3 BImSchG [2]

Sound immission

The noise effecting humans, animals, etc. in accordance with § 3 para. 2 BImSchG [2]

Sound pressure level L

Often simply referred to as sound level. 20-fold decimal logarithm of the ratio of a given effective value of sound pressure to a reference sound pressure (e.g. hearing threshold), where the effective value of the sound pressure is determined with a standard frequency and time weighting (L in dB). Sound pressure levels of the normal range of hearing are determined primarily by the frequency weighting A and the time rating F according to DIN EN 61672-1 [22] (see also frequency weighting). The types of frequency and time weightings are usually indicated as indices of the formula sign, e.g. L_{AF} in dB(A). The definition of the sound pressure level L for a sound pressure p is:

$$L = 10 \cdot lg \frac{p^2}{p_0^2} (dB) = 20 \cdot lg \frac{p}{p_0} (dB)$$

Here p_0 is a reference sound pressure in the region of the hearing threshold, defined as $2 \cdot 10^{-5}$ Pa. Sound level differences of 1 dB are only just recognisable, differences of 3 dB can be heard clearly. Sound level differences of 10 dB correspond to roughly double or half the impression of loudness respectively.

- The addition of two identical sound levels (doubling of the sound power) leads to an increase of the sum level by 3 dB.
- The reduction of a road's traffic volume by half results in a 3 dB lower level.
- In the case of a single point source, a doubling of distance leads to a reduction of the sound level by 6 dB.

The instantaneous sound pressure level is the current level value of a time-varying noise, for example specified as $L_{AF}(t)$ in dB(A).

The maximum sound pressure level or maximum level is the maximum value of the fluctuating sound pressure level curve within a reference period, referred to as L_{max} in dB. For the frequency weighting A and the time rating F, the level is referred to as L_{AFmax} and specified in dB(A).

The average sound level or equivalent continuous sound level L_{eq} is the energy equivalent mean value of the temporally variable sound pressure level curve L(t) within a reference period, expressed in dB. It is formed according to DIN 45641 [31] or directly with a measuring instrument according to DIN EN 61672-1 [22]. For the frequency weighting A and time weighting F, the time-average sound pressure level is referred to as L_{AFeq} and expressed in dB(A).

Spectral analysis

Spectral analysis is an important tool for the analysis of acoustic signals. The signal is fragmented into defined frequency bands and a sound level is determined for each individual band. A distinction is made between frequency bands of absolute and relative bandwidth.

In the case of narrowband spectra, the frequency range that is to be analysed is divided up into bands of the same absolute width. Here in this report, a bandwidth of 0.1 Hz was consistently used. That enabled a high resolution depiction of the frequency spectra of the sound signal.

Octave and third octave spectra (1/3-octave spectra) are composed of frequency bands of relative bandwidth. The centre frequency of an octave band has a ratio of 1:2 to the centre frequency of the adjacent bands; third octave bands have a ratio of 1:1.26. The starting value for the determination of the centre frequencies is the frequency of 1,000 Hz. The frequency bandwidths within octave or third octave spectra thus differ. The third octave centre frequencies from 1 Hz are: 1 Hz, 1.25 Hz, 1.6 Hz, 2 Hz, 2.5 Hz, 3.15 Hz, 4 Hz, 5 Hz, 6.3 Hz, 8 Hz, 10 Hz, 12.5 Hz, 16 Hz, 20 Hz, 25 Hz, 31.5 Hz, 40 Hz, 50 Hz, 63 Hz, 80 Hz, 100 Hz, 125 Hz etc. – see also [23].

Third octave representation

Representation of a sound signal in a frequency spectrum. See also spectral analysis and third octave spectrum.

Third octave level

Sound pressure level within a third octave frequency band. See also spectral analysis.

Third octave spectrum

Frequency spectrum in which the frequency range and the corresponding level proportions are divided into thirds. See also spectral analysis.

Total noise

Noise with wind turbine switched on, including background noise. Also referred to in the report as the operating condition "turbine on".

Turbulence intensity

The turbulence intensity (also known as degree of turbulence) was here formed from the average of the quotients of standard deviation and arithmetic mean of the wind speed. It is a measure of the variation of the wind speed (gusts). The turbulence intensity is given in percent and is subject to many influences, e.g. ground roughness, medium wind speed, atmospheric situation or buildings. Its lowest values (5 % or less) are reached over the sea, the highest (20 % or more) are reached over built-up areas and forest [32]. While the turbulence intensity has no significant effect on measurements in the A level range (audible sound) [33], this is not documented for low frequencies. Here an influence can by all means be expected. Some manufacturers of wind turbines link the warranty condition for their guaranteed values of acoustic power to maximum turbulence intensities during measurement, e.g. 16 %. The turbulence intensity is determined in accordance with DIN EN 61400-11 [6].

Vibrations

Vibrations are oscillations of solid bodies.

Vibrational immissions

Vibrational immissions are the oscillations that occur at the measurement point.

Vibration velocity

The vibration velocity (speed) is the velocity of an oscillating mass at the measurement point in the predetermined measurement direction, stated in millimetres per second (mm/s). This variable is based on the assessment of vibration impacts on buildings and on people in buildings. The vibration is defined initially through the ground motion, i.e. the vibration displacement (amplitude), characterized as a function of time. The vibration velocity can then be derived by differentiating with respect to time.

Table A3-1: *The hearing threshold levels used to represent the perception threshold in the report according to [5] and [11]*

Source	Third octave centre frequency in Hz	Perception threshold level W_{Terz} in dB
Threshold level - taken from [11]	1.60 2.00 2.50 3.15 4.00 5.00 6.30	124.0 122.0 120.0 117.0 113.0 108.5 105.0
Threshold level - taken from [5]	8.0 10.0 12.5 16.0 20.0 25.0 31.5 40.0 50.0 63.0 80.0 100.0 125.0	100.0 92.0 84.0 76.0 68.5 58.7 49.5 41.1 34.0 27.5 21.5 16.5 12.1

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Vibration severity

In the vibration frequency range of 1 Hz to 80 Hz that is relevant for the perception of vibration, the perceptibility is proportional to the vibration velocity. Below approximately 10 Hz, the perception at lower frequencies is significantly lower. This is taken into account for the evaluation of measurement data through the use of special filtering, the so-called KB-evaluation according to DIN 4150 Part 2. Inputs above 80 Hz are cut off by a blocking filter (band limitation) as they do not contribute to perception. The band-limited, frequency and time-weighted signal is designated as weighted vibration severity $KB_F(t)$. The highest value achieved during the assessment time, the maximum weighted vibration strength KB_{Fmax}, is an important evaluation parameter for the tactility of vibration effects.

Wavelength

For a wave (here acoustic wave), the distance from a "wave crest" to the next "wave crest" or "trough" to "trough" is referred to as wavelength (general distance from one point to the next point of the same phase). The wavelength is related to the frequency as follows: The wavelength is the propagation speed divided by the frequency of the wave. Sound waves in air can generally be registered by the human ear in the approximate wavelength range of 2 cm to about 20 m.

Z-weighting

Unweighted or linear noise or sound signal according to DIN EN 61672-1:2003 [22]. See frequency weighting and dB(Z).

Appendix A4 – Measuring systems used

Below is a description of the used measurement systems and equipment. The sound level measuring instruments used meet the specifications for Class 1 for sound level meters according to IEC 61672. The dynamic range of the microphone capsule type 40AZ is 14 dB(A) to 148 dB according to the manufacturer, the usable frequency range is 0.5 Hz to 20 kHz. For the remaining microphone capsules used, the usable frequency range is 3.15 Hz to 20 kHz.

Measurements at wind turbines (Section 4)

- 4 sound level meter combinations DUO Smart Noise Monitor, consisting of:
  - Sound level analyser type DUO, manufacturer: 01dB Metravib SAS, F-69760 Limonest
  - Free-field microphone 1/2" type 40AZ on reverbrant plate with primary and secondary wind screen in accordance with IEC 61400-11, manufacturer: G.R.A.S. Sound & Vibration A/S, DK-2840 Holte

- 1 meteorology sensor, consisting of:
  - Air pressure, humidity and temperature sensor type DTF 485, manufacturer: Reinhardt System- und Messelectronic GmbH, D-86911 Diessen-Obermühlhausen
  - Wind sensor type WMT 701, manufacturer: Vaisala GmbH, D-22607 Hamburg

- 1 acoustic emission measurement system type RoBin, manufacturer: Wölfel Meßsysteme, D-97204 Höchberg

- 4 vibration meters type SM 6 (triaxial) according to DIN 45669, consisting of:
  - Sensor Nederland / Wölfel Meßsysteme
  - Supply and AD conversion: System Red Sens with radio modules
  - Coupling of the measuring sensors according to DIN 45669-2. The measuring chain was checked before and after the measurement.

- 1 data acquisition system, consisting of:
  - Notebook Dell Latitude with Elovis radio antenna for Red Sens
  - Measurement and evaluation software MEDA
  - Sampling: upper limit frequency, 400 Hz corresponds to sampling rate of 976.6 μs, manufacturer: Wölfel Meßsysteme, D-97204 Höchberg

Road traffic measurements (Section 5.1)

- 1 sound level meter combinations DUO Smart Noise Monitor, consisting of:
  - Sound level analyser type DUO, manufacturer: 01dB Metravib SAS, F-69760 Limonest
  - Free-field microphone 1/2" Type 40AZ on reverberant plate with primary and secondary wind screen in accordance with IEC 61400-11, manufacturer: G.R.A.S. Sound & Vibration A/S, DK-2840 Holte

- 2 sound level meter combinations DUO Smart Noise Monitor, consisting of:
  - Sound level analyser type DUO, manufacturer: 01dB Metravib SAS, F-69760 Limonest
  - Free-field microphone 1/2" type 40AZ, manufacturer: G.R.A.S. Sound & Vibration A/S, DK-2840 Holte

- 1 meteorology sensor, consisting of:
  - Air pressure, humidity, temperature and wind sensor type WXT 520, manufacturer: Vaisala GmbH, D-22607 Hamburg

LUBW Long-term measuring stations (Section 5.2)

- 2 sound level meter combinations DUO Smart Noise Monitor, consisting of:
  - Sound level analyser type DUO, manufacturer: 01dB Metravib SAS, F-69760 Limonest
  - Free-field microphone 1/2" type 40CD, manufacturer: G.R.A.S. Sound & Vibration A/S, DK-2840 Holte

- 2 meteorology sensors, consisting of:
  - Precipitation monitor model 5.4103.10.00, manufacturer: Adolf Thies GmbH & Co. KG, D-37083 Göttingen
  - Temperature and humidity sensor type HMP 155, manufacturer: Vaisala GmbH, D-22607 Hamburg

- Ultrasonic aemometer type 85004, manufacturer: R. M. Young Company, USA-2801 Aero Park Drive

Measurements at motorway (Section 5.3)

- 3 sound level meters combinations type NOR 140, consisting of:
  - Sound level analyser type Nor 140, manufacturer: Norsonic AS, N-3421 Lierskogen
  - Free-field microphone 1/2" type 1225, manufacturer: Norsonic AS, N-3421 Lierskogen

Interior noise measurements car, minibus (Section 5.4)

- 1 sound level meter combination type NOR 140, consisting of:
  - Sound level analyser type Nor140, manufacturer: Norsonic AS, N-3421 Lierskogen
  - Free-field microphone 1/2" type 1225, manufacturer: Norsonic AS, N-3421 Lierskogen

Urban background measurements (Section 6)

- 2 sound level meter combinations type DUO Smart Noise Monitor, consisting of:
  - Sound level analyser type DUO, manufacturer: 01dB-Metravib SAS, F-69760 Limonest
  - Free-field microphone 1/2" type 40AZ on reverberant plate with primary and secondary wind screen in accordance with IEC 61400-11, manufacturer: G.R.A.S. Sound & Vibration A/S, DK-2840 Holte

- 1 sound level meter combination DUO Smart Noise Monitor, consisting of:
  - Sound level analyser type DUO, manufacturer: 01dB-Metravib SAS, F-69760 Limonest
  - Free-field microphone 1/2" type 40AZ, manufacturer: G.R.A.S. Sound & Vibration A/S, DK-2840 Holte

- 1 meteorology sensor, consisting of:
  - Air pressure, humidity, temperature and wind sensor type WXT 520, manufacturer: Vaisala GmbH, D-22607 Hamburg

Measurements in a residential building (Section 7)

- 1 sound level meter combination type NOR 140, consisting of:
  - Sound level analyser type Nor 140, manufacturer: Norsonic AS, N-3421 Lierskogen
  - Free-field microphone 1/2" type 40AZ, manufacturer: G.R.A.S. Sound & Vibration A/S, DK-2840 Holte

- 1 sound level meter combination type NOR 140, consisting of:
  - Sound level analyser type Nor 140, manufacturer: Norsonic AS, N-3421 Lierskogen
  - Free-field microphone 1/2" type 1225, manufacturer: Norsonic AS, N-3421 Lierskogen

Measurements in rural area (Section 8.1)

- 2 sound level meter combinations DUO Smart Noise Monitor, consisting of:
  - Sound level analyser type DUO, manufacturer: 01dB Metravib SAS, F-69760 Limonest
  - Free-field microphone 1/2" Type 40AZ on reverberant plate with primary and secondary wind screen in accordance with IEC 61400-11, manufacturer: G.R.A.S. Sound & Vibration A/S, DK-2840 Holte

- 1 sound level meter combinations DUO Smart Noise Monitor, consisting of:
  - Sound level analyser type DUO, manufacturer: 01dB Metravib SAS, F-69760 Limonest
  - Free-field microphone 1/2" type 40AZ on reverberant plate with primary and secondary wind screen in accordance with IEC 61400-11, manufacturer: G.R.A.S. Sound & Vibration A/S, DK-2840 Holte

- 1 meteorology sensor, consisting of:
  - Air pressure, humidity, temperature and wind sensor type WXT 520, manufacturer: Vaisala GmbH, D-22607 Hamburg

Note on the inherent noise of the measuring chain

In order to determine the minimum noise limit of the deployed acoustic measuring chain, sound level measurements were carried out inside buildings at two different locations during the night. The locations were chosen so that the least possible background noise was at hand. The measured values in the range of 1 Hz to 1 kHz are at least 20 dB below the sound levels to be determined here. The influence of the inherent noise of the measuring chain on the measurement results is therefore negligible.

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The Pattern of Complaints about Australian Wind Farms Does Not Match the Establishment and Distribution of Turbines: Support for the Psychogenic, 'Communicated Disease' Hypothesis

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Abstract

Background and Objectives: With often florid allegations about health problems arising from wind turbine exposure now widespread, nocebo effects potentially confound any future investigation of turbine health impact. Historical audits of health complaints are therefore important. We test 4 hypotheses relevant to psychogenic explanations of the variable timing and distribution of health and noise complaints about wind farms in Australia.

Setting: All Australian wind farms (51 with 1634 turbines) operating 1993–2012.

Methods: Records of complaints about noise or health from residents living near 51 Australian wind farms were obtained from all wind farm companies, and corroborated with complaints in submissions to 3 government public enquiries and news media records and court affidavits. These are expressed as proportions of estimated populations residing within 5 km of wind farms.

Results: There are large historical and geographical variations in wind farm complaints. 33/51 (64.7%) of Australian wind farms including 18/34 (52.9%) with turbine size >1 MW have never been subject to noise or health complaints. These 33 farms have an estimated 21,633 residents within 5 km and have operated complaint-free for a cumulative 267 years. Western Australia and Tasmania have seen no complaints. 129 individuals across Australia (1 in 254 residents) appear to have ever complained, with 94 (73%) being residents near 6 wind farms targeted by anti wind farm groups. The large majority 116/129(90%) of complainants made their first complaint after 2009 when anti wind farm groups began to add health concerns to their wider opposition. In the preceding years, health or noise complaints were rare despite large and small-turbine wind farms having operated for many years.

Conclusions: The reported historical and geographical variations in complaints are consistent with psychogenic hypotheses that expressed health problems are "communicated diseases" with nocebo effects likely to play an important role in the aetiology of complaints.

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Introduction

The attribution of symptoms and disease to wind turbine exposure is a contentious "modern health worry" [1] which has seen increasing attention from governments, their regulatory agencies and courts after organised opposition to wind farms, predominantly in Anglophone nations. Two broad hypotheses have been advanced about those reporting symptoms they attribute to exposure to wind turbines.

1. both audible noise and sub-audible infrasound generated by wind turbines can be directly harmful to the health of those exposed.
2. psychogenic factors – including nocebo responses to the circulation of negative information about their putative harms – are likely to be relevant to understanding why of those exposed, only small proportions claim to be adversely affected.

The evidence for a physical basis for these symptoms remains largely anecdotal. There has been a profusion of claims mostly by wind farm opponents about harms to exposed humans and animals (currently numbering 223 different diseases and symptoms) [2]. Despite this, 18 reviews of the research literature on wind turbines and health published since 2003 [3–20] have all reached the broad conclusion that the evidence for wind turbines being directly harmful to health is very poor. These suggest that only small minorities of exposed people claim to be annoyed by wind turbines – typically less than 10% [14]. They conclude that the relationship between wind turbines and human responses is ''influenced by numerous variables, the majority of which are non-physical'' [14].

Variables associated with wind turbine annoyance include pre-existing negative attitudes to wind farms [14], including their impact on landscape aesthetics [21], having a ''negative personality'' [22], subjective sensitivity to noise [14], and being able to see wind turbines [5,23]. Similarly, deriving income from turbines [24] or enjoying reduced power bills can have an apparent ''protective effect'' against annoyance and health symptoms [18]. Such factors, which are similar to characteristics of other psychogenic illnesses (''New Environmental Illnesses'' [25] and ''Modern Health Worries'' [26]) were found to be more predictive of symptoms than objective measures of actual exposure to sound or infrasound [14].

A large literature on nocebo effects exists about reported pain [27], but these effects have also been documented for other imperceptible agents such as electro-magnetic and radio frequency radiation [28–30]. Perceived proximity to mobile telephone base stations and powerlines, lower perceived control and increased avoidance (coping) behaviour were associated with non-specific physical symptoms in a study which found no association between reported symptoms and distance to these sources of electromagnetic radiation [31].

The psychogenic theory about wind turbine ''illness'' is supported by a recent New Zealand study [32], in which healthy volunteers exposed to both sham and true recorded infrasound who had been previously given information about possible adverse physiological effects of infrasound exposure reported symptoms aligned with that information. The adverse effects information provided to subjects was sourced from anti wind farm internet sites which the authors concluded indicated ''the potential for symptom expectations to be created outside of the laboratory, in real world settings.''

A psychogenic contagion model may be applicable to this phenomenon. Mass Psychogenic Illness (MPI) is described [33–35] as a constellation of somatic symptoms, suggestive of an environmental cause or trigger (but with symptoms without typical features of the contaminant, varying between individuals, and not related to proximity or strength of exposure) which occurs between two or more people who share beliefs related to those symptoms and experience epidemic spread of symptoms between socially connected individuals. The rapid development of fear and anxiety is key to the transmission of disease by disruption of behaviour and activities of those involved. Transmission or contagion is increased by the general excitement related to the phenomenon, including media reports, researcher interest, and labeling with a specific clinical diagnostic term.

Boss' review of factors promoting mass hysteria noted that ''media reports are used as cues by potential cases for appropriate illness behavior responses and can initially alarm those at risk …Too often, it is the media-created event to which people respond rather than the objective situation itself … Development of new approaches in mass communication, most recently the Internet, increase the ability to enhance outbreaks through communication.'' [33].

While modern wind farms have operated since the early 1980s [36], the earliest claims alleging that wind turbines might cause health problems in those exposed appear to date from 2003 (see below); this increased rapidly after 2008, following publicity given to a self-published book, ''Wind Turbine Syndrome'' [37], by US physician Nina Pierpont, whose partner edits a virulent anti wind farm website [38]. Google Trends data of web-based searches for ''Wind turbine noise'', ''Wind Turbine Syndrome'' and ''wind turbine health'' show that ''noise'' began to appear from 2007 and that ''syndrome'' and ''health'' began to track together from 2008, suggesting the book generated this sudden interest in the phenomenon, rather than riding a wave of interest. Furthermore, a 2007–11 Ontario study of newspaper coverage of wind farms showed that 94% of articles featured ''dread'' themes [39].

''Labeling'' of an illness is one of the key features associated with spread of mass psychogenic illness, along with community and media interest [33]. There have been three attempts to popularise portentous quasi-scientific names for health problems said to be caused by wind turbines: Wind Turbine Syndrome, Vibro Acoustic Disease [40] and Visceral Vibratory Vestibular Disturbance [41], although none of these have gained scientific acceptance as diagnostic terms. As described earlier, many features of MPI apply to Wind Turbine Syndrome. Furthermore, the most reported symptoms in over one third of all MPIs of nausea/vomiting, headache, and dizziness [33], are also frequently featured as common symptom complaints arising with wind turbines, suggesting these symptoms may be plausibly explained as psychogenic.

Wind farm opponent groups have been very active in the last five years in three Australian states (Victoria, NSW and South Australia) publicising the alleged health impacts of turbines. This has created insurmountable problems for researching the psychogenic and nocebo hypotheses using either cross-sectional or prospective research designs because it is unlikely that any communities near wind farms now exist which have not been exposed to extensive negative information. For this reason, audits of the history of complaints are essential because they allow consideration of whether health and noise complaints arose during years prior to the ''contagion'' of communities with fearful messages about turbines.

To date, there has been no study of the history and distribution of noise and health complaints about wind turbines in Australia. The two theories (the ''direct effects'' and the ''psychogenic''), would predict differing patterns of spatial and temporal spread of disease. We sought to test 4 hypotheses relevant to the psychogenic argument.

1. Many wind farms of comparable power would have no history of health or noise complaints from nearby residents (suggesting that exogenous factors to the turbines may explain the presence or absence of complaints).
2. Wind farms which have been subject to complaints would have only a small number of such complaining residents among those living near the farms (suggesting that individual or social factors may be required to explain different ''susceptibility'').
3. Few wind farms would have any history of complaints consistent with claims that turbines cause acute health problems (suggesting that explanations beyond turbines themselves are needed to explain why acute problems are reported).
4. Most health and noise complaints would date from after the advent of anti wind farm groups beginning to foment concerns about health (from around 2009) and that wind farms subject to organised opposition would be more likely to have histories of complaint than those not exposed to such opposition (suggesting that health concerns may reflect ''communicated'' anxieties).

Table 1 sets out both the predictions of the ''direct effects'' model of causation, and the observed findings of our historical

Table 1. Prediction of "direct effects" model versus observations explained by psychogenic model.

Key hypotheses re distribution of complainants	Characteristic	Predictions of Direct Effects Model	Observations with Psychogenic Model
Spatial (geographic)	Distribution of wind farms with complainants	All wind farms (especially those with >1 MB turbines) should have complainants	Inconsistent distribution associated with presence or absence of anti wind farm activity
	Proportion of complainants residing around wind farms	Only in those "susceptible" but should be similar across all wind farms	Generally very low, but higher at wind farms targeted by anti wind farm groups
Temporal	Timing and latency of first complaints	Turbine exposure followed by both acute (immediate) and chronic health effects	Absence of or long delays in reporting acute effects common

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review of the distribution and timing of complaints, which are more consistent with a psychogenic model.

Methods

Information on the commencement of turbine operation, the number of turbines operating, average turbine size and the megawatt (MW) capacity of each wind farm was located from public sources such as wind farm websites.

Wind farm operators have clear risk management interest in any reactions of nearby residents to the farms they operate. In the planning, construction and power generation phases of wind farm operation they monitor local community support and complaints submitted to them, in news media and via any complaint notifications from local government. In Victoria, companies are required by law to register all complaints with the state government. In September 2012 all wind farm owners in Australia were asked to provide information on:

- the actual or estimated number of residents within a 5 km radius of each wind farm they operated. Google Maps and census data were also used to obtain this data (see below).
- whether the company had received or was aware of any health and/or noise complaints, including sleeping problems, that were being attributed to the operation of their wind farms.
- the number of individuals ("complainants") who had made such complaints (direct complaints to the companies, those voiced in local media, to local government or state or national enquiries).
- the date at which the first complaint occurred.
- whether there had been any anti wind farm activity in the local area such as public meetings addressed by opponents, demonstrations or advertising in local media.

Any documentation of complaints such as internet links or news clips about public was requested. Companies were explicitly asked to de-identify any private complaints which could identify those complaining, unless these complaints had been made public by the complainants.

It is possible that wind companies may nonetheless be unaware of some health and noise complaints about their operations or that they might downplay the extent of complaints and provide underestimates of such complaints. To corroborate the information on the number of complainants provided by the companies, we therefore reviewed all 1,594 submissions made to three government enquiries on wind farms: the 2011–2012 Senate enquiry into the Social and Economic Impact of Rural Wind Farms (1,818 submissions) [42]; the 2012 NSW Government's Draft NSW Planning Guidelines for Wind Farms (359 submissions) [43]; and the Renewable Energy (Electricity) Amendment (Excessive Noise from Wind Farms) Bill 2012 (217 submissions) [44]. We searched all submissions for any mentions by residents living in the vicinity of operating wind farms (as opposed to those being planned) of their health or sleep being adversely affected or that they were annoyed by the sound of the turbines.

We also searched daily media monitoring records supplied to the Clean Energy Council by a commercial monitoring company from August 2011 (when the monitoring contract began) until January 2013. This monitoring covered print news items, commentary and letters published in Australian national, state and regional newspapers mentioning any wind farm, as well as television and radio summaries about all mentions of wind farms. It was important to use this source of monitoring rather than use on-line databases like Factiva, as the latter do not cover all small rural news media which is where much coverage of debate about rural wind farms was likely to be found.

Finally, a pre-print of this paper was published on the University of Sydney's e-scholarship repository on March 15 2013. In the next six months the paper was opened over 10,800 times, making it the most opened document among 7761 in that repository across these 4 months. This generated considerable correspondence, and in one case (Hallett 2), information was provided about extra complainants who had complained via a legal case. These were then included.

In reviewing the submissions and media monitoring, only complaints from those claiming to be personally affected by the operation of an existing wind farm in Australia were noted. Expressed concerns about possible future adverse effects or that wind turbines *could* be harmful were not classified as evidence of personal experience of harm or annoyance. There were many of these. Third party statements, such as comments about unnamed neighbours with problems, were not accepted as evidence of harm.

Where the numbers of complainants determined from this corroborative public source searching exceeded the numbers provided to us by the wind companies, we chose the larger number. Where the numbers determined from public sources were less, we used the larger number provided by the companies. Our estimate of the number of complainants thus errs on the least conservative side. Nearly all those who publicly complained did not seek anonymity, being named in media reports or not electing to have their parliamentary submissions de-identified. However, we have chosen not to list their names in this report.

The companies provided estimates of the number of residents currently living within 5 km of each wind farm. Some companies

Table 2. Complainant numbers at 51 Australian wind farms, 1993–2013.

Wind farm name (state) *owner*	Installed Capacity (MW)+(number of turbines)+average turbine size MW	Date commenced operation & total years (to Dec 2012)	Approx. population within 5 km	Health or noise complainants (Y/N) & number (persons unless specified)	Date of first complaint (months since opened)	Local or visiting opposition group activity?
A: Farms with total >10 MW capacity						
Albany/Grasmere (WA) *Verve*	35.4 (18) 1.96	Oct 2001 (11y 2m)	200	N	–	N
Bungendore/Capital/ Woodlawn (NSW) *Infigen*	189 (90) 2.1	Nov 2009 (3y 1m)	76 houses 198	Y:10	Dec 2009 (1 m)	Y
Canunda (SA) *International Power*	46 (23) 2.0	Mar 2005 (7y 10m)	20 houses 52	N	–	N
Cape Bridgewater (Vic) *Pacific Hydro*	58 (29) 2.0	Nov 2008 (4y 1m)	68 houses 177	Y:6	2 Feb 20110 (16m)	Y
Cape Nelson South (Vic) *Pacific Hydro*	44 (22) 2.0	Jun 2009 (3y 6m)	170 houses 425	Y:2	10 Feb 2010 (8m)	Y
Cathedral Rocks (SA) *TRUenergy, Acciona & EHN*	66 (33) 2.0	Sep 2005 (7 y 3 m)	0	N	–	N
Challicum Hills (Vic) *Pacific Hydro*	52.5 (35) 1.5	Aug 2003 (9 y 4 m)	55 houses 143	N	–	N
Clements Gap (SA) *Pacific Hydro*	56.7 (27) 2.1	Feb 2010 (2 y 10 m)	41	Y:3	On-going from earlier	Y
Codrington (Vic) *Pacific Hydro*	18.2 (14) 1.3	Jun 2001 (11 y 6 m)	50	N		N
Collgar/Merriden (WA) *Collgar*	206 (111) 1.85	May 2011 (1 y 7 m)	15	N	–	N
Cullerin Range (NSW) *Origin*	30 (15) 2.0	Jul 2009 (3 y 5 m)	50	N	–	N
Emu Downs (WA) *APA*	80 (48) 1.66	Oct 2006 (6 y 2 m)	50	N	–	N
Gunning/Walwa (NSW) *Acciona*	46.5 (31) 1.5	May 2011 (1 yr 7 m)	25 houses 65	Y:1	Jan 2012 (8 m)	N
Hallett 1/Brown Hill (SA) *AGL*	95 (45) 2.11	Sep 2008 (4 y 3 m)	120	N		Y
Hallett 2/Hallett Hill (SA) *AGL*	71.4 (34) 2.1	Mar 2010 (2 y 9 m)	120	Y:13*	On-going from earlier	Y
Hallett 4/North Brown Hill (SA) *AGL*	132 (63) 2.1	May 2011 (1 y 7 m)	200	Y:1	On-going from earlier	Y
Hallett 5/Bluff Range (SA) *AGL*	53 (25) 2.1	Mar 2012 (9 m)	140	Y:1	Apr 2012 (1 m)	Y
Lake Bonney (SA) *Infigen*	278.5 (112) 2.8	Mar 2005 (7 y 9 m)	255	Y:2	June 2012 (7 y 3 m)	N
MacArthur (Vic) *AGL/ Meridian*	420 (140) 3.0	Sep 2012 (3 m)	15	Y:8 houses = 21	2 days after 2/140 turbines commenced operation	Y
Mortons Lane (Vic) *CGN Wind Energy Ltd*	19.5 (13) 1.5	Dec 2012	14 houses 36	N	–	N
Mt Millar (SA) *Meridian*	70 (35) 2.0	Feb 2006 (6 y 10 m)	10 houses 26	N	–	N
Oaklands Hill (Vic) *AGL*	67.2 (32) 2.1	Feb 2012 (10 m)	250	Y:6	On-going from earlier	Y
Snowtown (SA) *Trust Power*	100.8 (47) 2.14	Nov 2008 (4 y 1 m)	4 houses 10	N	–	N
Starfish Hill (SA) *Ratch*	34.5 (23) 1.5	Sep 2003 (9 y 3 m)	200	N	–	N
Toora (Vic) *Ratch*	21 (12) 1.75	Jul 2002 (10 y 5 m)	674	Y:2	Early (precise date not known)	Y
Walkaway (Alinta) (WA) *Infigen*	89.1 (54) 1.65	Apr 2006 (6 y 8 m)	3 houses 8	N	–	N

Table 2. Cont.

Wind farm name (state) *owner*	Installed Capacity (MW)+(number of turbines)+average turbine size MW	Date commenced operation & total years (to Dec 2012)	Approx. population within 5 km	Health or noise complainants (Y/N) & number (persons unless specified)	Date of first complaint (months since opened)	Local or visiting opposition group activity?
Waterloo (SA) *TRUenergy*	111 (37) 3.0	Dec 201 (2 y)	75 houses 195	Y:11	Feb 2011 (2 m)	Y
Wattle Point (SA) *AGL Hydro*	91 (55) 1.65	Nov 2005 (7 y 1 m)	560	N	–	N
aubra (Vic) *Acciona*	192 (128) 1.5	Mar 2009 (3 y 10 m)	283 houses 736	Y:29	13 Mar 2009 (immediate)	Y
Windy Hill (Qld) *Ratch*	12 (20) 0.6	Feb 2000 (12 y 10 m)	200	Y:1	Early (precise date not known)	N
Wonthaggi (Vic) *Transfield*	12 (6) 2.0	Dec 2005 (7 y)	6900	Y:~10	Feb 2006 (2 m)	Y
Woolnorth:Bluff Point (Tas) *Roaring 40 s & Hydro Tas.*	65 (37) 1.76	Aug 2002 (10 y 4 m)	NI	N	–	N
Woolnorth:Studland Bay (Tas) *Roaring 40 s & Hydro Tas.*	75 (25) 3.0	May 2007 (5 yr 7 m)	NI	N	–	N
34.Yambuk (Vic) *Pacific Hydro*	192 (128) 1.5	Jan 2007 (5 y 11 m)	88	N	–	N
Sub-total: 34 farms	3130.3 MW (1567 turbines)		12334	16 farms with 119 complainants		14
B: Farms with <10 MW capacity						
Blayney (NSW) *Eraring Energy*	9.9 (15) 0.66	Oct 2000 (12 y 2 m)	37	N	–	N
Bremer Bay (WA) *Verve*	0.6 (1) 0.6	Jun 2005 (7 y 6 m)	250	N	–	N
Coober Pedy (SA) *Energy Generation*	0.15 (1) 0.15	1999 (13 y)	3500	N	–	N
Coral Bay (WA) *Verve*	0.825 (3) 0.275	Oct 2006 (6 y 2 m)	200	N	–	N
Crookwell (NSW) *Union Fenosa/Eraring*	4.8 (8) 0.6	Jul 1998 (14 y 5 m)	200	Y:4	Jan 2012 (13 y 6 m)	Y
Denham (WA) *Verve*	1.6 (4) 0.4	Jun 1998 (14 y 6 m)	600	N	–	N
Esperance, 9 Mile Beach (WA) *Verve*	3.6 (6) 0.6	2003 (8 y)	50	N	–	N
Esperance, 10 Mile Lagoon (WA) *Verve*	2.025 (9) 0.225	1993 (19 y)	50	N	–	N
Hampton Park (NSW) *Wind Corp*	1.32 (2) 0.66	Sep 2001 (11 y 3 m)	150	N	–	N
Huxley Hill, King Island (Tas) *Hydro Tas*	2.458 (5) 0.49	Feb 1998 (14 y 1 m)	10 houses (26)	N	–	N
Hopetoun (WA) *Verve*	1.2 (2) 0.6	Mar 2004 (8 y 9 m)	600	N	–	N
Kalbarri (WA) *Verve*	1.6 (2) 0.8	Jul 2008 (4 y 5 m)	10	N	–	N
Kooragang, Newcastle (NSW) Energy Australia	0.6 (1) 0.6	1997 (15 y)	3–4 km from Mayfield 9000	N	–	N
Leonards Hill (Vic) *Community owned*	4.1 (2) 2.05	Jun 2011 (1 y 6 m)	232	Y:6	On-going from earlier	Y
Mt Barker (WA) *Mt Barker Power*	2.4 (3) 0.8	Mar 2011 (1 y 9 m)	2000	N	–	N
Rottnest Island (WA) *Rottnest Island*	0.6 (1) 0.6	Sep 2006 (6 y 3 m)	150	N	–	N
Thursday Island (Qld) *Egon Energy*	0.225 (2) 0.113	Aug 1997 (15 y 5 m)	2500	N	–	N

Table 2. Cont.

Wind farm name (state) *owner*	Installed Capacity (MW)+(number of turbines)+average turbine size MW	Date commenced operation & total years (to Dec 2012)	Approx. population within 5 km	Health or noise complainants (Y/N) & number (persons unless specified)	Date of first complaint (months since opened)	Local or visiting opposition group activity?
Sub-total:17 farms	38 MW 67 turbines		20405	2 farms with 10 complainants		2
Total:51 farms	3168.3 MW 1634 turbines		32739	18 farms with 129 complainants		16

NI = no information.
*13 residents submitted affidavits in a court case but only 2 complained to the company (*AGL*), and none to the local Council or Environmental Protection Agency.
Average residents per house in 2011:2.6 http://www.censusdata.abs.gov.au/census_services/getproduct/census/2011/quickstat/0.
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provided estimates of the number of individuals, while others provided data on the number of houses. In Table 2, we have multiplied cells showing the number of *houses* by 2.6, this being the average number of residents per household in Australia today, to give a total estimate of surrounding residents.

Results

Table 2 shows the history and distribution of complaints from all 51 Australian wind farms. Complaints came either from individuals or from households with several occupants each or collectively complaining. Some wind companies initially reported the number of complainants as *households*, while others reported individual complainant numbers. In these cases we sought clarification from companies about whether complaints came from single individuals, couples or more than two members of a family so as to report total the estimated total number of individual complainants.

Hypothesis 1: Many Wind Farms would have no History of Complaints

Of all 51 wind farms, 33 (64.7%) had never been subject to health or noise complaints, with 18 (35.3%) receiving at least one complaint since operations commenced. The 33 farms with no histories of complaints, and which today have an estimated 21,633 residents living within 5 km of their turbines, have operated for a cumulative total of 267 years.

Of the 18 wind farms which had received complaints, 16 were larger wind farms (≥10 MW capacity). In summary, 18/34 (52.9%) of larger wind farms, and 15/17 (88.2%) of small farms have never experienced complaints. Wind farm opponents sometimes argue that it is mainly very large, "industrial" wind turbines which generate sufficient audible noise and infrasound to cause annoyance and health problems. If 1 MW is taken to define a "large" turbine, 18/34 (52.9%) of farms using large turbines had never attracted complaints while 15/17 (88%) of farms using smaller turbines had no histories of complaints. Both the total energy generating capacity of farms and whether the turbines used were over 1 MW were thus significant predictors of residents having ever complained, with small total capacity farms being far less likely to have complainants (88% vs 53%; $\chi^2 = 6.18$, 1 df, $p = 0.013$).

The distribution of farms which have ever received complaints is highly variable across Australia. Figure 1 shows no consistency between the percentages of farms receiving complaints in different states, whether they have many or few wind farms. Western Australia has 13 wind farms (3 with large turbines), including some of the longest running in Australia (Esperance 10 Mile Lagoon 1993, Denham 1998). No complaints have been received at any of these wind farms. Verve, which operates 8 farms in the state replied "we have never received any form of notification of health complaints in the vicinity of our wind farms." The three farms in Tasmania have also never received complaints.

Our hypothesis about many wind farms – including those with large turbines – having no history of complaints, with strong spatial (geographical) factors being associated with farms receiving complaints was thus strongly confirmed.

Hypothesis 2: There would be a Small Proportion of Complaining Residents

Nationally, a total of 129 individuals in Australia appear to have ever formally or publicly complained about wind farm noise or health problems affecting them. Of these, well over half (94 or 73%) came from residents living near just six wind farms (Waubra = 29, McArthur = 21, Hallett 2 = 13, Waterloo = 11, Capital = 10 and Wonthaggi ~10). Of the remaining farms which have experienced complaints, 9 had between 2 and 6 complainants, and 4 had only single complainants. Of 18 wind farms which had attracted complaints, 11 (72%) have had 6 or less complainants.

There are an estimated 32,789 people living within 5 km of the 50 wind farms for which we obtained residential estimates. Most (20,455 or 62%) live near the 17 smaller wind farms, while 12,334 live within 5 km of the 32 larger farms. In summary, nationally, an estimated 129 individuals have complained out of an estimated 32,789 nearby residents: a rate of about 0.4% or 1 in 254. Of the 34 wind farms with larger (>1 MW) turbines, their 124 complainants represented some 1 in 100 of the surrounding 12,366 residents. Large wind farms with relatively large surrounding rural populations and no histories of complaint include Wattle Point (560), Albany, Starfish Hill (each 200) and Challicum Hills (143).

Again, our hypothesis that the number of complainants living near those wind farms with any history of complaints would be a small proportion of the exposed population, was strongly confirmed.

Hypothesis 3: Few Wind Farms would have any History of Complaints Consistent with Claims that Turbines cause Acute Effects

Wind farm complainants describe both acute and chronic adverse effects. Acute effects are of particular interest to the psychogenic hypothesis because it is often claimed that even brief exposure to wind turbines can cause almost immediate onset of symptoms. For example, a recent report describes a visit to turbine-exposed houses where people become immediately affected: "The onset of adverse health effects was swift, within twenty minutes, and persisted for some time after leaving the study area" [45]. Symptoms are said to disappear when those affected move away temporarily, only to return as soon as they come back. A highly publicised Lake Bonney complainant who had hosted turbines on his previous property without complaint for six years today claims he and his wife are affected at their new address, further away, but that symptoms disappear as soon as they leave their new home for one or two days [46].

If wind turbine exposure can cause such "instant" problems, any history of delayed or non-reporting of such complaints and the absence of any reports about such complaints in the news media, months or sometimes years after various wind farms began operating creates serious coherency problems for such claims. Such delays would be incompatible with there being widespread or important "acute" effects from exposure.

Table 2 shows that first complaint timing ranged from immediately after turbines commenced operation (sometimes at only a fraction of full capacity) to many months and even many years later (eg: Crookwell, 13.5 years, Lake Bonney, over 7 years later. In five cases (Clements Gap, Hallet 2 & 4, Leonards Hill, Waubra), wind companies advised that complaints anticipating health problems were received before the farms commenced operation. Of the 51 wind farms, 33 (64.7%) have seen no complaints; 6 (11.8%) saw complaints commence at times ranging from 2 months to 13.5 years after turbine operation; and 12 (23.5%) saw either on-going complaints continue from before the wind farms commenced operation or within the first month.

Early complaints from some wind farms could be consistent with acute effects caused directly by turbine exposure but also with nocebo effects caused by anticipation of adverse effects [32]. However, gaps of months or sometimes years between the commencement of turbine operation and complaints are inconsistent with turbines causing acute effects. Moreover, if such effects were serious or common, clinical case reports would have almost certainly appeared in peer reviewed journals, given the many years that wind farms have operated in Australia. No such reports have been published.

Hypothesis 4: Most Complaints would Date from 2009 or Later, when Anti Wind Farm Groups began to Publicise Alleged Health Effects

The nocebo hypothesis would predict that the spread of negative, often emotive information would be followed by increases in complaints and that without such suggestions being spread, complaints would be less. Australia's first still operational wind farm commenced operation in 1993 at 10 Mile Lagoon near Esperance, Western Australia. However, objections to wind farms in Australia appear to date from the early years of the 2000 s when press reports mentioned negative reactions of some in rural communities to their intrusiveness in bucolic country landscapes ("behemoths" [47]), bird and bat strikes, the divisiveness engendered in communities by the perceived unfairness of some landowners being paid hosting fees of up to $15,000 per year per turbine while neighbours received none, and debates about the economics of green energy. Unguarded, frank NIMBYism "I'm quite happy to admit that this is a not-in-my-backyard thing, because my backyard is very special" was also evident in 2002 [47].

Groups explicitly opposing wind farms ostensibly because of agendas about preserving pristine bush and rural environments were active from these early years and included many branches of the Australian Landscape Guardians (for example Prom Coast (2002), Spa Country [48], Grampians-GlenThompson [49], Western Plains, Daylesford and District). Key figures in the Landscape Guardians have links with mining and fossil fuel industries [50]. Interests with overt climate change denial agendas also actively opposed wind farm developments, particularly in Victoria. Chief among these were the Australian Environment Foundation, registered in February 2005.

However, health concerns were marginal in these early oppositional years, with one early press report from September 2004 [48] noting "some objectors have done themselves few favours by playing up dubious claims about reflecting sunlight, mental health effects and stress to cattle".

An unpublished British report said to refer to data gathered in 2003 on symptoms in 36 residents near unnamed English wind farms is frequently noted by global wind turbine opponents as the first known report of health effects from wind turbines, although curiously, it does not appear to have been produced until 2007 [51]. The Daylesford and Districts Landscape Guardians referred to Harry's work in a 2007 submission opposing a wind farm at Leonards Hill [52].

In Australia, a rural doctor from Toora, Victoria, David Iser, produced another unpublished report [53] in April 2004 following his distribution of 25 questionnaires to households within 2 km of the local 12 turbine, 21 MW wind farm, which had commenced operation in October 2002. Twenty questionnaires were returned, with 12 reporting no health problems. Three reported what Iser classified as "major health problems, including sleep disturbances, stress and dizziness". Like that of Harry, Iser's report provides no details of sample selection; whether written or verbal information accompanying the delivery of the questionnaire may have primed respondents to make a connection between the wind turbines and health issues; whether those reporting effects had previous histories of the reported problems; nor whether the self-reported prevalence of these common problems were different to those which would be found in any age-matched population.

In the 10 years between the commencement of operation of the first Esperance wind farm and the end of 2003 when the Harry and Iser health impact reports [51,53] began being highlighted by turbine opposition groups, 12 more wind farms commenced operation in Australia. In that decade, besides two complainants from Toora, we aware of only one other person living near the north Queensland Windy Hill wind farm who complained of noise and later health soon after operation commenced in 2000. Importantly in that decade, five large turbined wind farms at Albany, Challicum Hills, Codrington, Starfish Hill and Woollnorth Bluff Point commenced operation but never received complaints.

With the exception of those just mentioned and Wonthaggi (~10 complainants in 2006, but none today) all other health and noise complainants (n = 116) first complained after March 2009–six years after Iser's Toora small, unpublished survey of health complaints [53] - and particularly from the most recent years when anti wind farm publicity from opposition groups focused on health has grown. Again, the nocebo and the 'communicated disease' hypotheses would predict this changed pattern and contagion of complaints, driven by increasing community concern. Sixty nine percent of wind farms began operating prior to 2009 while the majority of complaints (90%) were recorded after this date.

Responding to the nocebo hypothesis and the view that opposition groups were fomenting a 'communicated disease', the Waubra Foundation's Sarah Laurie stated: "There is also plenty of evidence that the reporting of symptoms for many residents at

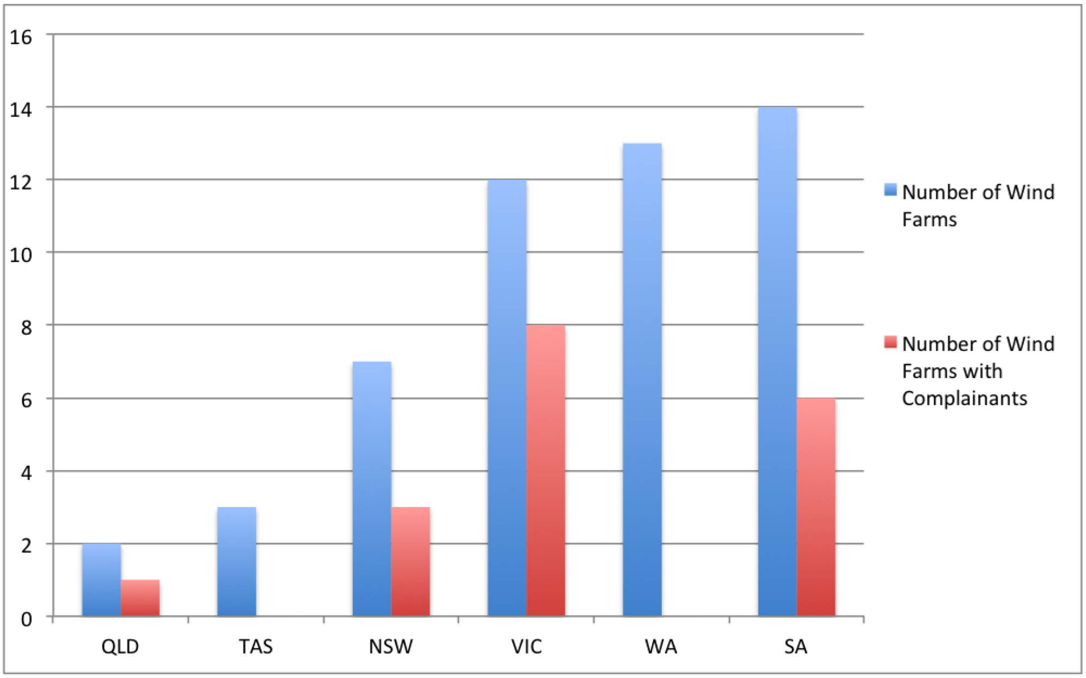

Figure 1. Farms with wind turbine complainants by state, Australia 1993–2012.
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wind developments in Victoria such as Toora, Waubra and Cape Bridgewater *preceded the establishment of the Waubra Foundation* (emphasis in original). In the case of Dr David Iser's patients at Toora the time elapsed is some 6 years.'' [54].

This statement neglects to note that the Waubra Foundation's registration in July 2010 was preceded by several years of virulent wind turbine opposition – which included health claims – by the Landscape Guardians and the Australian Environment Foundation. For example, in November 2009, 8 months before the formation of the Waubra Foundation the Western Plains Landscape Guardians published a full-page advertisement in the local Pyrenees Advocate newspaper headed ''Coming to a house, farm or school near you? Wind Turbine Syndrome also known as Waubra Disease''. It listed 12 common symptoms (e.g. sleeping problems, headaches, dizziness, concentration problems). Peter Mitchell is the founding chairman of the Waubra Foundation and in 2009 and at least until February 2011, was also actively advocating for the Landscape Guardians [55].

Table 2 shows that of the 18 wind farms which have seen complainants, 15 (83%) have experienced local opposition from anti wind farm groups. No wind farm with any history of wind turbine opposition avoided at least one health or noise complaint. We conclude that health and noise complaints were rare prior to the decision of anti wind farm groups to focus on these issues and that anti wind farm activists are likely to have played an important role in spreading concern and anxiety in all wind farms areas in which they have been active.

Discussion

This study shows there are large historical and geographical differences in the distribution of complainants to wind farms in Australia. There are many wind farms, large and small, with no histories of complaints and a small number where the large bulk of complaints have occurred. Just over half of wind farms with larger turbines have seen complaints, but nearly just as many have not. These differences invite explanations that lie beyond the turbines themselves.

Our historical audit of complaints complements recent experimental evidence [32], that is strongly consistent with the view that ''wind turbine syndrome'' and the seemingly boundless and sometimes bizarre range of symptoms associated with it has important psychogenic nocebo dimensions [2]. While wind turbines have operated in Australia since 1993, including farms with >1 MW turbines from 2001 (Albany and Codrington), health and noise complaints were very rare until after 2009, with the exception of Wonthaggi which saw about 10 complainants in 2006.

Several wind farm operators reported that many former complainants had now desisted. For example, Waubra management advised that not all complainants identified by our public searches had complained to them, and that more than half of the 17 complainant households who had complained to them, had had their complaints resolved. Similarly, Wonthaggi management said that none of some 10 complainants from 2006/2007 were still complaining today. Some of these former complainants from different farms had had their houses noise tested with the results showing they conformed to the relevant noise standard, some received noise mitigation (e.g. double glazing), while others simply stopped complaining.

Opponents sometimes claim that only ''susceptible'' individuals are adversely affected by wind turbines, using the analogy of motion sickness. Our data produce problems for that explanation: it is implausible that no susceptible people would live around any wind farm in Western Australia or Tasmania, around almost all older farms, nor around nearly half of the more recent farms. No credible hypotheses other than those implicating psycho-social factors have been advanced to explain this variability.

As anti wind farm interest groups began to stress health problems in their advocacy, and to target new wind farm developments, complaints grew. Significantly though, no older farms with non-complaining residents appear to have been targeted by opponents. The dominant opposition model appears to be to foment health anxiety among residents in the planning and construction phases. Health complaints can then appear soon after power generation commences. Residents are encouraged to interpret common health problems like high blood pressure and sleeping difficulties as being caused by turbines.

For example, sleeping problems are very common, with recent Australian and New Zealand estimates ranging from 34% [56], to moderately poor (26.4%) and very poor sleep quality (8.5%) [57]. A German study undertaken to obtain benchmark reference data on common symptoms and illnesses experienced in the past 7 days in the general population for comparison with those experienced by clinical trial enrollees presents data on several problems most often attributed to wind turbines. These include headache (45.3%), insomnia (25.6%), fatigue and loss of energy (19.1%), agitation (18.4%), dizziness (17%) and palpitations (8.6%) [58].

A case brought before The Ontario Environmental Review Tribunal by residents claiming to be affected by a wind farm, collapsed when the Tribunal requested that complaints supply their medical records to determine whether their complaints pre-dated the operation of the wind farm [59].

Wind farm opponents frequently argue complainants are legally "gagged" from speaking publicly about health problems, thus underestimating the true prevalence of those affected. This is said to apply to turbine hosts who are contractually gagged or to non-hosts who have reached compensation settlements with wind companies after claiming harm. The first claim is difficult to reconcile with the example provided by a high profile Lake Bonney wind farm host who continues to complain publicly without attracting any legal consequences [27]. Confidentiality clauses are routinely invoked in any legal settlement to protect parties' future negotiating positions with future complainants. They usually refer to the settlement figure rather than to the reasons for it.

We purposefully took a liberal view of what a "complainant" was, by including those who had voiced their displeasure about noise, sleep or health in news media or submissions even if they had never lodged a formal complaint with the relevant wind farm company. Despite this, the numbers complaining in Australia were very low and largely concentrated in a small number of "hotbeds" of anti wind farm activism.

A 2012 CSIRO report on nine wind farm developments in three Australian states found widespread acceptance among local residents of both operating and planned farms, and noted that: "The vocal minority are more often prominent in the media … These groups often contact local residents early in the project and share concerns about wind farms." And that "The reasons for opposition by some participants suggest that wind farms proposals are triggering a range of underlying cultural or ideological concerns which are unlikely to be addressed or resolved for a specific wind farm development. These underlying issues include pre-existing concerns that rural communities are politically neglected by urban centres, commitment to an anti-development stance, and opposition to a 'green' or 'climate action' political agenda." [60].

Limitations

The data we obtained on the number of individuals or occupied houses near the farms were current estimates. These numbers may have varied in different directions for different farms over the 20 year period that wind farms have operated in Australia. But no data are available on that variation. Our estimates of the ratios of complaints to population are therefore unavoidably fixed around the most current population estimates. They would include children who do not lodge complaints, but who are often mentioned by wind farm opponents as subject to health effects [2].

It is possible that there were other complainants who complained earlier than in the periods covered by our corroborative checks. However, this seems highly unlikely: Australian anti wind farm groups would have strong interests in widely publicising such complainants, had they existed. The Waubra Foundation for example, repeatedly refers to the 2004 Iser report [53], in its efforts to emphasise that health concerns had been raised before the Waubra Foundation became established [54] As wind farm opponents have not highlighted more complainants than we have identified, this strongly suggests there were no earlier health or noise complainants.

It is also possible that some of the health complainants are disingenuous, thereby inflating the true number of people actually claiming to experience turbine-related health problems when their objections may be only aesthetic. Controversy arose when an anti wind farm activist who lives 17 km from the Waterloo wind farm was recently accused of "coaching" residents who disliked the local wind farm to explicitly mention health issues [61].

We selected the 5 km distance from turbines as a compromise between the 2 km minimum setback distance designated by the Victorian government for future wind farm approvals, and the 10 km often named by the Waubra Foundation as the advisable minimum distance. We also note here, that one prominent critic of wind farms claims to to be able to personally sense low frequency noise up to 100 km away from wind turbines under certain conditions [62]. Had we chosen the 10 km distance counseled by the Waubra Foundation, this would have significantly increased the numbers of people exposed but not complaining.

The estimates provided by the wind companies of the number of residents within 5 km of wind farms need to be seen as approximations. Census data is available by local government areas and by the Australian Bureau of Statistics statistical regions. However, these do not correspond with the 5 km zone of residence of interest here. The wind companies which provided this data obtained it from their own knowledge of the number of residences near their wind farms and we checked local township sizes from Australian census data. This information is typically obtained during the planning stages of wind farm development when development applications often require such estimations to be provided. At least one company used Google Earth photography to calculate their estimate of the number if dwellings. However, such estimates will always be imprecise and approximations only. They nonetheless provide "ballpark" denominators against which the known number of complainants can be compared.

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Author Contributions

Analyzed the data: SC AStG KW VC. Wrote the paper: SC AStG KW VC. Conceived of study: SC. Collected data: SC AStG KW VC. Contributed to writing: SC AStG KW VC.

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**BEFORE THE PUBLIC UTILITIES COMMISSION
OF THE STATE OF SOUTH DAKOTA**

**IN THE MATTER OF THE APPLICATION OF
CROWNED RIDGE, LLC FOR A FACILITIES PERMIT TO
CONSTRUCTION 300 MEGAWATT WIND FACILITY**

Docket No. EL19-003

REBUTTAL TESTIMONY AND EXHIBITS

OF ANDREW BAKER

May 24, 2019

INTRODUCTION AND QUALIFICATIONS

Q. PLEASE STATE YOUR NAME AND BUSINESS ADDRESS.

A. My name is Andrew Baker. My business address is 10990 Quivira Road, Suite 100, Overland Park, Kansas 66210.

Q. BY WHOM ARE YOU EMPLOYED AND IN WHAT CAPACITY?

A. I am employed at Valbridge Property Advisors as a Director.

Q. PLEASE DESCRIBE YOUR BACKGROUND AND QUALIFICATIONS

A. I received a Bachelor of Arts from Case Western Reserve University in Cleveland, Ohio, with a major in Economics. In 2008, I began working for Integra Realty Resources, a commercial real estate appraisal firm in Westood, Kansas. In 2012, I switched firms and began working at Valbridge Property Advisors | Shaner Appraisals, Inc. ("Valbridge"). Valbridge is a commercial real estate firm located in Overland Park, Kansas and the largest appraisal firm in the Kansas City metropolitan area with 15 appraisers at present. Over the previous 11 years I have worked as a commercial appraiser and have completed assignments for many different property types, including retail, office, industrial, multifamily, and agricultural land. Since 2015, I have completed several Value Impact Studies on how wind turbines affect surrounding property values for proposed wind energy projects in Kansas, Missouri, and South Dakota. My curriculum vitae is attached as Exhibit AB-R-1.

Q. HAS THIS TESTIMONY BEEN PREPARED BY YOU OR UNDER YOUR DIRECT SUPERVISION?

A. Yes.

Q. HAVE YOU TESTIFIED BEFORE THE SOUTH DAKOTA PUBLIC UTILITIES COMMISSION ("COMMISSION")?

A. No.

Q. PLEASE DESCRIBE THE PURPOSE OF YOUR REBUTTAL TESTIMONY.

A. The purpose of my testimony is to respond to Intervenors' proposed conditions as set forth in Staff witness Darren Kearney's Direct Testimony, Exhibit DK-8.

Q. THE INTERVENORS' PROPOSED CONDITION 37 (KEARNEY EXHIBIT DK-8) WOULD REQUIRE THAT CROWNED RIDGE WIND, LLC ("CRW") OFFER EACH NON-PARTICIPATING LANDOWNER WITHIN 2 MILES OF THE BOUNDARY FOOTPRINT REIMBURSEMENT OF A PRE-CONSTRUCTION PROPERTY APPRAISAL UP TO $2,500 PER LANDOWNER. THIS OFFER WOULD NEED TO BE COMPLETED BEFORE ANY CONSTRUCTION IS COMPLETED AND REIMBURSEMENT WOULD NEED TO BE MADE BY THE APPLICANT WITHIN 30 DAYS OF SUBMISSION OF THE RECEIPT TO THE COMMISSION. IS THIS A REASONABLE AND NECESSARY CONDITION?

A. No. The proposed condition is premised on an incorrect and unsupported assumption that wind farms negatively impact property values. As more fully described in the supplemental information in attached Exhibit AB-R-2, I completed a Value Impact Study of the proposed project in December 2018, which shows the Intervenors' premise to be erroneous. The Value Impact Study demonstrates that there is no market evidence that the CRW wind project will have a negative impact on surrounding property values.

To assemble the Value Impact Study, I studied the details of the CRW wind project, surrounding land uses, and the zoning codes for Grant County and Codington County. Based upon these factors, I analyzed how the Project would likely impact surrounding agricultural and residential properties. I then reviewed the relevant academic literature, conducted a paired sales analysis, and interviewed knowledgeable market participants who had purchased or sold property near wind turbines in eastern South Dakota.

I reviewed a total of three academic articles that have appeared in peer reviewed journals over the past five years. These articles are attached as Exhibit AB-R-3. In each of these articles, the results of the study showed that the effects of wind farms on surrounding property values were not statistically significant. I would also point out that in Appendix K to CRW's Application there is a Lawrence Berkeley study that was completed by Ben Hoen and other researchers. This study is probably the best-known study on the topic and I summarized the results in Exhibit AS-R-2. This study collected data from more than 50,000 home sales near wind turbines in nine states, which was a much greater sample size than any previous study on the topic. The researchers used several different models to examine the effects on property values for homes within ½ mile and one mile of a wind turbine. The study concludes "Regardless of model specification, we find no statistical evidence that home values near wind turbines were affected in the post-construction or post announcement/pre-construction periods."

In my evaluation, I also conducted a paired sales analysis for agricultural properties and residential properties, and compared sales of agricultural properties with adjacent wind turbines to nearby properties in Brookings County, South Dakota. The analysis showed that the presence of wind turbines had no impact on property values. Also, interviews with market participants in Brookings County did not reveal that the wind turbines were a major concern or that they have impacted sales prices. Repeat sales of homes in Wright, Kansas and Spearville, Kansas that occurred shortly before the construction of a nearby wind farm and shortly after construction had been completed did not show an impact on value.

In addition, the consultation report by Rose M. Hoefs provided in Appendix K to CRW's Application, beginning on page 223, analyzes a total of 28 paired sales in four counties in North Dakota. I have reviewed this report, and it supports my conclusion that there is no market evidence that wind turbines have a negative impact on property values. Therefore, the Intervenors' requested condition is unnecessary, as it is based on the unsupported premise that the Project will affect property values.

Q. DOES THIS CONCLUDE YOUR TESTIMONY?

A. Yes.

STATE OF KANSAS)
) ss
COUNTY OF JOHNSON)

I, Andrew Baker, being duly sworn on oath, depose and state that I am the witness identified in the foregoing prepared testimony and I am familiar with its contents, and that the facts set forth are true to the best of my knowledge, information and belief.

Andrew Baker

Subscribed and sworn to before me this 24th day of May, 2019.

SEAL

Notary Public

State of Kansas, Notary Public
Janice S. Tittel
My Appt. Expires 8/21/2022

My Commission Expires 8/21/2022

Qualifications of Andrew Baker, MAI
Director
Valbridge Property Advisors | Kansas City

Independent Valuations for a Variable World

State Certifications

State of Kansas
State of Missouri

Education
BA Case Western Reserve University

Contact Details

913-647-4989

Valbridge Property Advisors | Kansas City
10990 Quivira Road
Suite 100
Overland Park, KS 66210

www.valbridge.com
abaker@valbridge.com

Membership/Affiliations:
Member: Appraisal Institute - MAI designation

Appraisal Institute and Related Courses:
Basic Appraisal Principles
Basic Appraisal Procedures
Uniform Standards of Professional Appraisal Practice
Real Estate Finance, Statistics and Valuation Modeling
Market Analysis and Highest and Best Use
Sales Comparison Approach
Income Approach Part 1 and 2
Report Writing and Case Studies
Appraisal Review
Apartment Appraisal, Concepts and Applications
Advanced Income Capitalization
Advanced Concepts & Case Studies
Advanced Market Analysis and Highest & Best Use

Experience:
Real Estate Analyst/Certified General Appraiser
Valbridge Property Advisors | Shaner Appraisals, Inc. (2012-Present)

Real Estate Analyst
Integra Realty Resources. (2008-2012)

Appraisal/valuation and consulting assignments have included many different property types including retail, office, industrial and multifamily. Assignments also include tax appeal valuations and rent comparability studies. Assignments have been concentrated in the Kansas City Metropolitan area.

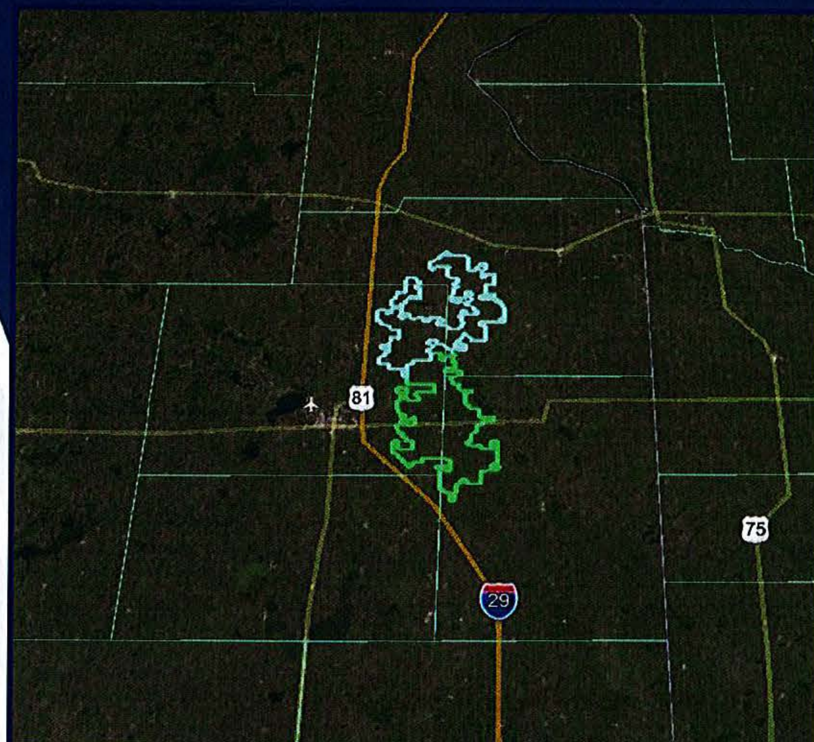
Exhibit A39-2

Valbridge
PROPERTY ADVISORS

Value Impact Study Report

Crowned Ridge Wind Farm
Grant County, Codington County, Deuel County
South Dakota

Report Date: December 13, 2018



FOR:
NextEra Energy Resources
Mr. Jamie Gentile
700 Universe Blvd., Bldg. E5023
Juno Beach, FL 33408

Valbridge Property Advisors | Kansas City
10990 Quivira Road, Suite 100
Overland Park, Kansas 66210
(913) 451-1451 phone
(913) 529-4121 fax

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Valbridge Job No:
KS01-18-0720

Valbridge
PROPERTY ADVISORS

10990 Quivira Road, Suite 100
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valbridge.com

December 13, 2018

Mr. Jamie Gentile
NextEra Energy Resources
700 Universe Blvd., Bldg. E5023
Juno Beach, FL 33408

RE: Value Impact Study
Crowned Ridge Wind Farm
South Dakota

Dear Mr. Gentile:

In accordance with your request, we have prepared a Value Impact Study of the proposed Crowned Ridge Wind Farm located in Grant, Codington, and Deuel Counties in northeastern South Dakota. The proposed project will contain approximately 260 wind turbines and provide 600 MW of energy when completed in 2020. This report sets forth the pertinent data gathered, the techniques employed, and the reasoning leading to our opinions. The purpose of this report is to examine the impact that the proposed Crowned Ridge Wind Farm will have on surrounding property values.

We developed our analyses, opinions, and conclusions and prepared this report in conformity with the Uniform Standards of Professional Appraisal Practice (USPAP) of the Appraisal Foundation; the Interagency Appraisal and Evaluation Guidelines; the Code of Professional Ethics and Standards of Professional Appraisal Practice of the Appraisal Institute; and the requirements of our client as we understand them.

NextEra Energy Resources is the client in this assignment. We understand that NextEra Energy Resources may share this report with county officials. The intended use is to assist in obtaining zoning approval for the project. The value opinions reported herein are subject to the definitions, assumptions and limiting conditions, and certification contained in this report.

Based upon our analysis, the report demonstrates the following:

The proposed Crowned Ridge Wind Farm will not measurably impact the value of surrounding properties located within Grant County, Codington County, or Deuel County.

This letter of transmittal is not considered valid if separated from this report, and must be accompanied by all sections of this report as outlined in the Table of Contents, in order for the value opinions set forth above to be valid.

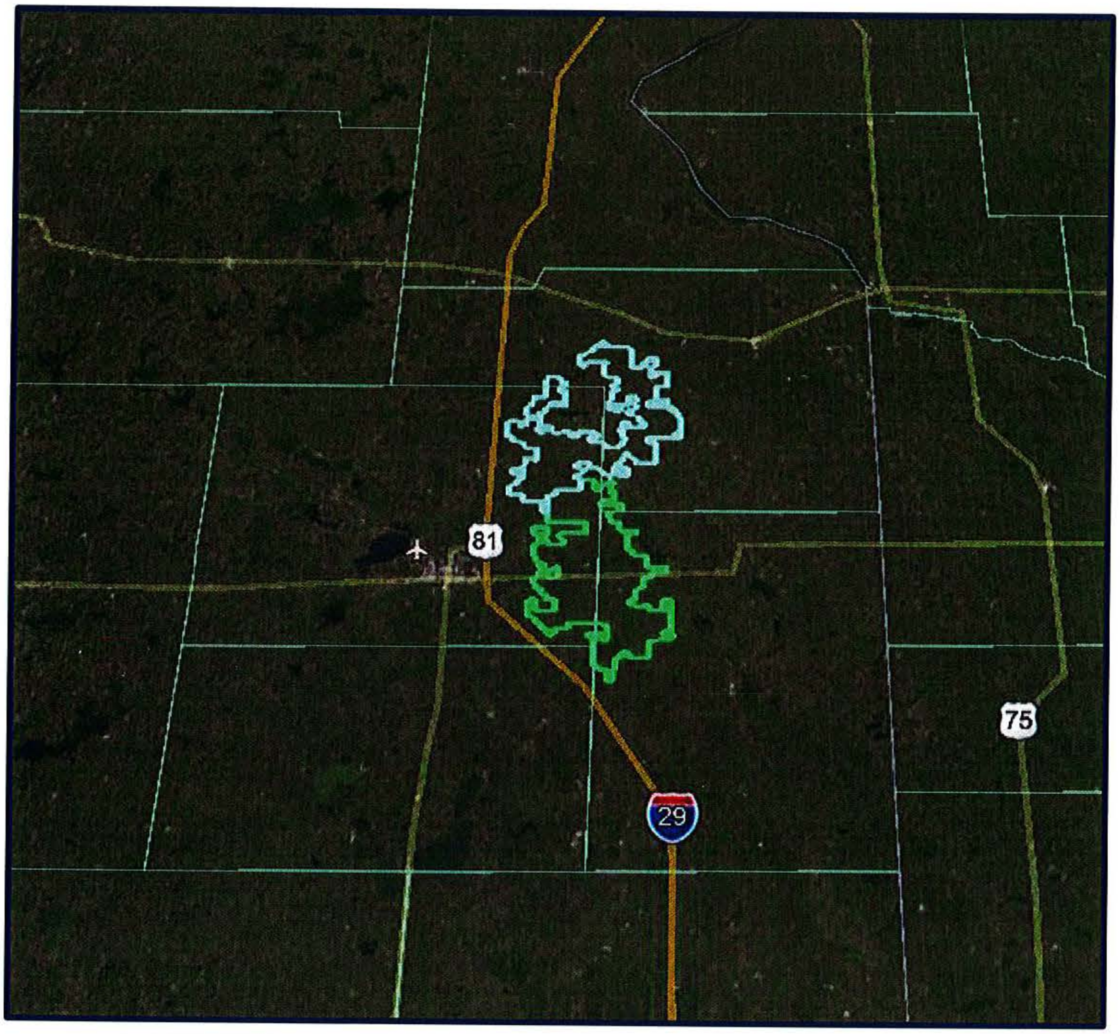
Respectfully submitted,
Valbridge Property Advisors | Kansas City

Andrew Baker

Andrew Baker, MAI
Senior Appraiser
South Dakota Appraiser Permit Number: 1729-T-2018

Table of Contents

Location Map



Introduction

Client of the Report

The client in this assignment is NextEra Energy Resources and no others.

Intended Users of the Report

The intended users of this report is NextEra Energy Resources. We understand that the client may share this report with public officials in Grant, Codington, and Deuel Counties as part of the zoning approval process.

Intended Use of the Report

The intended use of this report is to assist in zoning approval for the project.

Identification of the Project

Our identification of the project is based upon our on-site inspection, public records, news articles, as well as information provided to us by the client. The purpose of this report is to analyze the impact that the project will have on the value of surrounding property.

Type and Definition of Value

The purpose of this appraisal is to develop an opinion as to the impact that the proposed project will have on surrounding agricultural, business and residential property values. "Market Value," as used in this appraisal, is defined as "the most probable price that a property should bring in a competitive and open market under all conditions requisite to a fair sale, the buyer and seller each acting prudently and knowledgeably, and assuming the price is not affected by undue stimulus." Implicit in this definition is the consummation of a sale as of a specified date and the passing of title from seller to buyer under conditions whereby:

- *Buyer and seller are typically motivated.*
- *Both parties are well informed or well advised, each acting in what they consider their own best interests;*
- *A reasonable time is allowed for exposure in the open market;*
- *Payment is made in terms of cash in U.S. dollars or in terms of financial arrangements comparable thereto; and*
- *The price represents the normal consideration for the property sold unaffected by special or creative financing or sale concessions granted by anyone associated with the sale."*

(Source: The Dictionary of Real Estate Appraisal, Fifth Edition, page 123)

The "as is" value is the value of the property in its present condition under market conditions prevalent on the effective date of value.

Please refer to the Glossary in the Addenda section for further definitions of value type(s) employed in this report.

Valuation Scenarios and Effective Dates of Value

Per the scope of our assignment we developed opinions for how the value of surrounding properties will be impacted by the project.

Value Perspective	Value Premise	Effective Date
Current	As Is	December 5, 2018

Date of Report

The date of this report is December 13, 2018 which is the same as the date of the letter of transmittal.

Assumptions and Conditions of the Appraisal

If there are extraordinary assumptions and/or hypothetical conditions used in this report, the use of these extraordinary assumptions and hypothetical conditions might have affected the assignment results.

Extraordinary Assumptions

An extraordinary assumption is defined as "An assumption, directly related to a specific assignment, as of the effective date of the assignment results, which, if found to be false, could alter the appraiser's opinions or conclusions." There are no extraordinary assumptions assumed in this appraisal.

Hypothetical Conditions

A hypothetical condition is defined as "A condition, directly related to a specific assignment, which is contrary to what is known by the appraisers to exist on the effective date of the assignment results, but is used for the purposes of analysis." There are no hypothetical conditions assumed in this appraisal.

Scope of Work

The scope of work includes all steps taken in the development of the appraisal. These include 1) the extent to which the subject property is identified, 2) the extent to which the subject property is inspected, 3) the type and extent of data researched, 4) the type and extent of analysis applied, and the type of report prepared. These items are discussed as follows:

Extent to Which the Impacted Properties Was Identified

Economic Characteristics

Economic characteristics of the project were identified via a review of market surveys, academic literature, interviews with market participants, as well as a comparison to properties with similar locational and physical characteristics.

Physical Characteristics

The subject area was physically identified via our on-site inspection. We have also analyzed information sent to us by the client, including maps of the proposed project.

Extent to Which the Property Was Inspected

Andrew Baker, MAI inspected the area of the proposed project and the surrounding area on December 5, 2018. The purpose of this inspection was to determine the land uses in the area.

Type and Extent of Data Researched

We researched the project based upon information provided to us by the client. We reviewed the zoning codes for each of the three counties in which the project will be located. Based upon these factors, we analyzed the positive and negative externalities of the project and its impact on the surrounding property.

As part of the process, we conducted the following analysis:

1) A review of the academic literature that relates to the impact of wind farms on surrounding property values.
2) A paired sales analysis of agricultural land located in Brookings County, South Dakota.
3) A paired sales analysis of residential properties located in Ford County, Kansas. We also examined a 16 year sales history of all residential properties located in Spearville, Kansas, a city that is surrounded by wind turbines.
4) Interviews with market participants in eastern South Dakota, including brokers and county assessors that have experience with the impact of wind farms on property values.

Appraisal Conformity

We developed our analyses, opinions, and conclusions and prepared this report in conformity with the Uniform Standards of Professional Appraisal Practice (USPAP) of the Appraisal Foundation; the Code of Professional Ethics and Standards of Professional Appraisal Practice of the Appraisal Institute; and the requirements of our client as we understand them.

Regional Analysis

STATE MAP

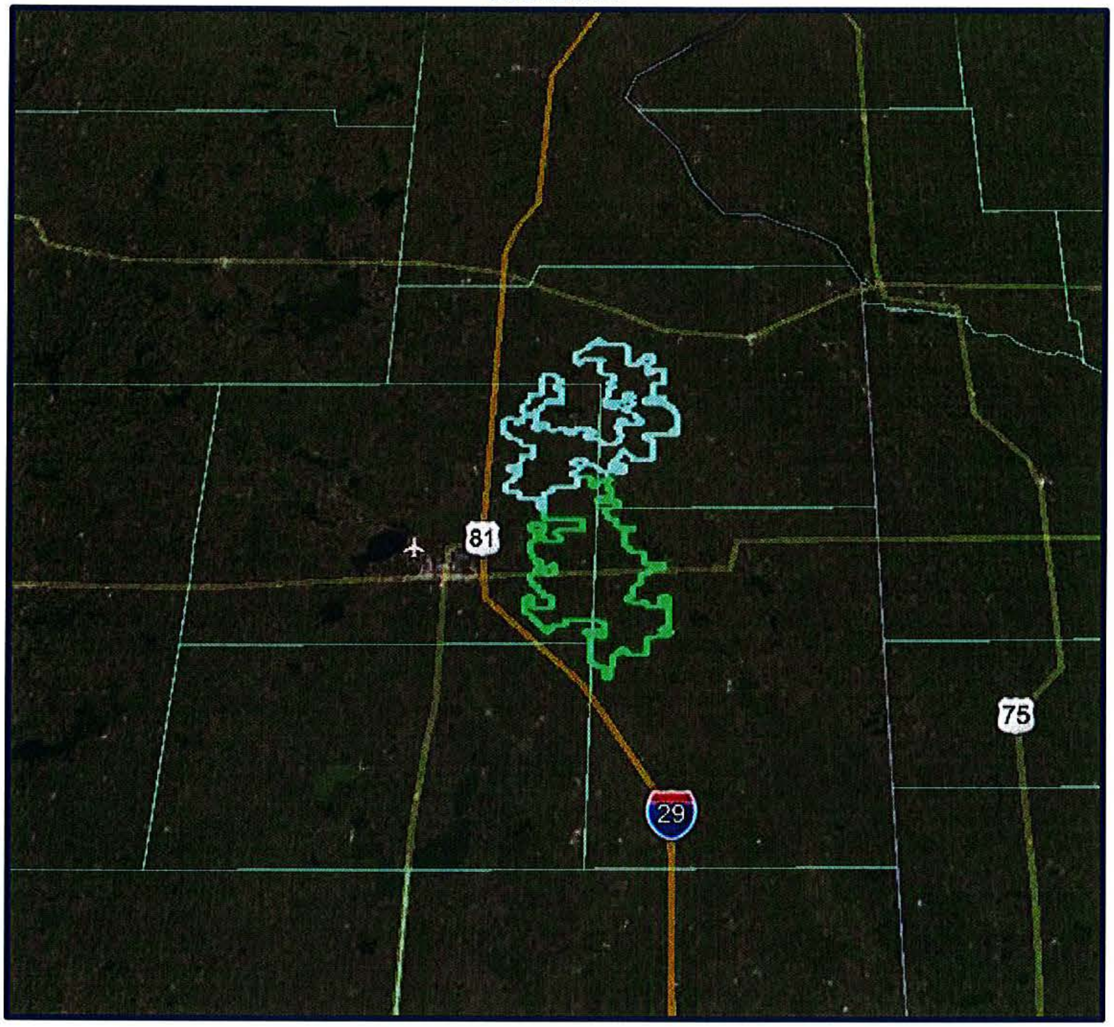
Overview

The proposed Crowned Ridge Wind Farm is located in southwestern Grant County, eastern Codington County, and northwestern Deuel County. The area is generally rural in nature and is located in northeastern South Dakota. The following analysis focuses on the social, economic, government, and environmental forces that form the elements of supply and demand and subsequently affect local real estate values.

Location and Boundaries

According to *Market Analysis for Real Estate*, published by the Appraisal Institute, the trade/market area is delineated by physical, political, and socioeconomic boundaries or by the time-distance relationship represented by travel times to and from common destinations. A market area is an area in which alternative, similar properties effectively compete with the Study Area in the minds of probable, potential users. For the purposes of this value impact study, the neighborhood boundaries are considered to be Grant County, Codington County, and Deuel County.

LOCAL MAP



Demographics

The following demographic information was obtained from the 2000 U.S. Census, 2010 U.S. Census, and Site to do Business (STDB) forecasts for 2018 and 2023. Unemployment information was provided by the Bureau of Labor Statistics (BLS). We have included the data from Grant County, Codington County, Deuel County, as well as the State of South Dakota.

Population

Since 2010, the population in Codington County has grown slightly. This is in contrast to the population in Grant County and Deuel County, which have each slightly decreased.

Population

Area	2000	2010	Annual % Change 2000 - 10	Estimated 2018	Projected 2023	Annual % Change 2018 - 23
South Dakota	754,844	814,180	0.8%	889,876	937,436	1.1%
Grant County	7,847	7,356	-0.6%	7,263	7,181	-0.2%
Codington County	25,897	27,227	0.5%	28,673	29,532	0.6%
Deuel County	4,498	4,364	-0.3%	4,367	4,286	-0.4%

Source: Site to Do Business (STDB Online)

Household Income

STDB projects median household income to be between $50,000 and $54,000 in Grant County, Codington County and Deuel County. The median household income in these counties is generally in-line with the State of South Dakota.

Median Household Income

Area	Estimated 2018	Projected 2023	Annual % Change 2018 - 23
South Dakota	$54,091	$59,888	2.1%
Grant County	$53,306	$57,072	1.4%
Codington County	$50,972	$55,747	1.9%
Deuel County	$53,852	$59,196	2.0%

Source: Site to Do Business (STDB Online)

Unemployment

Over the past several years, the unemployment rate in each of the counties as well as the State of South Dakota has been generally decreasing. The unemployment rate is now below 3.5% in the region and the State of South Dakota.

Unemployment Rates

Area	YE 2011	YE 2012	YE 2013	YE 2014	YE 2015	YE 2016	YE 2017	2018 YTD
United States	8.5%	7.9%	6.7%	5.6%	5.0%	4.7%	4.1%	3.8%
South Dakota	4.4%	4.0%	3.6%	3.3%	2.9%	3.2%	3.4%	3.0%
Grant County	5.2%	4.8%	4.3%	4.1%	3.8%	4.2%	4.1%	2.3%
Codington County	4.3%	3.7%	3.5%	3.6%	3.4%	3.5%	3.6%	2.5%
Deuel County	6.8%	7.0%	7.5%	6.8%	6.7%	5.8%	6.4%	3.5%

Source: Bureau of Labor Statistics - Year End - National & State Seasonally Adjusted

Transportation Routes

Within the region, the major Highway is Interstate 29, which runs along the eastern portion of South Dakota in a north/south direction. Major cities along Interstate 29 include Grand Forks and Fargo, North Dakota to the north, and Sioux Falls, South Dakota, Omaha, Nebraska, and Kansas City, Missouri to the south. The local area is on a grid system with roadways running every mile. The area has good highways which connect the cities in the area.

Major Employers

Major employers in the area include the Prairie Lakes Healthcare System, Terex Utilties, Premier Bankcard, local major retailers, as well as the local school districts. These employers are in the retail, health care, education and government industries and are considered to be stable.

The area is rural in nature and agriculture is the major demand driver. According to the United State Department of Agriculture, the main agricultural land uses in the area are corn, soybeans, wheat, and cattle ranching.

Land Uses

An approximate breakdown of the development in the areas is as follows:

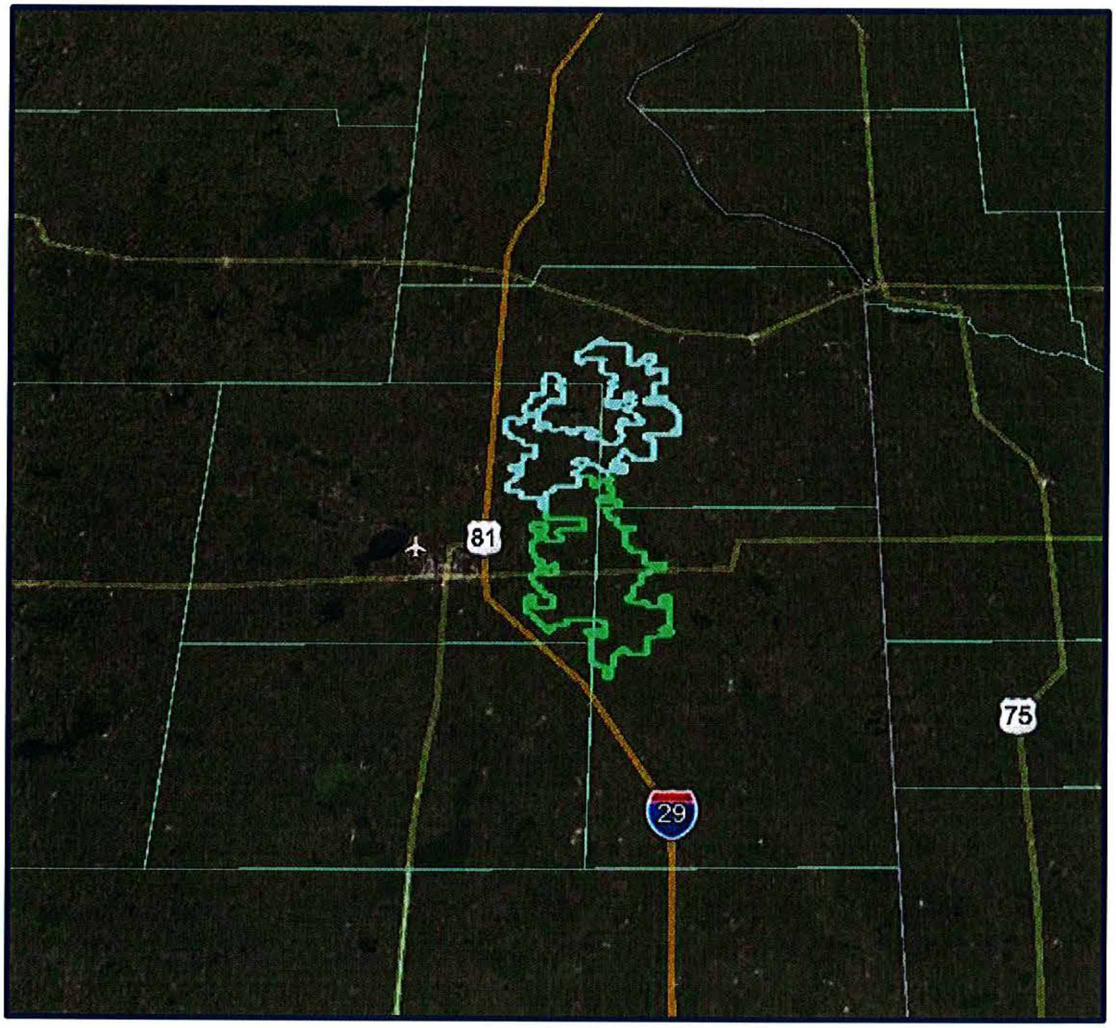
Predominant Age of Improvements	50+ years
Predominant Quality and Condition	Fair to average
Approximate Percent Developed	<5%
Life Cycle Stage	Second-stability

Conclusions

The subject is located in an area with stable population, and supply and demand factors are expected to be in balance for the foreseeable future. The area is rural in nature and agriculture is the primary demand driver. The subject has access to surrounding communities via Interstate 29 as well as local highways. Overall, it is our opinion that the outlook for the market area is continued stability with no major changes anticipated.

Description of Project

The following description is based on our property inspection, public records, and information provided by the client.



General Data

Approximate Location:	Generally bounded by 149th Street to the north, 472nd Avenue to the east, 182nd Street to the south, and Interstate 29 to the west
Total Area:	Approximately 97,668 acres, or 152.60 square miles.
Shape:	Irregular
Area Location:	The area is located in the southeast portion of the county.

Access

Access to the area is provided by Interstate 29. The area is on a grid system, with every street interval representing one mile. Within the area, several of the roads are paved with asphalt. The remainder of the roads in the area are currently dirt roads that are in various conditions.

Turbines:

Total Number of Turbines:	260
Turbine Type:	GE 2.3 MW, GE 2.1 MW, and GE 1.7 MW. The vast majority of turbines will be GE 2.3 MW.
Turbine Density:	1.70 turbines per square mile
Turbine Height:	432 to 485 Feet

Municipalities

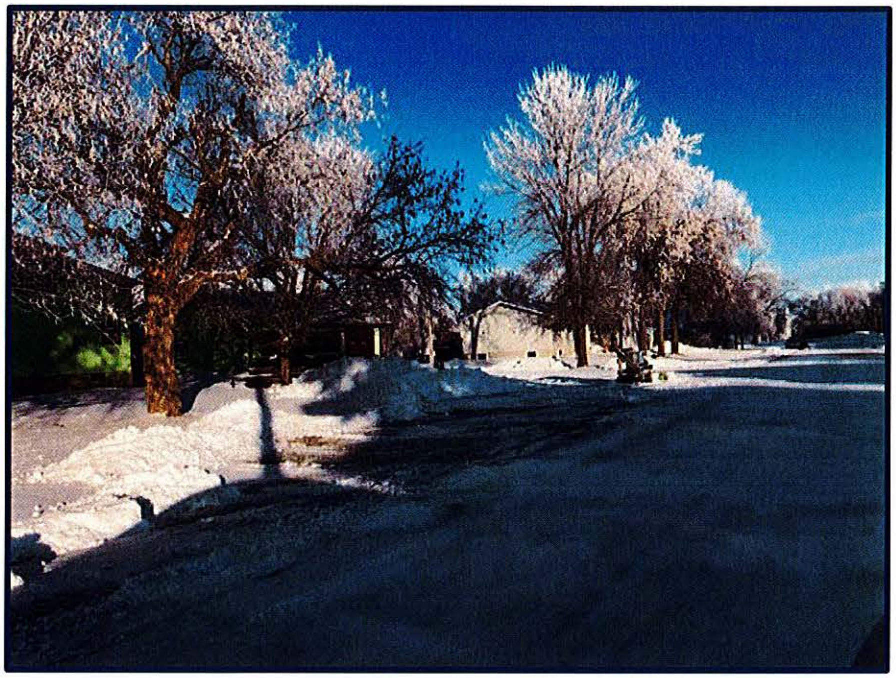
Within the project boundaries, there are a total of four municipalities, including Waverly which is not incorporated. In addition, South Shore is surrounded by the project boundaries in the northern portion of Codington County but is not located within the boundaries. The following table shows the counties on which these cities reside as well as the population reported in the 2010 census.

Name	County	Population
Stockholm	Grant	108
Waverly (Unincorporated)	Codington	37
Kranzburg	Codington	172
Goodwin	Deuel	146

Conclusion

The area of the proposed wind farm is located in northeastern South Dakota and includes portions of Grant, Codington, and Deuel County. The project will contain approximately 260 wind turbines, or an average of 1.70 turbines per square mile. The area is currently agricultural in nature and access to properties are mainly provided by dirt roads. Located within the project boundaries, there are a total of four municipalities.

PHOTOGRAPHS



Single-Family Homes-Kratzburg

Single-Family Homes-Kratzburg

Rural Residential

Agricultural Land

Agricultural Land

Street View

Street View

Street View

Zoning Requirements

We have reviewed the zoning code related to wind projects in each of the three counties. Overall, the zoning requirements are very similar in each of the counties. The zoning requires a 1,500 foot setback from any building structure, defined as home, business, church, school, or building owned or operated by a government entity. There is also at least a 1.0 mile setback from any city located within the counties. The zoning code also require measurable standards to minimize the effects of shadow flicker and sound on structures and non-participating landowners. In addition, the developer of the project must have a haul road agreement which will restore roads to their previous condition after construction of the project.

Grant County

The following information summarizes the ordinance for Grant County.

Setback Requirements

Building Structure:	1,500 feet
Municipal Boundaries:	1.0 Miles
Public Right-Of-Way:	500 Feet, or 110% of the vertical height of the turbine, whichever is greater
Distance From Property Line	500 Feet, or 110% of the vertical height of the turbine, whichever is greater

Noise Standards

The maximum sound level permitted cannot exceed 45 decibels for non-participating residences or 50 decibels for participating residences.

Shadow Flicker

The "Shadow Flicker" effect occurs during the early morning or late evening when the sun is low and the wind turbine creates a shadow. As the turbine blades rotate, a shadow moves and appears to flickers on and off. The developer will analyze the impact of shadow flicker on any building structure within one mile of a turbine. Shadow flicker is not allowed to exceed 30 hours per year on these structures, which is an average of less than five minutes per day.

Roads Requirement

The zoning requires that prior to construction, the developer identifies all haul roads that will be used for the project. The roads that will be subject to excess wear will be repaired after construction subject to a "haul road agreement" with the county. The developer also agrees to repair all private roads that may be damaged during construction and utilize reasonable measures to control dust.

Codington County

The following information summarizes the ordinance for Codington County

Setback Requirements

Building Structure:	1,500 feet
Municipal Boundaries:	1.0 miles
Public Right-Of-Way:	110% of the vertical height of the turbine (Up to 535 feet)
Distance From Property Line	110% of the vertical height of the turbine (Up to 535 Feet)

Noise Standards

The maximum sound level permitted cannot exceed 50 decibels for non-participating residences.

Shadow Flicker

The developer will analyze the impact of shadow flicker on any building structure within one mile of a turbine. Shadow flicker is not allowed to exceed 30 hours per year on these structures, which is an average of less than five minutes per day.

Roads Requirement

The zoning requires that prior to construction, the developer identifies all haul roads that will be used for the project. The roads that will be subject to excess wear will be repaired after construction subject to a "haul road agreement" with the county. The developer also agrees to repair all private roads that may be damaged during construction and utilize reasonable measures to control dust.

Zoning Requirements-Deuel County

The following information summarizes the ordinance for Deuel County.

Setback Requirements

Building Structure:	1,500 feet
Non-Participating Residents:	Four times the height of the turbine (Up to 1,940 feet, depending on the turbine)
Municipal Boundaries:	1.0 to 1.5 Miles. Goodwin requires a setback of 1.0 miles
Public Right-Of-Way:	110% of the vertical height of the turbine (Up to 535 feet)
Distance From Property Line	110% of the vertical height of the turbine(Up to 535 feet)

Noise Standards

The maximum sound level permitted cannot exceed 45 decibels for non-participating residences.

Shadow Flicker

The developer will analyze the impact of shadow flicker on any building within one mile of a turbine. Shadow flicker is not allowed to exceed 30 hours per year on these structures, which is an average of less than five minutes per day.

Roads Requirement

The zoning requires that prior to construction, the developer identifies all haul roads that will be used for the project. The roads that will be subject to excess wear will be repaired after construction subject to a "haul road agreement" with the county. The developer also agrees to repair all private roads that may be damaged during construction and utilize reasonable measures to control dust.

Impact of the Project

In this section, we discuss the impact of the project on the utility of surrounding properties. As discussed earlier, the area is primarily agricultural in nature with four cities located within the boundaries. Therefore, our analysis has focused on how the project will impact agricultural land and residential properties. Real estate markets are influenced by attitudes, interactions and the motivations of buyers and sellers in a particular market. Real estate values are affected by risk and future expectations. The proposed Crown Ridge Wind Project will represent an externality on the surrounding properties, which is defined as "1. The principle that economies outside a property have a positive effect on value while diseconomies outside a property have a negative effect on value. 2. In appraisal, off-site conditions that affect a property's value. Exposure to street noise or proximity to blighted property may exemplify negative externality, whereas proximity to attractive or well-maintained properties or easy access to mass transit may exemplify positive externalities." (Dictionary of Real Estate Appraisal, Sixth Edition). Below, we discuss both the positive and negative externalities that the proposed project will have on surrounding land uses.

Positive Externalities

The project will have several positive externalities that should improve the value of surrounding agricultural, and residential properties. These positive externalities include:

1. Job growth in the area, including temporary construction jobs that will last for about one year, and permanent jobs that are necessary for the maintenance of the project.
2. Annual payments made to local owners for the leasing of the land.
3. Additional property tax revenue that will be paid by the project. A large portion of this tax revenue will fund the local school districts. The quality of schools are an important consideration to the valuation of residential properties.

Agricultural

Agricultural land has specific characteristics that are important to value, according to The Appraisal of Real Estate, 14th Edition. These characteristics include location and distance to major markets, climate and potential crops that can be grown, crop values, soil quality, water rights, and environmental controls. Agricultural land values are determined by the future expected rate of return, either through the value of the crops sold or rental payments that can be collected through leases.

The zoning in each of the three counties requires the project to have as minimal impact as possible on the surrounding agricultural uses. The developer must mitigate any impact the construction will have on the surrounding topsoil, compaction of land during all phases of the projects life and only clear the site to the extent that it is necessary to ensure suitable access of construction and safe operation and maintenance of the project. Also, each of the three counties has a "road haul" agreement that the developer will repair all roadways after completion of construction of the project. The developer also agrees to repair all private roads that may be damaged during construction and utilize reasonable measures to control dust. In order to install the wind turbines, the developers will need to access public roadways in the area. The project will also require the construction of interior roadways that will provide access to the turbines themselves. Farm equipment will be able to cross these interior roads and they will not meaningfully interfere with the surrounding agricultural uses.

Residential

Major characteristics that affect residential values are location and distance to employment and support services, quality of schools, size, condition, number of bedrooms and bathrooms, and layout. Concerns about the nuisance impacts of wind projects on residential property values, can generally be categorized as follows:

1. View: Some people believe that the wind turbines are unattractive and tower over surrounding homes in the area. The issue of view is mitigated by the zoning requirements in each of the three counties. A turbine is not allowed to be constructed within 1,500 feet of a building structure such as a home, business, church, school, or building owned or operated by a government entity. A turbine also cannot be constructed within 1.0 miles (5,280 feet) of a municipality. The zoning requirements do permit participating landowners to construct turbines close to occupied structures, up to a distance of only 550 linear feet. However, an official and NextEra Energy Resources informed us that they try to minimize the construction of turbines closer than 1,500 linear feet for participating landowners.
2. Sound: The wind turbines can produce a whooshing sound during operation. The effect of this sound on the surrounding area is also mitigated by the zoning requirements. The maximum sound level permitted at the boundary of the district shall not exceed 50 decibels for a non-participating landowner in each of the three counties. Grant County and Deuel County requires that sound be not exceed 45 decibels for non-participating landowners.

   The decibel is a logarithmic unit used to express the intensity of sound, where 10 db corresponds to a change in power by a factor of 10. 50 decibels is considered to be moderate noise and is approximately as loud as a typical dishwasher or a mid-size window air conditioner. The sound levels are considered to be low enough to have a minimal impact on residential use.

3. Shadow Flicker: The "Shadow Flicker" effect occurs during the early morning or late evening when the sun is low and the wind turbine creates a shadow. As the turbine blades rotate, a shadow moves and appears to flickers on and off. The location of the shadow varies by time of day and season, but usually only falls on a single location for a few minutes each sunny day. The issue of shadow flicker is mitigated by the zoning requirements in each of the three counties. The zoning requires that a shadow flicker analysis be conducted on any school church, business or occupied dwelling within a one-mile radius of turbine. Shadow flicker at any of these building shall not exceed 30 hours per year, which equates to an average of approximately five minutes per day.

Conclusion

The area surrounding the wind farms is mainly agricultural with a total of four cities within the project area. The project will have several positive externalities which should have a positive impact on property values, including job growth in the area, rental payments to other property owners, and additional tax revenue. The zoning requirements require the project to have as minimal impact as possible on the surrounding agricultural uses. Based upon our discussion with market participants, the project is not considered to have a major impact on the utility of agricultural use in the area. There is a concern in the market for nuisance impacts on residential uses, which include obstructed view, sound, and shadow flicker. However, these nuisance impacts are diminished by the zoning requirements at the project for each of the three counties.

Academic Literature

We have reviewed current academic literature that has examined if wind farms have an impact on surrounding residential, commercial or agricultural real estate values. We have searched Google Scholar and JSTOR, a digital library that contains full text for more than 2,000 academic journals. We have also reviewed articles from third party sources such as Realtor.com, American Wind Energy Association, and Wind-Watch.org, a website that is critical of Wind Energy Projects. Our standards require that the articles described below have been published in an academic peer-reviewed journal, and that the areas analyzed are located within the United States.

In all, we have reviewed three articles that are discussed in greater detail below. Each of the three articles found that the impact of wind farms on surrounding home values is not statistically significant. A result that is statistically significant is not likely to occur randomly, but rather is likely to be attributable to a specific cause. Before these tests were performed, a threshold value of 0.1, or 10%, was chosen as a significance level. In other words, none of the studies were able to predict with a 90% confidence that any decrease in property value was due to the presence of the wind farm, as opposed to other factors. The ability to find results that are statistically significant increases as the sample size increases. Within the past several years, there have been several studies that have analyzed a large number of sales over a much longer period that have added to our understanding of the affect that wind turbines have on surrounding property values. Below, we quote the abstract of these articles and briefly discuss the results.

1. Corey Lang, James J. Opaluch and George Sfinarolakis. "The windy city: Property value impacts of wind turbines in an urban setting." *Energy Economics* (June 2014)

"This paper examines the impact of wind turbines on house values in Rhode Island. In contrast to wind farms surrounded by sparse development, in Rhode Island single turbines have been built in relatively high population dense areas. As a result, we observe 48,554 single-family owner-occupied transactions within five miles of the turbine site, including 3,254 within one mile, which is far more than most related studies... Across a wide variety of specifications, the results suggest that wind turbines have no statistically significant negative impacts on house prices, in either the post public announcement phase or post construction phase. Further, the lower bound of statistically possible impacts is still outweighed by the positive externalities generated by CO2 mitigation."

The article used three models to examine the effects on property values within ½ mile, one mile, two miles and three miles during both the post-announcement pre-construction phase as well as the post-construction phase. For homes located within one half mile of a turbine, the study found an effect on value of less than 1% in both phases. For homes between one half mile and one mile from a turbine, the authors found an effect of -2% to -3% in the post announcement, pre-construction phase. However, there was essentially no effect on home values in the post construction phase. The following table shows the results of the study. The top line shows the impact on home values, while the line below in parenthesis shows the standard deviations. None of the results are statistically significant.

Difference-in-differences		Model 1	Model 2	Model 3
2 - 3 miles	PAPC	-0.008	-0.009	-0.008
		(0.020)	(0.020)	(0.018)
	PC	0.007	0.008	0.006
		(0.014)	(0.014)	(0.015)
1 - 2 miles	PAPC	-0.041	-0.040	-0.039
		(0.037)	(0.036)	(0.036)
	PC	-0.002	-0.009	-0.010
		(0.017)	(0.019)	(0.018)
0.5 - 1 miles	PAPC	-0.029	-0.032	-0.029
		(0.030)	(0.028)	(0.028)
	PC	-0.001	0.003	0.002
		(0.033)	(0.031)	(0.030)
0 - 0.5 miles	PAPC	-0.009	-0.001	-0.004
		(0.060)	(0.053)	(0.054)
	PC	-0.004	-0.001	-0.004
		(0.042)	(0.039)	(0.038)

2. Carol Atkinson-Palombo and Ben Hoen "Relationship between Wind Turbines and Residential Property Values in Massachusetts." *A Joint Report of University of Connecticut and Lawrence Berkeley National Laboratory* (January 2014)

"To determine if wind turbines have a negative impact on property values in urban settings, this report analyzed more than 122,000 home sales, between 1998 and 2012, that occurred near the current or future location of 41 turbines in densely-populated Massachusetts communities. The results of this study do not support the claim that wind turbines affect nearby home prices... Weak evidence suggests that the announcement of the wind facilities had a modest adverse impact on home prices, but those effects were no longer apparent after turbine construction and eventual operation commenced. The analysis also showed no unique impact on the rate of home sales near wind turbines."

This study was able to find the statistically significant effects from a variety of negative features, such as landfills and major roadways, as well as positive features such as beaches. In fact, the study found a small positive impact (0.5%) on value for single-family homes within a half mile of the turbine, although this impact was not statistically significant.

3. Ben Hoen, Jason P. Brown, Thomas Jackson, Ryan Wiser, Mark Thayer and Peter Capers. "A Spatial Hedonic Analysis of the Effects of Wind Energy Facilities on Surrounding Property Values in the United States." *Ernest Orlando Lawrence Berkeley National Laboratory* (August 2013)

This study "collected data from more than 50,000 home sales among 27 counties in nine states. These homes were within 10 miles of 67 different wind facilities, and 1,198 sales were within one miles of a turbine—many more than previous studies had collected. The data span the periods well before the announcement of the wind facilities to well after their construction...Regardless of model specification, we find no statistical evidence that home values near turbines were affected in the post-construction or post announcement/pre-construction periods."

The article used various models to examine the effects on property values within ½ mile and one mile during both the post-announcement pre-construction phase as well as the post-construction phase. The models showed some moderate effects for home values, mostly in the range of a 0% to 4% decrease in home values. However, none of the results were statistically significant. For an effect in the post-construction period to be found for homes within one mile of a turbine, then a difference in value of 4.9%, either positive or negative, would have to be present. Therefore, it is highly unlikely that the average effect for homes located within one mile of a turbine is larger than +/-4.9%.

Conclusion

In all, we reviewed a total of three academic articles that have appeared in peer reviewed journals over the past five years. In each of the articles that we that we reviewed, the results of the study showed that the effects on wind farms on surrounding property value were not statistically significant. We would expect that the impact on property values to be the greatest on homes that are very close to a wind turbine, where the nuisances are most apparent. Many of the studies that we reviewed were in densely populated areas in the northeast. The area around the proposed project is generally rural in nature. It is typical for a single-family home to represent only a small portion of the total value of an agricultural farm. Therefore, we would expect the impact on value to be even less than in densely populated areas that have been discussed earlier. Considering the results of the academic literature, as well as the rural nature of the area, we would expect there to be no measurable impact on property values.

Paired Sales Analysis-Agricultural Land

Methodology

According the The Appraisal of Real Estate, 14th Edition, published by the Appraisal Institute, paired data analysis is defined as follows:

> *A quantitative technique used to identify and measure adjustments to the sale prices or rents of comparable properties; to apply this technique, sales or rental data on nearly identical properties except for one characteristic is analyzed to isolate the single characteristic's effect on value or rent.*[1]

The text also cautions that *paired data analysis should be made with extreme care to ensure that the properties are truly comparable and that other differences do not exist.*[2]

The sales comparison approach is based on the premise that a buyer would pay no more for a specific property than the cost of obtaining a property with the same quality, utility, and perceived benefits of ownership. It is based on the principles of supply and demand, balance, substitution and externalities. In the sales comparison approach, an indication of market value is developed by analyzing closed sales of similar properties, using the most relevant units of comparison. The comparative analysis focuses on the difference between the comparable sales and the subject property using all appropriate elements of comparison.

Methodology

We have examined sales in Brookings County, South Dakota in order to determine the impact on wind turbines on agricultural land. Brookings County is the home of three wind farms that began operation between 2008 and 2010. The MinnDakota Wind Farm is located on the eastern edge of the county and contains a total of 36 turbines and began operation in 2008. The Buffalo Ridge I Wind Farm is located in the northern portion of the county and contains a total of 24 wind turbines. This wind farm began operation in 2009. The Buffalo Ridge II Wind Farm is located in the northern portion of the Brookings County and the southern portion of Deuel County. This wind farm contains a total of 105 turbines and began operation in 2010.

In total, we have reviewed all of the sales of agricultural land in Brookings County since the beginning of 2011. We have also reviewed all of the recent agricultural land sales in Deuel County and Day County. Each of these counties have wind farms that have been in operation for since 2009 and 2010 respectively. However, there have been very few sales in the areas around wind turbines in Day County and Deuel County, which have not permitted a paired sales analysis.

[1] The Appraisal of Real Estate, 14th Edition, Appraisal Institute, page 399
[2] Ibid, page 398

Paired Sales Analysis-Brookings County, South Dakota

Unit of Comparison

The primary unit of comparison selected depends on the appraisal problem and nature of the property. The primary unit of comparison in the market for agricultural land is price per acre.

Elements of Comparison

Elements of comparison are the characteristics or attributes of properties and transactions that cause the prices of real estate to vary. The main elements of comparison that should be considered in sales comparison analysis are as follows: (1) real property rights conveyed, (2) financing terms, (3) conditions of sale, (4) expenditures made immediately after purchase, (5) market conditions, (6) location and (7) physical characteristics.

Comparable Sales Data

In total, we have examined all of the agricultural land sales in Brookings County since the beginning of 2011, as provided to us by the Brookings County Assessor. We have confirmed the relevant details of each of the sales analyzed in this section with a knowledgeable party, such as a buyer, seller or listing broker.

We have completed a paired sales analysis on properties that are located adjacent to turbines (within 1/2 mile) and properties that are located at least two miles away from a turbine in order to estimate if there is any impact from the project. We have concentrated on properties that are closest to turbines because this is where the perceived negative effects of the wind turbine would be the greatest.

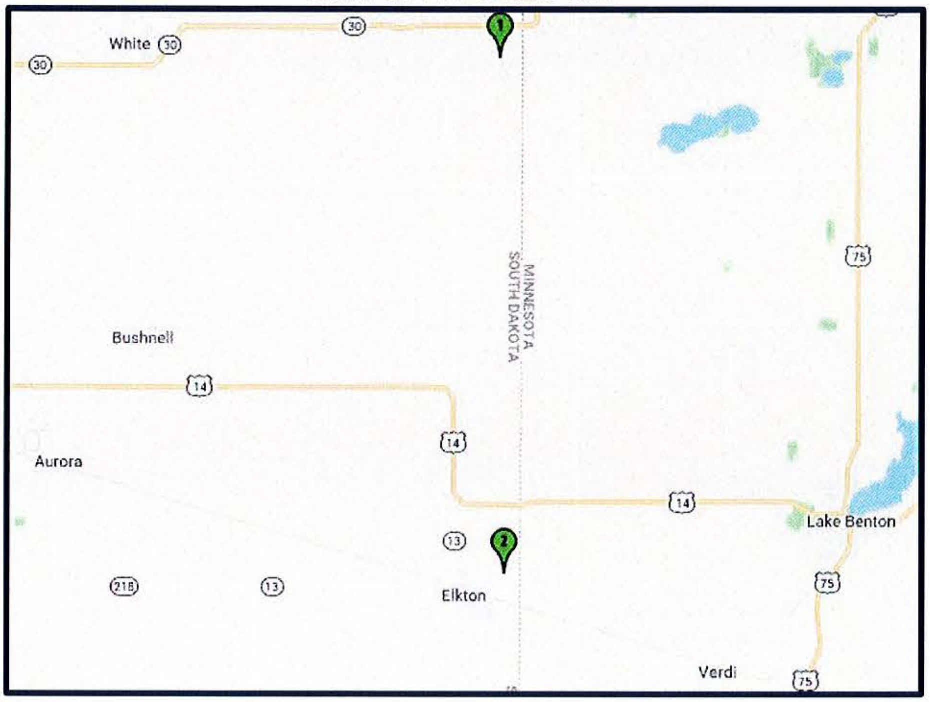
Pair A

The following table summarizes the sales that will be analyzed in Pair A. The subject is crop land located in Hendricks Township. This land has a wind turbines that are located within one half of a mile. Our paired sale is the crop land that is located two miles away from a turbine.

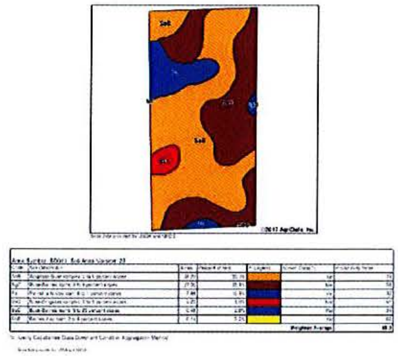
Land Sales Summary

Comp. No.	Date of Sale	Usable Acres	Usable Sq. Ft.	% of Crop Land	Location	Township, County	Sales Price Actual	Per Acre
Sub	September-17	80.000	3,484,800	84%	20380 487th Avenue	Hendricks Township, Brookings County	$340,000	$4,250
1	October-17	80.000	3,484,800	58%	21674 487th Street	Elkton Township, Brookings County	$304,000	$3,800

COMPARABLE SALES MAP



LAND COMPARABLE 1



Property Identification

Property/Sale ID	10240498/674492
Property Type	Agricultural Undeveloped
Property Name	Blackfork Land
Address	20380 487th Avenue
City, State Zip	Hendricks Township, South Dakota 57268
County	Brookings
MSA	0
Latitude/Longitude	44.429756/-96.463238
Tax ID	09000-11147-103-00

Transaction Data

Sale Date	09-19-2017	**Conditions of Sale**	Typical
Sale Status	Closed	**Deed Book/Page**	D151/814
Grantor	Sun Ray Acres	**Sale Price**	$340,000
Grantee	Blackfork, LLC	**Exp. Imm. After Sale**	$0
Property Rights	Fee Simple	**Adjusted Price**	$340,000
Financing	Cash to Seller		

Property Description

Gross Acres	80.000	**Utilities**	Only Electric
Gross SF	3,484,800	**Zoning Jurisdiction**	AG
Usable Acres	80.000	**Zoning Code**	Agricultural
Usable SF	3,484,800		

Indicators

$/Gross Acre	$4,250	**$/Usable Acre**	$4,250
$/Gross SF	$.10	**$/Usable SF**	$.10

Verification

Confirmed With	Seller Broker-Heller Group Land Sales
Confirmation Date	12-12-2018

Remarks

Property was sold at auction. According to the listing broker, the wind turbines were not a significant concern during the listing. The buyer received a small amount of income for easement on the northern edge of their property so that the wind farm operator (MinnDakota Wind, LLC) could access a turbine located one quarter mile to the east. However, the listing broker did not believe that this small amount of income had an impact on the sales price.

LAND COMPARABLE 2

Property Identification

Property/Sale ID	10240538/674514
Property Type	Agricultural Undeveloped
Property Name	Xochitil Enterprises
Address	21674 487th Street
City, State Zip	Elkton Township, South Dakota 57026
County	Brookings
MSA	0
Tax ID	070001094715210

Transaction Data

Sale Date	10-10-2017	**Financing**	Typical
Sale Status	Closed	**Conditions of Sale**	Typical
Grantor	Henrietta Dezeeuw	**Deed Book/Page**	D151/872
Grantee	Xochitl Enterprises	**Sale Price**	$304,000
Property Rights	Fee Simple	**Adjusted Price**	$304,000

Property Description

Gross Acres	80.000	**Utilities**	Electric Only
Gross SF	3,484,800	**Zoning Jurisdiction**	AG
Usable Acres	80.000	**Zoning Code**	Agricultural
Usable SF	3,484,800		

Indicators

$/Gross Acre	$3,800	**$/Usable Acre**	$3,800
$/Gross SF	$.09	**$/Usable SF**	$.09

Verification

Confirmed With	Burlege Peterson Auctioneers and Realtors
Confirmed By	Andrew Baker
Confirmation Date	12-12-2018

Land Sales Comparison Analysis

We analyzed the sales and made adjustments for differences in the elements of comparison previously listed. The comparable sales are adjusted to the subject: if the comparable sale was superior to the subject, we applied a negative adjustment to the comparable sale. A positive adjustment to the comparable property was applied if it was inferior to the subject. A summary of the elements of comparison follows.

Transaction Adjustments

These items are applied prior to the application of property adjustments. Transaction adjustments include:

1. Real Property Rights Conveyed
2. Financing Terms
3. Conditions of Sale
4. Expenditures Made Immediately After Purchase
5. Market Conditions

Real Property Rights Conveyed

Before a comparable sale property can be used in the sales comparison approach, we must first ensure that the sale price of the comparable property applies to property rights that are similar to those being appraised. In the case of the subject property, a fee simple interest is being appraised. All of the sales should reflect a similar interest or an adjustment would be required for this element of comparison. Each of the sales was sold on the fee simple basis and no adjustment is required.

Financing Terms

The transaction price of one property may differ from that of an identical property due to different financial arrangements. Sales involving financing terms that are not at or near market terms require adjustments for cash equivalency to reflect typical market terms. A cash equivalency procedure discounts the atypical mortgage terms to provide an indication of value at cash equivalent terms. Each of the sales provided cash to the seller and no adjustment is required.

Conditions of Sale

When the conditions of sale are atypical, the result may be a price that is higher or lower than that of a normal transaction. Adjustments for conditions of sale usually reflect the motivations of either a buyer or a seller who is under duress to complete the transaction.

A review of the land sales did not indicate any condition of sale adjustments to be warranted for atypical conditions or for sale listings.

Expenditures Made Immediately After Purchase

A knowledgeable buyer considers expenditures that will have to be made upon purchase of a property because these costs affect the price the buyer agrees to pay. Such expenditures may include: (1) costs to cure deferred maintenance, (2) costs to demolish and remove any portion of the improvements, (3) costs to petition for a zoning change, (4) costs to remediate environmental contamination and/or (5) costs to occupy or lease-up the property to a stabilized occupancy

The relevant figure is not the actual cost incurred but the cost that was anticipated by both the buyer and seller. We have made no adjustment to any of the sales in order to account for expenditures made immediately after purchase.

Market Conditions Adjustment

Market conditions may change between the time of sale of a comparable property and the date of the appraisal of the subject property. Changes in market conditions may be caused by inflation, deflation, fluctuations in supply and demand, or other factors. Market conditions that change over time create the need for an adjustment. If market conditions have changed, an adjustment would be required for this element of comparison.

The subject sale (Sale 1) was sold in September 2017. The comparable sale (Sale 2) was sold in October 2018. The sales represent transactions near the same time and no adjustment is required.

Property Adjustments

Property adjustments are usually expressed quantitatively as percentages that reflect the increase or decrease in value attributable to the various characteristics of the property. In some instances, however, qualitative adjustments are used. These adjustments are based on locational and physical characteristics and are applied after the application of transaction adjustments. The adjustments include:

1. Location
2. Size
3. Shape/Depth
4. % Cropland
5. Soil Rating of Cropland

Location

Location adjustments may be required when the locational characteristics of a comparable are different from those of the subject. Each of the comparable sales are located in the eastern portion of Brookings County and no adjustment is considered to be necessary.

Size

The size adjustment identifies variances in the physical size of the comparables and the subject improvements. Typically, the larger a parcel, the lower the sale price per unit. This has to do, in part, with the fact that there is a larger pool of potential purchasers for smaller sites. We have made no adjustment to any of the sales in order to account for differences in size.

Shape

Each of the comparable sales have a rectangular shape and no adjustment is considered to be necessary

Percent Cropland

The subject sale (Sale 1) has 84% of the total land area as cropland. The comparable sale (Sale 2) has 58% of the total land are as cropland. We have adjusted Sale 2 upward 10% in order to account for its inferior amount of cropland.

Soil Rating of Cropland

According to information provided by Surety AgriData, Sale 1 has a productivity index of 65.3 and Sale 2 has a productivity index of 67.3. The soil rating of the two sales is considered to be similar and no adjustment is required.

Summary of Adjustments

Based on the preceding analysis, we have summarized adjustments to the sale comparables on the following adjustment grid. These quantitative adjustments are based on our market research, best judgment, and experience in the appraisal of similar properties.

Land Sales Adjustment Grid

Subject	Subjectt	Comp 1
Sale ID	674492	674514
Date of Value & Sale	September-17	October-17
Unadjusted Sales Price	$340,000	$304,000
Usable Acres	80.000	80.000
Unadjusted Sales Price per Usable Acre	**$4,250**	**$3,800**
Transactional Adjustments		
Property Rights Conveyed	*Fee Simple*	*Fee Simple*
Adjusted Sales Price	$4,250	$3,800
Financing Terms	*Cash to Seller*	*Typical*
Adjusted Sales Price	$4,250	$3,800
Conditions of Sale	*Typical*	*Typical*
Adjusted Sales Price	$4,250	$3,800
Expenditures after Sale	*$0*	
Adjusted Sales Price	**$4,250**	**$3,800**
Market Conditions Adjustments		
Elapsed Time from Date of Value	*-117.80 years*	*-117.86 years*
Market Trend Through	-	-
Analyzed Sales Price	**$4,250**	**$3,800**
Physical Adjustments		
Location	*20380 487th Avenue*	*21674 487th Street*
	Hendricks Township, South Dakota	*Elkton Township, South Dakota*
Adjustment	-	-
Size	*80.000 acres*	*80.000 acres*
Adjustment	-	-
Shape/Depth	*Rectangular*	*Rectangular*
Adjustment	-	-
% Cropland	*84%*	*58%*
Adjustment	-	10.0%
Soil Rating of Cropland	*65.3*	*67.3*
Adjustment	-	-
Net Physical Adjustment	-	10.0%
Adjusted Sales Price per Usable Acre	**$4,250**	**$4,180**

Conclusion-Analysis Pair A

From the market data, two sales in competitive market areas were selected as most comparable. The subject sale (Sale 1) is located within a half mile of a wind turbine has a sale price of $4,250 per acre. The comparable sale (Sale 2) is not located near a wind turbine and had a sale price of $3,800 per acre. We have adjusted our paired sale upward 10% as this property contains a lower percentage of cropland than the subject. The difference in adjusted sales price was a positive 1.7% for the subject sale.

Pair B

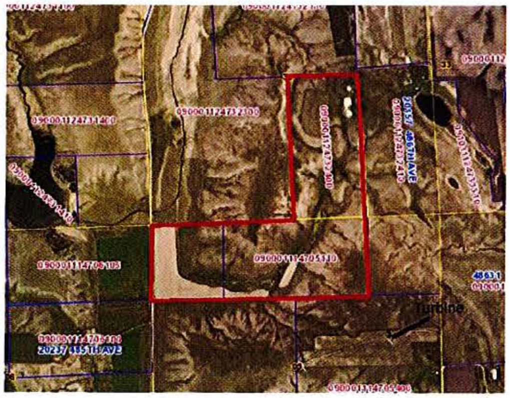
The following table summarizes the sales that will be analyzed in Pair B. The subject (Sale 3) is pasture land, which is located within one half mile of a wind turbine. Our paired sale (Sale 4) is also pasture land that is located about 2.5 miles away from the nearest wind turbine.

Land Sales Summary

Comp. No.	Date of Sale	Usable Acres	Usable Sq. Ft.	% of Crop Land	Location	Township, County	Sales Price Actual	Per Acre
SUB	July-15	206.450	8,992,962	9%	20240 485th Avenue	Lake Hendricks Township, Brookings County	$500,640	$2,425
1	December-13	240.000	10,454,400	0%	48461 200th Street	Oaklake Township, Brookings County	$679,200	$2,830

COMPARABLE SALES MAP

LAND COMPARABLE 3



Property Identification

Property/Sale ID	10240513/674501
Property Type	Agricultural Undeveloped
Property Name	Pasture Land
Address	20240 485th Avenue
City, State Zip	Lake Hendricks Township, South Dakota 57268
County	Brookings
MSA	0
Latitude/Longitude	44.447185/-96.499529
Tax ID	09000-11147-052-00, 09000-11147-051-10, 09000-11247-324-00

Transaction Data

Sale Date	07-10-2015	**Conditions of Sale**	Typical
Sale Status	Closed	**Deed Book/Page**	D149/676
Grantor	Leona Moen Trust	**Sale Price**	$500,640
Grantee	Eastview Farms, LLC	**Exp. Imm. After Sale**	$0
Property Rights	Fee Simple	**Adjusted Price**	$500,640
Financing	Cash to Seller		

Property Description

Gross Acres	206.450	**Utilities**	Electric Only
Gross SF	8,992,962	**Zoning Jurisdiction**	Ag
Usable Acres	206.450	**Zoning Code**	Agricultural
Usable SF	8,992,962		

Indicators

$/Gross Acre	$2,425	**$/Usable Acre**	$2,425
$/Gross SF	$.06	**$/Usable SF**	$.06

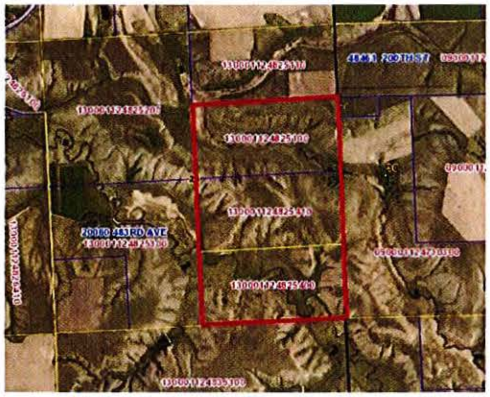
Verification

Confirmed With	Tyler Burlage-Burlage Peterson Auctions
Confirmed By	Andrew Baker
Confirmation Date	12-12-2018

Remarks

Property was sold at auction and purchased as pasture ground for cattle. According to the listing broker, the price was in-line with other pasture ground in the area, which was in the range of $2,000 to $2,500 as of 2015.

LAND COMPARABLE 4



zweep land

Property Identification

Property/Sale ID	10240643/674611
Property Type	Agricultural Undeveloped
Property Name	Zweep Land
Address	48461 200th Street
City, State Zip	Oaklake Township, South Dakota 57268
County	Brookings
MSA	0
Latitude/Longitude	44.475726/-96.531053
Tax ID	13000-11248-251-00, 13000-11248-254-00, 13000-11248-254-10

Transaction Data

Sale Date	12-06-2013	**Financing**	Cash to Seller
Sale Status	Closed	**Conditions of Sale**	Typical
Grantor	Emily Reitman Et Al	**Deed Book/Page**	D147/1093
Grantee	Thomas William Zweep Et Al	**Sale Price**	$679,200
		Exp. Imm. After Sale	$0
Property Rights	Fee Simple	**Adjusted Price**	$679,200

Property Description

Gross Acres	240.000	**Utilities**	Electric Only
Gross SF	10,454,400	**Zoning Code**	Ag
Usable Acres	240.000	**Zoning Description**	Agricultural
Usable SF	10,454,400		

Indicators

$/Gross Acre	$2,830	**$/Usable Acre**	$2,830
$/Gross SF	$.06	**$/Usable SF**	$.06

Verification

Confirmed With	Dale Zweep (Representative of Buyer)
Confirmation Date	12-12-2018

Remarks

Property was purchased as pasture ground for cattle ranching.

Transaction Adjustments

We have made no adjustment to any of transaction adjustments that we have previously described. The subject sale (Sale 3) was sold in September 2017. The comparable sale (Sale 4) was sold in October 2018. The sales represent transactions near the same time and no adjustment is required.

Property Adjustments

Location

Each of the comparable sales are located in the eastern portion of Brookings County and no adjustment is considered to be necessary.

Size

The size adjustment identifies variances in the physical size of the comparables and the subject improvements. Typically, the larger a parcel, the lower the sale price per unit. This has to do, in part, with the fact that there is a larger pool of potential purchasers for smaller sites. The subject sale (Sale 3) contains 206.45 acres and the comparabl sale (Sale 3) contains 240.00 acres. The sales are considered to have a similar size and no adjustment is considered to be necessary.

Shape

The subject sale (Sale 2) has an irregular shape. In addition, the listing broker informed us that the fence around this property was in poor condition and the shape would increase the costs to replace this fence. The comparable sale (Sale 4) has a rectangular shape and has been adjusted downward 10% in order to account for its superior shape.

Land Sales Adjustment Grid

Subject	Subject	Comp 1
Sale ID	674501	674611
Date of Value & Sale	July-15	December-13
Unadjusted Sales Price	$500,640	$679,200
Usable Acres	206.450	240.000
Unadjusted Sales Price per Usable Acre	**$2,425**	**$2,830**
Transactional Adjustments		
Property Rights Conveyed	*Fee Simple*	*Fee Simple*
Adjusted Sales Price	$2,425	$2,830
Financing Terms	*Cash to Seller*	*Cash to Seller*
Adjusted Sales Price	$2,425	$2,830
Conditions of Sale	*Typical*	*Typical*
Adjusted Sales Price	$2,425	$2,830
Expenditures after Sale	*$0*	*$0*
Adjusted Sales Price	**$2,425**	**$2,830**
Market Conditions Adjustments		
Elapsed Time from Date of Value		
Market Trend Through	-	-
Analyzed Sales Price	**$2,425**	**$2,830**
Physical Adjustments		
Location	*20240 485th Avenue*	*48461 200th Street*
	Lake Hendricks Township, South Dakota	*Oaklake Township, South Dakota*
Adjustment	-	-
Size	*206.450 acres*	*240.000 acres*
Adjustment	-	-
Shape/Depth	*Irregular*	*Rectangular*
Adjustment	-	-10.0%
Net Physical Adjustment	-	-10.0%
Adjusted Sales Price per Usable Acre	**$2,425**	**$2,547**

Analysis-Pair B

We have adjusted our paired sale downward 10% as this property contains a lower percentage of cropland than the subject. The difference in adjusted sales price was 1.0%.

Conclusion-Paired Sales B

The subject sale (Sale 3) is located within a half mile of a wind turbine has a sale price of $2,425 per acre. The comparable sale (Sale 4) is not located near a wind turbine and had a sale price of $2,830 per acre. We have adjusted our paired sale downward 10% due to its superior shape. The difference in adjusted sales price was a negative 4.8% for the subject sale.

Interviews with Market Participants in Brookings County

During the course of our research, we interviewed multiple individuals that had purchased or sold property in the area in order to determine what impact the wind turbines had on their marketing and sales prices.

David Bierman is a farmland manager for Capitaline, a company based in Brookings, South Dakota that invests in farmland throughout the region. He confirmed to us several sales of farmland that Capitaline had purchased near wind turbines in Brookings County. This included Sale 1 that was previously analyzed in this section. In addition, he confirmed the sale of 250.00 acres of cropland with four wind turbines that Capitaline had purchased for $5,190 per acre in April 2018. He was not able to disclose the income that was received from these wind turbines. He said that the company did not see a negative impact for those properties located near turbines as it did not impact the agricultural uses at the site. He said that there may be a slight positive impact on value if there was the potential to add turbines to farmland in the future.

Tyler Burlege is a listing broker with Burlege Peterson Auctioneers. He confirmed to us the details of Sale 3 which were previously analyzed in this section. He estimated that at the time of this sale (July 2015) that pasture land in the region was selling in the range of $2,000 to $2,500 per acre. He said that he did not believe that the presence of the wind turbines had an impact on the sale price.

Pat Keltgen is an associate broker with Heller Group Land Sales. She confirmed to us the details of Sale 1, which was previously analyzed in this section. She informed us that this the buyer received a small amount of income from an easement to access a wind turbine directly to the east of this land. However, she did not believe that this additional income had a major impact on the sale price. Overall, she did not believe that the presence of the wind turbines had an impact on the sale price.

In addition to the sales analyzed in this section, we spoke with an official as the Brookings County Equalization Department. Based upon the sales that they have reviewed, Brookings County does not make any adjustment to property value for the presence of wind turbines.

Paired Sales Analysis-Residential Property

Methodology

In order to determine the impact of wind farms on residential property, we examined sales that were located in cities. Residences on large farms may only be a small portion of the overall value of the property, which makes precise adjustment difficult to measure. We have focused on repeat sales of homes that sold shortly before the construction of the wind farm and shortly after the construction of the wind. We have examined sales in the City of Toronto and City of Astoria, which are located in southern Deuel County near the Buffalo Ridge II wind farm. However, there have been very few sales in these cities and we were not able to find any repeat sales.

Our focus on the impact of wind turbines on residential properties have focused on two cities in Ford County, Kansas. Ford County is the home of the Speavrille Wind Farm, which was constructed in three stages in 2006, 2008 and 2012. In total, this wind farm contains approximately 160 turbines. The windfarm completely surrounds the City of Speaville in all directions. There are multiple turbines that are located within a half mile of the municipality. This is closer than the zoning requirements in Grant County, Codington County and Deuel County, which each require a one mile setback from a municipality.

City of Spearville

The City of Spearville is located approximately 15 miles to the northeast of Dodge City, Kansas. As of the 2010 census, Spearville had a total population of 773 and the population has been steadily growing in recent years. This is in contrast to many of the small towns in the area, which typically have a stable or decreasing population. The following table shows basic demographic information for Spearville, Kansas.

Neighborhood Demographics

Demographics	Spearville, KS
Population Summary	
2000 Population	736
2010 Population	773
2016 Estimated Population	836
2021 Estimated Population	887
Annual % Change (2016 - 2021)	1.2%
Household Summary	
2016 Estimated Households	343
% Owner Occupied	72.3%
% Renter Occupied	21.6%
Income Summary	
2016 Estimated Median Household Income	$59,788
2021 Estimated Median Household Income	$71,604
Annual % Change	4.0%


Constructed in 2006
Spearville Truck Stop
Spearville
B & S Drywall & Construction
Constructed in 2012
Google

Market Analysis-City of Spearville

The following is an analysis of the current residential market trends from 2001 to 2016 in the Spearville area. We have analyzed every valid residential sale that has been submitted to the Ford County Appraisers Office.

Sale Closings

In total, there have been 210 sales over the 16 year period, or an average of 13.1 sales per year. The data shows that years in which there has been additions to the wind farm (2006, 2008, and 2012) there have been a higher number of sale closings. The data does not show a significant change in the number of sale closings after the construction of the wind projects.

Number of Sales

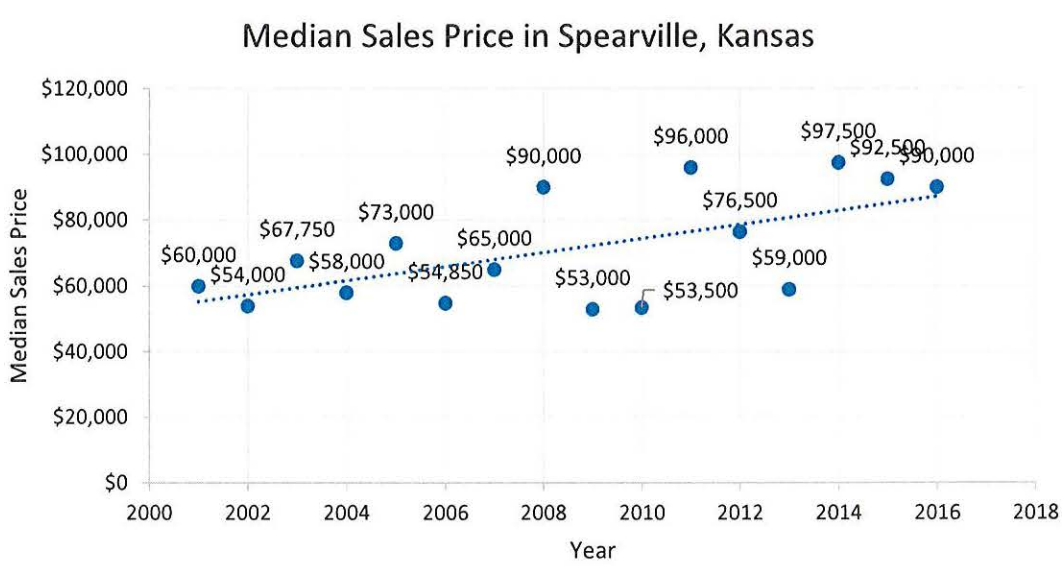
Year	Number of Sales	% Change
2001	12	
2002	26	117%
2003	10	-62%
2004	9	-10%
2005	12	33%
2006	18	50%
2007	16	-11%
2008	19	19%
2009	9	-53%
2010	11	22%
2011	7	-36%
2012	18	157%
2013	9	-50%
2014	12	33%
2015	12	0%
2016	10	-17%
Average:	13.1	
Total:	210	

Median Sale Price

During the 16 year period, sales prices for residential homes have varied between $8,000 and $266,000, with a total median sale price of $67,950. In general, the median sale price of homes has increased steadily over the 16 year period. Median home prices were $60,000 or less in the two years preceding the announcement of the first Spearville Windfarm (2001-2002). Over the previous three full years, median home price have been over $90,000. The following table shows the median sale price each year.

Median Sale Price

Year	Number of Sales	% Change
2001	$60,000	
2002	$54,000	-10%
2003	$67,750	25%
2004	$58,000	-14%
2005	$73,000	26%
2006	$54,850	-25%
2007	$65,000	19%
2008	$90,000	38%
2009	$53,000	-41%
2010	$53,500	1%
2011	$96,000	79%
2012	$76,500	-20%
2013	$59,000	-23%
2014	$97,500	65%
2015	$92,500	-5%
2016	$90,000	-3%
Total Median Price	$67,950	



Pair A-102 Sill Street

The following table summarizes the sales that will be analyzed in Pair A. Pair A is a single-family home located at 102 Sill Street. This property sold for $38,500 in August 2002, which was before the wind farm was approved by the zoning board. The property sold again in August 2006 for $38,000, which indicated a 1% decease in the sales price. Construction on the first phase of Spearville Wind Farm began in April 2006 and was completed in September 2006.

Physical Characteristics-102 Sill Street	
Address	102 Sill Street
City, State	Spearville, KS
Size (SF)	831
Year Built	1940
Number of Bedrooms	2
Number of Bathrooms	1

(102 Sill Street)

102 Sill Street Sale Information	
Sale 1 Information	
Date:	Aug-02
Sale Price:	$38,500
Grantor:	Becki I. Stephenson
Grantee:	Kurt R. Peinter
Book/Page Number:	220/238
Property Rights:	Fee Simple
Financing:	Cash to Seller
Sale 2 Information	
Date:	Aug-06
Sale Price:	$38,000
Grantor:	Kurt R. & Ashley M. Peinter
Grantee:	William M. & Stephanie A. Hornug
Intrument Number:	228/543
Property Rights:	Fee Simple
Financing:	Cash to Seller
Difference in Price	-$500
% Change in Price	-1%
Annual change in Price	0%

Property Adjustments Adjustments-Paired Sale 1

We have made no adjustment to any of transaction adjustments or physical property adjustment that we have previously described. We have also not made adjustment to the physical characteristics of the property. The subject sale (Sale 1) sold in August 2002 for $38,500. The comparable sale (Sale 2) sold in August 2006 for $38,000, which indicated a 1% change in value.

We spoke with the individual who purchased the property in 2002 and sold the property in 2006. He informed us that he got married in 2006 and was trying to quickly sell the house so that he could move to another town with his wife. He said that he believed if he had marketed the property longer in 2006 that he believed he could have gotten a higher sales price. During the time that he owned the property, he made no significant changes or renovations. He further stated that he grew up in Spearville, Kansas and wished to move back but could not due to the high real estate prices.

City of Wright, Kansas

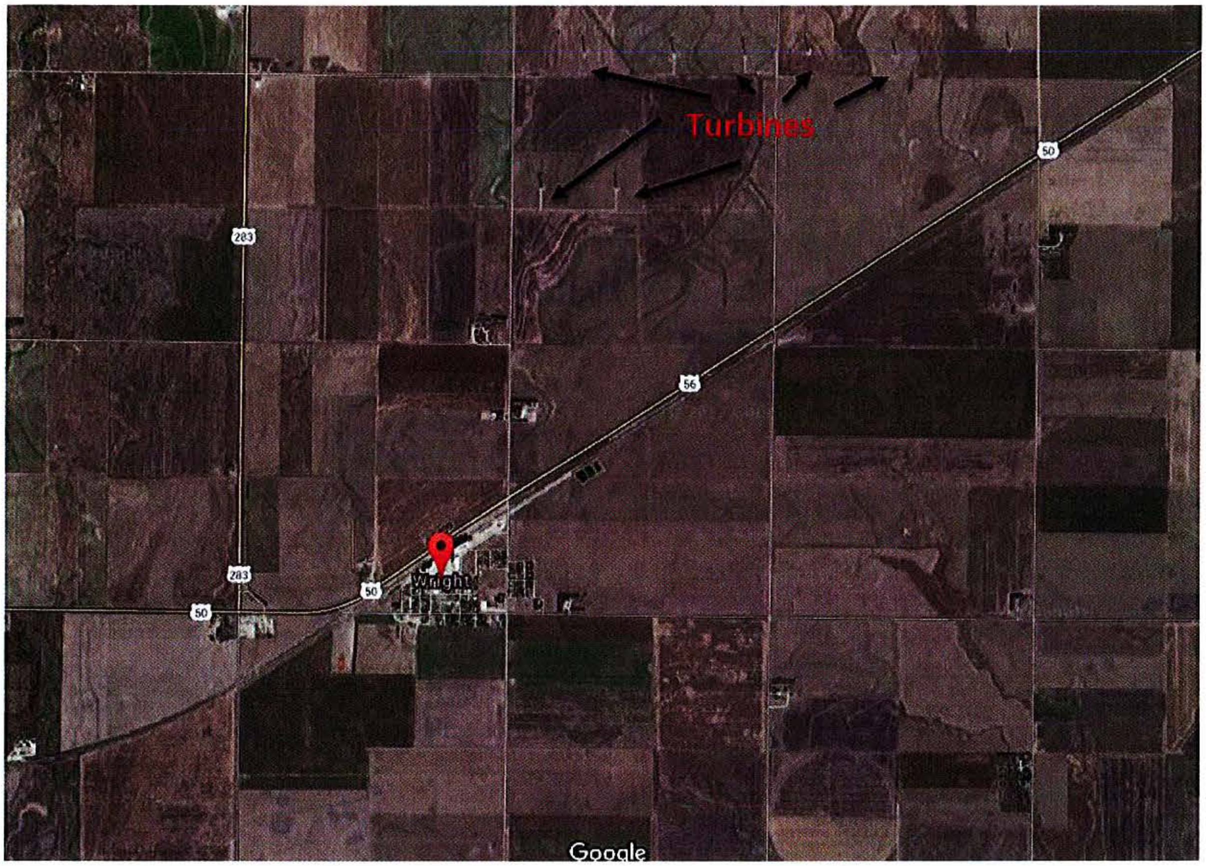
The City of Wright is located approximately five miles to the northeast of Dodge City, Kansas. As of the 2010 census, Wright had a total population of 163 and the population has been relatively stable in recent years. The following table shows basic demographic information for Wright, Kansas.

Neighborhood Demographics

Demographics	Wright, KS
Population Summary	
2010 Population	163
2016 Estimated Population	168
2021 Estimated Population	173
Annual % Change (2016 - 2021)	0.6%
Household Summary	
2016 Estimated Households	67
% Owner Occupied	69.6%
% Renter Occupied	26.1%
Income Summary	
2016 Estimated Median Household Income	$62,932
2021 Estimated Median Household Income	$73,040
Annual % Change	3.2%

Wright is located approximately one mile to the south of wind turbines in the Spearville 3 wind farm. This wind farm contains a total of 72 wind turbines. Construction for this wind farm began in the first quarter of 2012 and began operation in October 2012. The following aerial map shows Wright and the wind turbines that are located approximately one mile to the north.

In order to determine how the addition of the wind turbines has affected residential home values, we have examined repeat sales of homes in the City of Wright.


Turbines
283
50
56
Wright
Google

Pair B-11798 Wiseman Avenue

The following table summarizes the sales that will be analyzed in Pair B. Pair B is a single-family home located at 11796 Wiseman Avenue. This property sold for February 2012, which was shortly before the construction of the Spearville III Wind Farm. This property sold again in December 2014 which was after the completion of the windfarm.

Physical Characteristics-11796 Wiseman Ave	
Address	11796 Wiseman Ave.
City, State	Wright, KS
Size (SF)	1,012
Year Built	1928
Condition	Average
Number of Bedrooms	4
Number of Bathrooms	2

(11796 Wiseman Ave.)

11796 Wiseman Sale Information	
Sale 1 Information	
Date:	Feb-12
Sale Price:	$65,000
Grantor:	James O. Slattery
Grantee:	Christopher A. & Katrina L. Hines
Book/Page Number:	239/277
Property Rights:	Fee Simple
Financing:	Cash to Seller
Sale 2 Information	
Date:	Dec-14
Sale Price:	$65,000
Grantor:	Christopher A. & Katrina L. Hines
Grantee:	Jenny A. Hirschfeld
Intrument Number:	244/418
Property Rights:	Fee Simple
Financing:	Cash to Seller
Difference in Price	$0
% Change in Price	0%
Annual change in Price	0%

Property Adjustments Adjustments-Paired Sale B

We have made no adjustment to any of transaction adjustment that we have previously described. We have also not made adjustment to the physical characteristics of the property. This property sold for $65,000 in February 2012, which was shortly before the construction of the Spearville III Wind Farm. This property sold for $65,000 in February 2012, near the time when construction of the Spearville Wind Farm began. The property sold again in December 2014 for $65,000, which indicates no change.

We spoke with the individual who purchased the property in February 2012 and sold the property in December 2014. He informed us that he had made no changes to the property except for some exterior paint work. He further stated that he did not believe that the construction of the wind farm had any effect on the marketing of the home or the eventual sales price.

Pair C-11970 Doll Street

The following table summarizes the sales that will be analyzed in Pair B. Pair B is a single-family home located at 11796 Wiseman Avenue. This property sold in March 2009 and was sold again in January of 2013.

Physical Characteristics-11790 Doll Street	
Address	11790 Doll Street
City, State	Wright, KS
Size (SF)	1,200
Year Built	1977
Condition	Average to Good
Number of Bedrooms	3
Number of Bathrooms	2

(11790 Doll Street)

11790 Doll Street Sale Information	
Sale 1 Information	
Date:	Mar-09
Sale Price:	$93,000
Grantor:	Kirwin & Kimberly Ricke
Grantee:	Michael & Jamie Hartman
Book/Page Number:	234/50
Property Rights:	Fee Simple
Financing:	Cash to Seller
Sale 2 Information	
Date:	Jan-13
Sale Price:	$117,000
Grantor:	Michael & Jamie Hartman
Grantee:	David & Betty McClaren
Intrument Number:	241/336
Property Rights:	Fee Simple
Financing:	Cash to Seller
Difference in Price	$24,000
% Change in Price	26%
Annual change in Price	7%

Property Adjustments Adjustments-Paired Sale C

We have made no adjustment to any of transaction adjustments adjustment that we have previously described. We have also not made adjustment to the physical characteristics of the property. This property sold for $93,000 in March 2009, which was near the height of the financial crisis that had a negative impact on home values. The property sold again in January 2013 for $117,000, which indicated a 26% change in value, or 7% per year.

We spoke with the individual who purchased the property in January 2013. She informed us that the previous owner had made no significant renovations to the property. Public records lists that a small shed was constructed on the property in 2011. There were no other permits for changes to the property in between the two sale dates. The buyer rented the property to a family member after the sale and did not have any concern about that the wind farm would impact the sales price.

Conclusion

In determining the affect that wind farms have on surrounding property values, we considered the academic literature, interviewed knowledgeable market participants, and analyzed sales data. Based upon all of the academic literature that we have reviewed, the presence of wind turbines does not have a statistically significant impact on surrounding home values. We conducted a paired sales analysis of properties located near wind turbines in Brookings County, South Dakota. The two paired sales that we analyzed did not show any significant impact on property value from the presence of the wind turbines. Interviews with local brokers in Brookings County also do not indicate that the wind turbines have impacted sales prices. Finally, we analyzed sales data for single-family homes in Wright, Kansas and Spearville, Kansas. This data did not show a measurable impact on value for repeat sales of home that occurred shortly before the construction of the wind farm and shortly after construction had been completed. Furthermore, interviews with buyers and sellers do not indicate that that the wind turbines are a significant consideration in determining the sales price.

Based upon our analysis, the report demonstrates the following:

The proposed Crowned Ridge Wind Farm will not measurably impact the value of surrounding properties located within Grant County, Codington County, or Deuel County.

Respectfully submitted,
Valbridge Property Advisors | Kansas City

Andrew Baker

Andrew Baker, MAI
Senior Appraiser
South Dakota Appraiser Permit Number: 1729-T-2018

General Assumptions & Limiting Conditions

This value impact study is subject to the following limiting conditions:

1. All information in this report has been obtained from reliable sources. We cannot, however, guarantee or be responsible for the accuracy of information furnished by others.

2. Possession of this report or a copy thereof does not imply the right of publication or use for any purpose by any other than the addressee, without the written consent of the appraiser. This report was prepared for the sole and exclusive use of the appraiser's client. No third parties are authorized to rely upon this report without the express written consent of the appraiser.

3. The appraiser is not required to give testimony or attendance in court by reason of this study, unless prior agreements have been made in writing.

4. Neither all nor any part of the contents of this report shall be conveyed to the public through advertising, public relations, news, sales, or other media, without the written consent and approval of the author, particularly as to the conclusions, the identity of the consultant or firm with which he is connected, or any reference to the Appraisal Institute.

Certification – Andrew Baker, MAI

I certify that, to the best of my knowledge and belief:

1. The statements of fact contained in this report are true and correct.
2. The reported analyses, opinions, and conclusions are limited only by the reported assumptions and limiting conditions and are my personal, impartial, and unbiased professional analyses, opinions, and conclusions.
3. I have no present or prospective interest in the property that is the subject of this report and no personal interest with respect to the parties involved.
4. The undersigned has previously performed services regarding the impact of wind farms on surrounding property values within the three-year period immediately preceding acceptance of this assignment.
5. I have no bias with respect to the property that is the subject of this report or to the parties involved with this assignment.
6. My engagement in this assignment was not contingent upon developing or reporting predetermined results.
7. My compensation for completing this assignment is not contingent upon the development or reporting of a predetermined value or direction in value that favors the cause of the client, the amount of value opinion, the attainment of a stipulated result, or the occurrence of a subsequent event directly related to the intended use of this appraisal.
8. My analyses, opinions and conclusions were developed, and this report has been prepared, in conformity with the Uniform Standards of Professional Appraisal Practice.
9. Andrew Baker has personally inspected the subject area.
10. No one provided significant real property appraisal assistance to the person signing this certification, unless otherwise noted.
11. The reported analyses, opinions and conclusions were developed, and this report has been prepared, in conformity with the requirements of the Code of Professional Ethics and Standards of Professional Appraisal Practice of the Appraisal Institute.
12. The use of this report is subject to the requirements of the Appraisal Institute relating to review by its duly authorized representatives.
13. As of the date of this report, the undersigned has completed the continuing education program for Designated Members of the Appraisal Institute.

Andrew Baker

Andrew Baker, MAI
Senior Appraiser
South Dakota Appraiser Permit Number: 1729-T-2018

Addenda

Glossary

Definitions are taken from the Dictionary of Real Estate Appraisal, 5th Edition (Dictionary), the Uniform Standards of Professional Appraisal Practice (USPAP) and Building Owners and Managers Association International (BOMA).

Absolute Net Lease

A lease in which the tenant pays all expenses including structural maintenance, building reserves, and management; often a long-term lease to a credit tenant. (Dictionary)

Additional Rent

Any amounts due under a lease that is in addition to base rent. Most common form is operating expense increases. (Dictionary)

Amortization

The process of retiring a debt or recovering a capital investment, typically though scheduled, systematic repayment of the principal; a program of periodic contributions to a sinking fund or debt retirement fund. (Dictionary)

As Is Market Value

The estimate of the market value of real property in its current physical condition, use, and zoning as of the appraisal date. (Dictionary)

Base (Shell) Building

The existing shell condition of a building prior to the installation of tenant improvements. This condition varies from building to building, landlord to landlord, and generally involves the level of finish above the ceiling grid. (Dictionary)

Base Rent

The minimum rent stipulated in a lease. (Dictionary)

Base Year

The year on which escalation clauses in a lease are based. (Dictionary)

Building Common Area

The areas of the building that provide services to building tenants but which are not included in the rentable area of any specific tenant. These areas may include, but shall not be limited to, main and auxiliary lobbies, atrium spaces at the level of the finished floor, concierge areas or security desks, conference rooms, lounges or vending areas food service facilities, health or fitness centers, daycare facilities, locker or shower facilities, mail rooms, fire control rooms, fully enclosed courtyards outside the exterior walls, and building core and service areas such as fully enclosed mechanical or equipment rooms. Specifically excluded from building common areas are; floor common areas, parking spaces, portions of loading docks outside the building line, and major vertical penetrations. (BOMA)

Building Rentable Area

The sum of all floor rentable areas. Floor rentable area is the result of subtracting from the gross measured area of a floor the major vertical penetrations on that same floor. It is generally fixed for the life of the building and is rarely affected by changes in corridor size or configuration. (BOMA)

Certificate of Occupancy (COO)

A statement issued by a local government verifying that a newly constructed building is in compliance with all codes and may be occupied.

Common Area (Public) Factor

In a lease, the common area (public) factor is the multiplier to a tenant's useable space that accounts for the tenant's proportionate share of the common area (restrooms, elevator lobby, mechanical rooms, etc.). The public factor is usually expressed as a percentage and ranges from a low of 5 percent for a full tenant to as high as 15 percent or more for a multi-tenant floor. Subtracting one (1) from the quotient of the rentable area divided by the useable area yields the load (public) factor. At times confused with the "loss factor" which is the total rentable area of the full floor less the useable area divided by the rentable area. (BOMA)

Common Area Maintenance (CAM)

The expense of operating and maintaining common areas; may or may not include management charges and usually does not include capital expenditures on tenant improvements or other improvements to the property.

CAM can be a line-item expense for a group of items that can include maintenance of the parking lot and landscaped areas and sometimes the exterior walls of the buildings. CAM can refer to all operating expenses.

CAM can refer to the reimbursement by the tenant to the landlord for all expenses reimbursable under the lease. Sometimes reimbursements have what is called an administrative load. An example would be a 15 percent addition to total operating expenses, which are then prorated among tenants. The administrative load, also called an administrative and marketing fee, can be a substitute for or an addition to a management fee. (Dictionary)

Condominium
A form of ownership in which each owner possesses the exclusive right to use and occupy an allotted unit plus an undivided interest in common areas.

A multiunit structure, or a unit within such a structure, with a condominium form of ownership. (Dictionary)

Conservation Easement
An interest in real property restricting future land use to preservation, conservation, wildlife habitat, or some combination of those uses. A conservation easement may permit farming, timber harvesting, or other uses of a rural nature to continue, subject to the easement. In some locations, a conservation easement may be referred to as a conservation restriction. (Dictionary)

Contributory Value
The change in the value of a property as a whole, whether positive or negative, resulting from the addition or deletion of a property component. Also called deprival value in some countries. (Dictionary)

Debt Coverage Ratio (DCR)
The ratio of net operating income to annual debt service (DCR = NOI/Im), which measures the relative ability to a property to meet its debt service out of net operating income. Also called Debt Service Coverage Ratio (DSCR). A larger DCR indicates a greater ability for a property to withstand a downturn in revenue, providing an improved safety margin for a lender. (Dictionary)

Deed Restriction
A provision written into a deed that limits the use of land. Deed restrictions usually remain in effect when title passes to subsequent owners. (Dictionary)

Depreciation
1) In appraising, the loss in a property value from any cause; the difference between the cost of an improvement on the effective date of the appraisal and the market value of the improvement on the same date. 2) In accounting, an allowance made against the loss in value of an asset for a defined purpose and computed using a specified method. (Dictionary)

Disposition Value
The most probable price that a specified interest in real property is likely to bring under the following conditions:

- Consummation of a sale within a exposure time specified by the client;
- The property is subjected to market conditions prevailing as of the date of valuation;
- Both the buyer and seller are acting prudently and knowledgeably;
- The seller is under compulsion to sell;
- The buyer is typically motivated;
- Both parties are acting in what they consider to be their best interests;
- An adequate marketing effort will be made during the exposure time specified by the client;
- Payment will be made in cash in U.S. dollars or in terms of financial arrangements comparable thereto; and
- The price represents the normal consideration for the property sold, unaffected by special or creative financing or sales concessions granted by anyone associated with the sale. (Dictionary)

Easement
The right to use another's land for a stated purpose. (Dictionary)

EIFS
Exterior Insulation Finishing System. This is a type of exterior wall cladding system. Sometimes referred to as dry-vit.

Effective Date
1) The date at which the analyses, opinions, and advice in an appraisal, review, or consulting service apply. 2) In a lease document, the date upon which the lease goes into effect. (Dictionary)

Effective Rent
The rental rate net of financial concessions such as periods of no rent during the lease term and above- or below-market tenant improvements (TIs). (Dictionary)

EPDM
Ethylene Diene Monomer Rubber. A type of synthetic rubber typically used for roof coverings. (Dictionary)

Escalation Clause
A clause in an agreement that provides for the adjustment of a price or rent based on some event or index. e.g., a provision to increase rent if operating expenses increase; also called an expense recovery clause or stop clause. (Dictionary)

Estoppel Certificate
A statement of material factors or conditions of which another person can rely because it cannot be denied at a later date. In real estate, a buyer of rental property typically requests estoppel certificates from existing tenants. Sometimes referred to as an estoppel letter. (Dictionary)

Excess Land
Land that is not needed to serve or support the existing improvement. The highest and best use of the excess land

may or may not be the same as the highest and best use of the improved parcel. Excess land may have the potential to be sold separately and is valued separately. (Dictionary)

Expense Stop

A clause in a lease that limits the landlord's expense obligation, which results in the lessee paying any operating expenses above a stated level or amount. (Dictionary)

Exposure Time

1) The time a property remains on the market. 2) The estimated length of time the property interest being appraised would have been offered on the market prior to the hypothetical consummation of a sale at market value on the effective date of the appraisal; a retrospective estimate based on an analysis of past events assuming a competitive and open market. (Dictionary)

Extraordinary Assumption

An assumption, directly related to a specific assignment, which, if found to be false, could alter the appraiser's opinions or conclusions. Extraordinary assumptions presume as fact otherwise uncertain information about physical, legal, or economic characteristics of the subject property; or about conditions external to the property such as market conditions or trends; or about the integrity of data used in an analysis. (Dictionary)

Fair Market Value

The price at which the property should change hands between a willing buyer and a willing seller, neither being under any compulsion to buy or sell and both having reasonable knowledge of relevant facts. [Treas. Reg. 20.2031-1(b); Rev. Rul. 59-60. 1959-1 C.B. 237]

Fee Simple Estate

Absolute ownership unencumbered by any other interest or estate, subject only to the limitations imposed by the governmental powers of taxation, eminent domain, police power, and escheat. (Dictionary)

Floor Common Area

Areas on a floor such as washrooms, janitorial closets, electrical rooms, telephone rooms, mechanical rooms, elevator lobbies, and public corridors which are available primarily for the use of tenants on that floor. (BOMA)

Full Service (Gross) Lease

A lease in which the landlord receives stipulated rent and is obligated to pay all of the property's operating and fixed expenses; also called a full service lease. (Dictionary)

Going Concern Value

- The market value of all the tangible and intangible assets of an established and operating business with an indefinite life, as if sold in aggregate; more accurately termed the market value of the going concern.
- The value of an operating business enterprise. Goodwill may be separately measured but is an integral component of going-concern value when it exists and is recognizable. (Dictionary)

Gross Building Area

The total constructed area of a building. It is generally not used for leasing purposes (BOMA)

Gross Measured Area

The total area of a building enclosed by the dominant portion (the portion of the inside finished surface of the permanent outer building wall which is 50 percent or more of the vertical floor-to-ceiling dimension, at the given point being measured as one moves horizontally along the wall), excluding parking areas and loading docks (or portions of the same) outside the building line. It is generally not used for leasing purposes and is calculated on a floor by floor basis. (BOMA)

Gross Up Method

A method of calculating variable operating expense in income-producing properties when less than 100 percent occupancy is assumed. The gross up method approximates the actual expense of providing services to the rentable area of a building given a specified rate of occupancy. (Dictionary)

Ground Lease

A lease that grants the right to use and occupy land. Improvements made by the ground lessee typically revert to the ground lessor at the end of the lease term. (Dictionary)

Ground Rent

The rent paid for the right to use and occupy land according to the terms of a ground lease; the portion of the total rent allocated to the underlying land. (Dictionary)

HVAC

Heating, ventilation, air conditioning. A general term encompassing any system designed to heat and cool a building in its entirety.

Highest & Best Use

The reasonably probable and legal use of vacant land or an improved property that is physically possible, appropriately supported, financially feasible, and that results in the highest value. The four criteria the highest and best use must meet are 1) legal permissibility, 2) physical possibility, 3) financial feasibility, and 4) maximally profitability. Alternatively, the probable use of land or improved –specific with respect to the user and timing of the use–that is adequately supported and results in the highest present value. (Dictionary)

Hypothetical Condition
That which is contrary to what exists but is supposed for the purpose of analysis. Hypothetical conditions assume conditions contrary to known facts about physical, legal, or economic characteristics of the subject property; or about conditions external to the property, such as market conditions or trends; or about the integrity of data used in an analysis. (Dictionary)

Industrial Gross Lease
A lease of industrial property in which the landlord and tenant share expenses. The landlord receives stipulated rent and is obligated to pay certain operating expenses, often structural maintenance, insurance and real estate taxes as specified in the lease. There are significant regional and local differences in the use of this term. (Dictionary)

Insurable Value
A type of value for insurance purposes. (Dictionary) (Typically this includes replacement cost less basement excavation, foundation, underground piping and architect's fees).

Investment Value
The value of a property interest to a particular investor or class of investors based on the investor's specific requirements. Investment value may be different from market value because it depends on a set of investment criteria that are not necessarily typical of the market. (Dictionary)

Just Compensation
In condemnation, the amount of loss for which a property owner is compensated when his or her property is taken. Just compensation should put the owner in as good a position as he or she would be if the property had not been taken. (Dictionary)

Leased Fee Interest
A freehold (ownership interest) where the possessory interest has been granted to another party by creation of a contractual landlord-tenant relationship (i.e., a lease). (Dictionary)

Leasehold Interest
The tenant's possessory interest created by a lease. (Dictionary)

Lessee (Tenant)
One who has the right to occupancy and use of the property of another for a period of time according to a lease agreement. (Dictionary)

Lessor (Landlord)
One who conveys the rights of occupancy and use to others under a lease agreement. (Dictionary)

Liquidation Value
The most probable price that a specified interest in real property should bring under the following conditions:

- Consummation of a sale within a short period.
- The property is subjected to market conditions prevailing as of the date of valuation.
- Both the buyer and seller are acting prudently and knowledgeably.
- The seller is under extreme compulsion to sell.
- The buyer is typically motivated.
- Both parties are acting in what they consider to be their best interests.
- A normal marketing effort is not possible due to the brief exposure time.
- Payment will be made in cash in U.S. dollars or in terms of financial arrangements comparable thereto.
- The price represents the normal consideration for the property sold, unaffected by special or creative financing or sales concessions granted by anyone associated with the sale. (Dictionary)

Loan to Value Ratio (LTV)
The amount of money borrowed in relation to the total market value of a property. Expressed as a percentage of the loan amount divided by the property value. (Dictionary)

Major Vertical Penetrations
Stairs, elevator shafts, flues, pipe shafts, vertical ducts, and the like, and their enclosing walls. Atria, lightwells and similar penetrations above the finished floor are included in this definition. Not included, however, are vertical penetrations built for the private use of a tenant occupying office areas on more than one floor. Structural columns, openings for vertical electric cable or telephone distribution, and openings for plumbing lines are not considered to be major vertical penetrations. (BOMA)

Market Rent
The most probable rent that a property should bring in a competitive and open market reflecting all conditions and restrictions of the lease agreement including permitted uses, use restrictions, expense obligations; term, concessions, renewal and purchase options and tenant improvements (TIs). (Dictionary)

Market Value

The most probable price which a property should bring in a competitive and open market under all conditions requisite to a fair sale, the buyer and seller each acting prudently and knowledgeably, and assuming the price is not affected by undue stimulus. Implicit in this definition is the consummation of a sale as of a specified date and the passing of title from seller to buyer under conditions whereby:

a. Buyer and seller are typically motivated;
b. Both parties are well informed or well advised, and acting in what they consider their own best interests;
c. A reasonable time is allowed for exposure in the open market;
d. Payment is made in terms of cash in United States dollars or in terms of financial arrangements comparable thereto; and
e. The price represents the normal consideration for the property sold unaffected by special or creative financing or sales concessions granted by anyone associated with the sale.

Market Value As If Complete

Market value as if complete means the market value of the property with all proposed construction, conversion or rehabilitation hypothetically completed or under other specified hypothetical conditions as of the date of the appraisal. With regard to properties wherein anticipated market conditions indicate that stabilized occupancy is not likely as of the date of completion, this estimate of value shall reflect the market value of the property as if complete and prepared for occupancy by tenants.

Market Value As If Stabilized

Market value as if stabilized means the market value of the property at a current point and time when all improvements have been physically constructed and the property has been leased to its optimum level of long term occupancy.

Marketing Time

An opinion of the amount of time it might take to sell a real or personal property interest at the concluded market value level during the period immediately after the effective date of the appraisal. Marketing time differs from exposure time, which is always presumed to precede the effective date of an appraisal. (Advisory Opinion 7 of the Standards Board of the Appraisal Foundation and Statement on Appraisal Standards No. 6, "Reasonable Exposure Time in Real Property and Personal Property Market Value Opinions" address the determination of reasonable exposure and marketing time). (Dictionary)

Master Lease

A lease in which the fee owner leases a part or the entire property to a single entity (the master lease) in return for a stipulated rent. The master lessee then leases the property to multiple tenants. (Dictionary)

Modified Gross Lease

A lease in which the landlord receives stipulated rent and is obligated to pay some, but not all, of the property's operating and fixed expenses. Since assignment of expenses varies among modified gross leases, expense responsibility must always be specified. In some markets, a modified gross lease may be called a double net lease, net net lease, partial net lease, or semi-gross lease. (Dictionary)

Option

A legal contract, typically purchased for a stated consideration, that permits but does not require the holder of the option (known as the optionee) to buy, sell, or lease real property for a stipulated period of time in accordance with specified terms; a unilateral right to exercise a privilege. (Dictionary)

Partial Interest

Divided or undivided rights in real estate that represent less than the whole (a fractional interest). (Dictionary)

Pass Through

A tenant's portion of operating expenses that may be composed of common area maintenance (CAM), real estate taxes, property insurance, and any other expenses determined in the lease agreement to be paid by the tenant. (Dictionary)

Prospective Future Value Upon Completion

Market value "upon completion" is a prospective future value estimate of a property at a point in time when all of its improvements are fully completed. It assumes all proposed construction, conversion, or rehabilitation is hypothetically complete as of a future date when such effort is projected to occur. The projected completion date and the value estimate must reflect the market value of the property in its projected condition, i.e., completely vacant or partially occupied. The cash flow must reflect lease-up costs, required tenant improvements and leasing commissions on all areas not leased and occupied.

Prospective Future Value Upon Stabilization

Market value "upon stabilization" is a prospective future value estimate of a property at a point in time when stabilized occupancy has been achieved. The projected stabilization date and the value estimate must reflect the absorption period required to achieve stabilization. In addition, the cash flows must reflect lease-up costs, required tenant improvements and leasing commissions on all unleased areas.

Replacement Cost

The estimated cost to construct, at current prices as of the effective appraisal date, a substitute for the building being appraised, using modern materials and current standards, design, and layout. (Dictionary)

Reproduction Cost

The estimated cost to construct, at current prices as of the effective date of the appraisal, an exact duplicate or replica of the building being appraised, using the same materials, construction standards, design, layout, and quality of workmanship and embodying all of the deficiencies, super-adequacies, and obsolescence of the subject building. (Dictionary)

Retrospective Value Opinion

A value opinion effective as of a specified historical date. The term does not define a type of value. Instead, it identifies a value opinion as being effective at some specific prior date. Value as of a historical date is frequently sought in connection with property tax appeals, damage models, lease renegotiation, deficiency judgments, estate tax, and condemnation. Inclusion of the type of value with this term is appropriate, e.g., "retrospective market value opinion." (Dictionary)

Sandwich Leasehold Estate

The interest held by the original lessee when the property is subleased to another party; a type of leasehold estate. (Dictionary)

Sublease

An agreement in which the lessee (i.e., the tenant) leases part or all of the property to another party and thereby becomes a lessor. (Dictionary)

Subordination

A contractual arrangement in which a party with a claim to certain assets agrees to make his or her claim junior, or subordinate, to the claims of another party. (Dictionary)

Substantial Completion

Generally used in reference to the construction of tenant improvements (TIs). The tenant's premises are typically deemed to be substantially completed when all of the TIs for the premises have been completed in accordance with the plans and specifications previously approved by the tenant. Sometimes used to define the commencement date of a lease.

Surplus Land

Land that is not currently needed to support the existing improvement but cannot be separated from the property and sold off. Surplus land does not have an independent highest and best use and may or may not contribute value to the improved parcel. (Dictionary)

Triple Net (Net Net Net) Lease

A lease in which the tenant assumes all expenses (fixed and variable) of operating a property except that the landlord is responsible for structural maintenance, building reserves, and management. Also called NNN, triple net leases, or fully net lease. (Dictionary)

(The market definition of a triple net leases varies; in some cases tenants pay for items such as roof repairs, parking lot repairs, and other similar items.)

Usable Area

The measured area of an office area, store area or building common area on a floor. The total of all the usable areas or a floor shall equal floor usable area of that same floor. The amount of floor usable area can vary over the life of a building as corridors expand and contract and as floors are remodeled. (BOMA)

Value-in-Use

The value of a property assuming a specific use, which may or may not be the property's highest and best use on the effective date of the appraisal. Value in use may or may not be equal to market value but is different conceptually. (Dictionary)

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Appraisal/valuation and consulting assignments have included many different property types including retail, office, industrial and multifamily. Assignments also include tax appeal valuations and rent comparability studies. Assignments have been concentrated in the Kansas City Metropolitan area.

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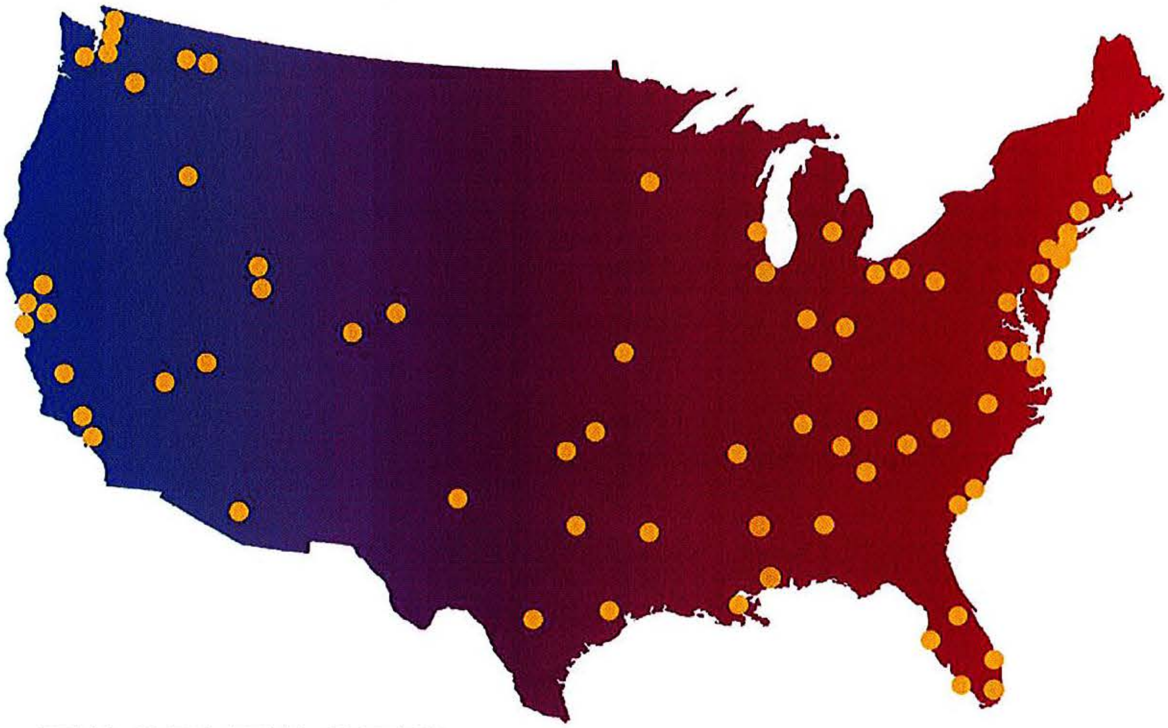

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Exhibit A39-3

2014

The Windy City: Property Value Impacts of Wind Turbines in an Urban Setting

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The Windy City:
Property Value Impacts of Wind Turbines in an Urban Setting

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March 7, 2014

Abstract
This paper examines the impact of wind turbines on house values in Rhode Island. In contrast to wind farms surrounded by sparse development, in Rhode Island single turbines have been built in relatively high population dense areas. As a result, we observe 48,554 single-family, owner-occupied transactions within five miles of a turbine site, including 3,254 within one mile, which is far more than most related studies. We estimate hedonic difference-in-differences models that allow for impacts of wind turbines by proximity, viewshed, and contrast with surrounding development. Across a wide variety of specifications, the results suggest that wind turbines have no statistically significant negative impacts on house prices, in either the post public announcement phase or post construction phase. Further, the lower bound of statistically possible impacts is still outweighed by the positive externalities generated from CO_2 mitigation.

Keywords: wind energy; hedonic valuation; viewshed; Rhode Island
JEL codes: Q42, Q51, R31

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1 Introduction

Society is highly dependent on high polluting and nonrenewable fossil fuels that constitute roughly 80% of our energy supplies. There is increasing recognition that we need to develop new low polluting renewable energy sources, and wind power is among the most promising technologies. As of December 2012, there are over 200,000 wind towers around the world with combined nameplate capacity of nearly 300 GW, and wind energy is among the fastest growing energy sources (Global Wind Energy Council 2013).

Public opinion polls commonly find a strong majority of respondents indicating support for wind power in general, with up to 90% of respondents voicing support for wind energy (e.g., Firestone and Kempton 2007, Mulvaney et al. 2013). Despite the stated preference for wind energy in the abstract, proposed wind energy projects frequently meet with fervent opposition by the local community. Numerous reasons have been given for opposition to wind turbines, ranging from adverse effects on birds, bats and other wildlife, aesthetic effects by compromising views, annoyance and potentially even health problems related to noise and shadow flicker, and a general industrialization of the landscape. One of the most common concerns voiced by nearby residents is the potential impact of wind towers on property values (Hoen et al. 2011).

Property values are an important issue in and of themselves, but also reflect an accumulation of preferences for the suite of impacts caused by turbines. For example, if wind turbines created adverse effects due to noise, visual disamenities or other nuisance effects, nearby property values would likely reflect these effects. Further, hedonic valuation theory (reviewed in Section 2) suggests that property values should decrease enough such that homeowners are indifferent between living near a turbine or paying more to live far away. Importantly, this disparity in house values can quantify the cost to nearby residents, which is arguably the sum of negative externalities (perhaps excluding wildlife impacts), to be used in cost-benefit analysis of wind energy expansion.

This paper examines the effect of wind turbines on property values in Rhode Island. While Rhode Island is the smallest state in the U.S., it is the second most densely populated. Given this and the fact that 12 turbines have been erected at 10 sites in the past seven years, Rhode Island offers an excellent setting to examine homeowner preferences for wind turbines because there are so many observations. We construct a data set (detailed in Section 3) of 48,554 single-family, owner-occupied transactions within five miles of a turbine site over the time range

January 2000 to February 2013. Further, 3,254 of these transactions occur within one mile, and it is these observations that are critical for understanding the impacts.

Beyond sample size, Rhode Island is an excellent case study because turbine development is plausibly exogenous to changes in house prices, unlike many other settings. In Rhode Island, the wind turbines have been sited and built by the state government or private parties, often with opposition from nearby homeowners (Faulkner 2013). Thus, the possibility that a community collectively decides to build a turbine and such a community may have different house price dynamics is not an issue here. In addition, these are not large-scale wind farm developments and there is no wind industry so-to-speak, so there is essentially no local economic impact through job creation or lease payments to property owners as is the case in Iowa and Texas (Brown et al. 2012, Slattery et al. 2011).[1] Thus, Rhode Island sales prices should offer an unadulterated reflection of homeowner preferences.

Within a hedonic valuation framework, we estimate a difference-in-differences (DD) model. In the most basic model, the treatment group is defined by proximity; we create concentric rings around turbines and regard the set of houses in each distance band as a separate treatment group. We define two distinct treatments. The first is when it is publicly announced that a wind turbine will be built at a specific location; this aspect of the model determines if homeowner's expectations of disamenities affect property values. The second is when the construction of the turbine is completed and measures if the realized disamenity has an effect on property values.

Proximity is a crude measure of the potential impacts of a wind turbine, and we took several additional steps to model likely impacts. We delve into heterogeneous impacts by the size of the turbine and the setting (i.e., industrial or residential area). In addition, we account for the fact that other obstructions such as large buildings or trees might mitigate the effects of a nearby wind tower on particular properties. To do so we physically visited 1,354 properties that transacted after construction and are within two miles of a turbine to assess the extent of view of the turbine.[2]

[1] Two exceptions exist. The owner of the North Kingstown Green Turbine pays $150/year to the dozen or so residents in the same development as the turbine and the Tiverton turbine offsets electricity expenditure to residents of the Sandy Woods Farm community. Only a single transaction in our data set occurred after turbine construction for these houses affected by payments, thus we feel confident that our results are unaffected by payments.

[2] In the appendix, we also examine the property value impacts of shadow flicker, though there are very few observations affected.

Across a wide variety of cross sectional and repeat sales specifications, the results (discussed in Section 4) suggest that wind turbines have no statistically significant negative impacts on house prices, in either the post public announcement phase or post construction phase. The DD models indicate that turbines are built in less desirable areas to begin with, which is consistent with intuition because several turbines are built near highways or industrial areas. However, even when we isolate residential areas where turbines are likely to contrast most with surroundings, our results still indicate no statistically significant negative price impacts. Further, our results suggest no statistically significant negative impacts to houses with substantial views of a turbine.

Our preferred model indicates that for houses within a half mile of a turbine, the point estimate of price change relative to houses 3-5 miles away is -0.4%. While the standard error of the point estimate is not small (3.8%), we can rule out negative impacts greater than 5.2% with 90% confidence. Further, in Section 5, we quantify the external benefits of wind generation in Rhode Island due to CO_2 mitigation and find that in order to offset the benefits, the price change would need to be greater than 5.8% if considering all turbines, and greater than 12.3% if only considering the industrial sized turbines. Thus, our results indicate that not only do negative externalities appear to be small and insignificant, but even the lower bound of statistically possible impacts is still outweighed by the positive externalities generated from CO_2 mitigation.

The literature examining the impacts of wind turbines on property values is still in its infancy. To date, hedonic studies have focused on large scale wind farms comprised of as many as 150 turbines, as district from our study that examines the case of individual wind turbines, so the disamenities present and resulting valuation may be different. There are several studies that suffer from small sample sizes or unsound econometric modeling. Sims and Dent (2007) used only post construction observations, and Sims et al. (2008) only had 199 observations – all within a half mile of a single wind farm. Neither of these studies use the DD framework, which is essential for controlling for confounding factors, either that exist prior to wind energy development or that affect all houses regardless of turbine construction. This is most evident for Sims and Dent (2007), who show an aerial picture of one of their study wind farms, and between it and the housing development is an already existent, enormous, open pit quarry, which surely could have affected housing prices prior to the wind farm. More recently, Sunak and Madlener (2012) collect 1,202 observed transactions, both before and after construction, but the models they estimate constrain either the effect of construction to be constant across distance or the effect of distance to be constant across time.

More complete studies have been carried out recently. Heintzelman and Tuttle (2012) examine impacts of wind farms in three counties of Upstate New York using over 11,000 transactions and a specification that treats distance as a single continuous variable. They do find some significant price effects from proximity, though they are not consistent across counties. Their results imply that a newly built wind farm within a half mile of a property can decrease value by 8-35%. It is important to note, however, that the average distance to a turbine of a transaction in their data is over 10 miles, and they interpolate effects to close proximity. The strongest research to date is a recent report from Hoen et al. (2013), which updates Hoen et al. (2011). They collect over 50,000 transactions within 10 miles of wind farms spanning 27 counties in nine states. They utilize a DD methodology similar to ours with distance bands around the wind farms and both a post announcement and post construction treatment. Similar to our results, Hoen et al. (2013) find no statistical effect of wind turbines on property values. It is important to note that both the Hoen et al. (2013) and Heintzelman and Tuttle (2012) results are for large scale wind farms with as many as 194 turbines, as distinct from our study that examines the case of individual wind turbines.

This paper contributes to the understanding of property value impacts of turbines by providing an econometrically sound analysis with far more observations than all but one existing analysis. Further, we go beyond proximity and offer the most thorough to-date analysis of how impacts may be heterogeneous due to viewshed of a property and size and setting of a turbine. Lastly, because we are working in a single state, we have been able to take part in multiple stakeholder meetings related to wind energy development and gain an understanding of the local perceptions, sentiments, and institutions, which have all informed our analysis. For instance, homeowners feel certain turbines are more odious than others, which suggested we should look for heterogeneous property value effects.

2 Methodology

In the absence of explicit markets, there are generally two approaches that economists use to determine the value of environmental amenities and disamenities: revealed and stated preference methods (e.g., Freeman 2003). Revealed preference methods use actual choices made by people to infer the value they place on an amenity. Stated preference methods infer values using responses of what individuals would do in a given situation, such as what is the most the individual would pay to participate in an activity rather than go without.

The Hedonic Price Method (HPM) is among the most popular revealed preference methods for determining values of non-market environmental amenities. The Hedonic method is based on the concept that many market commodities are comprised of several bundled attributes, and the market prices are determined by their attributes. Applied to residential properties, the price of a property is affected by attributes such as the size of the house, the size of the lot, the number of bathrooms, bedrooms, etc.; the neighborhood attributes such as the condition of nearby homes, the crime rate, quality of schools, etc.; and environmental attributes such as air quality, adjacent open space, ocean views, etc. The basic idea is that houses with desirable attributes (e.g., an ocean view) will be bid up by potential buyers, and the extent to which prices are bid up depends upon how much buyers value the attribute. If one can estimate the price premium associated with an attribute, one can gain insights into the extent to which potential buyers value an environmental amenity. HPM models have been applied to estimate implicit values associated with a wide range of amenities and disamenities: airport noise (Pope 2008), crime (Bishop and Murphy 2011), power plants (Davis 2011), air quality (Bento et al. 2013), and school quality (Cellini et al. 2010).

This paper applies HPM to the impacts of wind turbines on property values. Within the HPM framework, we estimated a DD model. DD models typically compare treated units to untreated units, both before and after treatment has occurred. There are two modifications to the basic framework for our application. First, treatment is defined by distance and is thus continuous. In order to avoid parametric assumptions, we group houses into *D* discrete bands of concentric circles surrounding the location of a turbine. The furthest distance band is chosen such that no effect of the wind turbine is expected and serves as the control group. Second, instead of two time periods, we have three: 1) pre-announcement (PA), in which no one knows that a wind turbine will be built nearby, 2) post-announcement pre-construction (PAPC), which is after the public has been made aware that a turbine will be built, but prior to the construction, and 3) post construction (PC). PA is the before treatment time period, and we allow the two treatment periods, PAPC and PC, to have differential impacts on property values, the first based on expectations and the second based on the realized (dis)amenity. The specification is:

$$\ln(p_i) = \sum_{k=2}^{D} \alpha_k\, dist_{ki} + \beta_1 PAPC_i + \beta_2 PC_i$$
$$+ \sum_{k=2}^{D} \gamma_{1k} dist_{ki} PAPC_i + \sum_{k=2}^{D} \gamma_{2k} dist_{ki} PC_i$$
$$+ X_i' \delta + \varepsilon_i \qquad (1)$$

where p_i is the sales price of transaction *i*, $dist_{ki}$ is a dummy variable equal to one if transaction *i* is within the k^{th} distance band, and $PAPC_i$ and PC_i are dummy variables equal to one if transaction *i* occurs PAPC or PC, respectively. X_i is a set of housing, location, and temporal controls. X_i also includes a constant to capture the omitted group of the 1st distance band in time period PA. Finally, ε_i is the error term.

The coefficients are interpreted as follows. α_k measures the PA (i.e., pre-treatment) difference in housing prices for distance band *k* relative to distance ring 1. β_1 and β_2 measure the change in housing prices for distance band 1 (the control group) in the PAPC and PC time periods, respectively. γ_{1k} and γ_{2k} are the coefficients of interest and measure, for PAPC and PC, respectively, the differential change in property values from the pre-announcement time period for distance band *k* relative to the change in property values of distance band 1.

The timing of our data, 2000-2013, corresponds to the housing boom and bust. Further, as detailed in the next section, the PAPC and PC periods almost always occur during bust years. Relative to a simple before-after estimate of the impacts of wind turbines on property values using only houses in close proximity, the DD model goes a long way to mitigate spurious correlation creeping into the treatment effect coefficients. To further guard against spurious correlation, we follow the advice of Boyle et al. (2012) and include city by year-quarter fixed effects and an interaction of lot size and its square with city fixed effects and year fixed effects. The city by year-quarter fixed effects flexibly controls for the boom and bust in prices for each city separately. The lot size interactions not only allow the value of land to be different in each city, but allow the value to evolve over time with the boom and bust. For more standard reasons, we also include census tract fixed effects and we interact distance from the coast with city. Tract fixed effects capture time invariant locational heterogeneity.[3] Interactions of coast and city allow

[3] In the spirit of Abbott and Klaiber (2010), one may be concerned that the tract fixed effects and city by year-quarter fixed effects will capture all relevant variation needed for the identification of wind turbines on property values. The spatial scale of influence could reasonably be at the tract level, however, because the tract fixed effects

the value of coastal living to change in different parts of Rhode Island. As with other DD estimators, identification of the treatment effects relies on the assumption that house prices would have changed identically across distance bands in the absence of turbines being built. See Figure A1 in the appendix for suggestive evidence that this assumption is reasonable.

Within the framework of Equation (1), we additionally estimate models that examine impacts that vary due to type of turbine, turbine surroundings, and viewshed (and shadow flicker, in the appendix).

Finally, we analyze property value impacts of turbines in a repeat sales model. There are many idiosyncratic features of a property that are unobserved by the researcher, and these may lead to omitted variables bias. A repeat sales model that includes property level fixed effects will account for all unobserved property attributes as long as they are time invariant. We estimate the following model:

$$\begin{aligned}\ln(p_{it}) &= \alpha_i + \beta_1 PAPC_{it} + \beta_2 PC_{it} \\ &+ \sum_{k=2}^{D} \gamma_{1k} dist_{ki} PAPC_{it} + \sum_{k=2}^{D} \gamma_{2k} dist_{ki} PC_{it} \\ &+ X'_{it}\delta + \varepsilon_{it} \qquad (2)\end{aligned}$$

where p_{it} is the sales price of unit *i* at time *t*, and α_i is a unit-level fixed effect. $dist_{ki}$, $PAPC_{it}$ and PC_{it} are as defined in Equation (1). Due to their time-invariant nature, property characteristics drop out of X_{it}. However, we still can include lot size and its square interacted with year fixed effects to allow for changes in the value of land through the boom and bust. X_{it} also includes city by year-quarter fixed effects. Identification of γ_{1k} and γ_{2k} (the coefficients of interest) comes from properties that transact in more than one of the three periods (PA, PAPC, PC).

3 Data

3.1 Wind turbines

Table 1 provides information on the 10 sites in Rhode Island that currently have turbines of 100 kW or above. All of these are single turbine sites, with the exception of Providence

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do not vary over time, within tract temporal variation will identify the effect of turbines if there is one. Our intuition is that effects of turbines are much smaller than the scale of a city. Thus, even with the inclusion of city by year-quarter fixed effects will, there will still be within-city variation to identify property value impacts. Further, the five mile radius around each turbine includes 4.1 cities, on average.

Narragansett Bay Commission, which has three. There is a wide range in the nameplate generation capacity; four turbines are 100 kW, one at 250 kW, one at 275 kW, one at 660 kW, and five at 1.5 mW. Table 1 also lists the date of public announcement that the wind turbine will be built and the date that construction was complete. The date of public announcement is marked by either an abutter notice or a public forum. The first turbine was built in 2006 and the second not until 2009; the remainder were built in 2011 and 2012. Time period PA is defined as before the announcement date, PAPC defined as between the announcement date and construction completed date, and PC is defined as after the construction completed date.[4] The last column of Table 1 describes the location and surroundings of each turbine. Of note is that several are in primarily residential areas. Others are in mixed use areas with either industrial or commercial activity, and sometimes coupled with an existing disamenity such as proximity to a highway or water treatment plant. Figure 1 shows the location of the turbine sites around the state.

One threat to identification could be that turbines are sited in neighborhoods that are strongly in favor of wind energy and that the treatment effect on the treated is substantially different than the average treatment effect (or what the price effect would be if the turbines were randomly placed). With the exception of Tiverton Sandywoods Farm, the turbines have been sited by private or government parties with little to no backing from surrounding neighbors. In fact, several turbines have been sited and erected despite substantial community protest. Given this history, we are not concerned about endogenous placement of turbines threatening identification.

3.2 Housing data

Our housing data include nearly all Rhode Island transactions between January 2000 and February 2013. Figure 1 displays the location of all transactions in our data in relation to the turbines. The data offer information on sales price, date of transaction, street address, living square feet, lot size, year of construction, number of bedrooms, fell and half bathrooms, and whether or not the unit has a pool, fireplace, air conditioning or view of the water. To get latitude and longitude, we geocoded all addresses to coordinates using the Rhode Island GIS E-911

[4] Several turbines in our sample were built quite recently, which makes the length of the PC period relatively short in our sample. This could cause problems for estimating true treatment effects if prices are slow to respond to changes in amenities. However, Lang (2012) examines the dynamic path that house prices take responding to changes in air quality (an amenity more difficult to observe), and finds that owner-occupied house prices capitalize changes immediately.

geolocater.[5] Using GIS, we calculated the Euclidian distance to the nearest eventual turbine site, as well as the distance to the coast.[6] We limit the sample to arm's length transactions of single family homes within 5 miles of an eventual wind turbine site and with a sales price of at least $10,000. This yields 66,487 observations. From that, we drop 385 observations for incomplete data.

One downside to the housing data is that characteristics of the house (bedrooms, bathrooms, square feet, etc.) come from assessor's data and only reflect the current characteristics of the house. If a house was remodeled or a property was split into two or more properties, the data do not capture the characteristics of the property or house before the change. One concern is that "flipped" properties could bias our estimates. To deal with this potential problem, we search the data for properties with multiple sales occurring less than six months apart and drop any sale that occurred prior to the last sale in the set of rapid sales. For example, if we observe a property transact 1/1/2000, 1/1/2005, 2/1/2005, and 1/1/2010, we would drop the 1/1/2000 and 1/1/2005 transactions because the characteristics of the property may be dramatically different for those transactions than what is current. This drops 26.5% of observations, leaving us with a sample of 48,554.

We define five distance bands surrounding turbines needed to estimate Equation (1): 0-0.5 miles, 0.5-1 miles, 1-2 miles, 2-3 miles, and 3-5 miles. Table 2 presents the distribution of transactions across the bands for the three time periods. For identifying the effect of proximity on prices, we need a substantial number of observations in close range. There are 584 transactions within half a mile, with 75 occurring PAPC and 74 occurring PC, which should be sufficient for identifying an effect if it is there. This table makes clear the benefits of examining wind turbine valuation in a population dense state. In addition, Table 2 gives the proportion of transactions occurring in each distance band for each time period, which can give a sense of whether transaction volume is substantially different for nearby distance intervals in either PAPC or PC. The proportions appear roughly constant across time suggesting neither announcement nor construction affects transaction volume.

Table 3 presents summary statistics for our sample properties. Prices are adjusted for inflation and brought to February 2013 levels using the monthly CPI. The average price in our

[5] Available at http://www.edc.uri.edu/rigis/.

[6] A house located within 5 miles of two eventual turbine sites is matched only to the nearest turbine site to ensure that a house treated as a control for one turbine is not a treated unit for another turbine.

sample is $305,800. The average lot size is 0.34 acres and the average living area is 1559 square feet. The average distance from the coast is only 1.59 miles (Rhode Island deserves its nickname "The Ocean State"!). Additionally, Table 3 compares houses in the 0-1 mile band to the 3-5 mile band PA to examine differences between the treatment and control group prior to treatment. The last column gives the difference in means divided by the combined standard deviation, which is the best statistic for assessing covariate balance (Imbens and Wooldridge 2009).[7] Sales price seems well balanced, as do most of the covariates with the exception of Fireplace and Distance from the coast, both of which exceed 0.25, which is considered to be a limit for covariate balance.[8] If the implicit values of these characteristics are different across space or change over time, then the differences in means could be a threat to identification. However, comparing the 0-1 mile band to the 2-3 mile band (not shown), Distance to the coast has much better overlap, and both variables have strong overlap comparing the 0-1 mile band to the 1-2 mile band. Thus, the treated units have common support with the spectrum of control units. Further, as explained in Section 2 (following the advice of Boyle et al. 2012), to guard against changing implicit prices affecting the estimated valuation of turbines, we allow the implicit value of lot size and distance from the coast to vary between cities and for lot size to vary over time too.

3.3 Viewshed

Equation (1) examines how house prices change with proximity to a turbine, but proximity is a crude measure for some of the impacts of living near a turbine. One source of heterogeneity in impacts by proximity could come from whether or not residents can actually see the turbine from their property. Unfortunately, we are unable to capture this variation with GIS due to the presence of obstructions such as trees and buildings that might mitigate the impacts of a nearby wind turbine. To overcome this limitation, we completed site visits to all 1,354 properties that transacted PC a`nd are within two miles of a turbine. Based on what we could see from the street in front of a given house, plus a bit of walking in both directions (to account for the possibility that a turbine may only be visible from certain parts of the house or backyard), the view was rated into one of five categories based on the proportion of the blade spinning diameter

[7] The problem with the frequently used t-statistic is that, as sample size grows, equivalent means can be rejected even when a covariate is well balanced.

[8] Using voter registration data, we were also able to show that partisanship is similar between the 0-1 mile band and the 3-5 mile band. This further supports the idea that the areas where turbines were sited were not meaningfully different than other areas and the valuation estimates should not be impacted by selection issues.

visible and the degree of dominance it had on the landscape: no view (0%), minor (1-30%), moderate (31-60%), high (61-90%), extreme (91-100%). A view is coded extreme only if the turbine is both nearby and unobstructed. As a consequence, two houses with an unobstructed view of a turbine will be coded differently if the turbine takes up a different amount of view in the horizon, either due to proximity or height of the turbine. While the classification was subjective, a single person did all of the ratings and went to great length to be consistent.

The results of the site visits confirmed substantial heterogeneity in views. Despite Rhode Island's minimal topography, only 0.4% of properties in the 1-2 mile band had any view of the turbine (see Table A1 in the Appendix). Within half a mile, 24.3% have a full view, 13.5% have a partial view, and 63.2% have no view. Figure 2 illustrates the heterogeneity in viewshed for PC transactions surrounding the Portsmouth High School turbine. While viewshed and proximity are certainly correlated, it is far from a perfect correlation and there are several instances of properties with similar location and different views.

4 Results

Table 4 presents the main DD results on the full sample of transactions. There are three columns that represent three different models that each add additional variables described at the bottom of the table. All three models include housing characteristic controls, detailed further in the notes of the table, and tract fixed effects. The first set of coefficients, corresponding to the α_k in Equation (1), measure the difference in housing values among the various distance bands relative to the 3-5 mile band. All models suggest that there is a negative premium for living near the eventual site of a wind turbine, prior to an announcement that a wind a turbine will be built. For instance, Model 1 indicates that houses located within half a mile of a future turbine site are worth 9.0% less than those houses 3-5 miles away from the future site.[9] This finding implies that turbines are being sited in areas that have lower house prices conditional on property and locational characteristics. This makes sense since several of the turbines are located in less desirable areas, i.e., near the highway or on the grounds of a wastewater treatment facility. The second set of coefficients, which correspond to β_1 and β_2 in Equation (1), measure the change in housing prices for the 3-5 mile distance band in the PAPC and PC time periods, respectively.

[9] Though we are not concerned about endogeneity bias given the manner of turbine development in Rhode Island, this spatial price gradient PA suggests that even if endogeneity were a problem, our results would likely be biased downwards making it more likely to find a negative effect.

Across all models, the results suggest that these time periods are associated with lower sales prices relative to PA (due to the crash of the housing market), though given the inclusion of city by year-quarter fixed effects the magnitudes of β_1 and β_2 do not fully reflect the large drop in house prices during those periods. Taken together, the distance and timeline results indicate that a purely cross-sectional or before-after research design would both provide negatively biased estimates of the effect of wind turbines on property values. The DD approach we apply controls for these potential problems.

The third set of coefficients in Table 4 are the DD estimates, corresponding to γ_{1k} and γ_{2k} in Equation (1), which are the estimated treatment effects of PAPC and PC for the various distance bands. The coefficients for the 2-3 mile band are small in magnitude and statistically insignificant. Intuition suggests that 2-3 miles away from a turbine is probably too far for an impact to occur, so observing that these prices closely track those 3-5 miles away gives confidence in the assumption of common trends needed for the DD research design. Moving into closer distance bands, no coefficients are statistically significant and all are small in magnitude. For all models, the Akaike Information Criterion (AIC) is calculated and Model 3 minimizes this statistic, which is the objective, and so we deem Model 3 to be our preferred specification. The point estimates of the treatment effects for this model suggest that for houses within half a mile of a turbine, values decreased 0.4% PAPC and decreased 0.4% PC.[10] The standard error on the PC estimate is 3.8%, which implies a one-sided hypothesis can rule out decreases in prices more than 5.1% with 90% confidence. This implies that the large negative impacts, such as -10% or more, that are routinely hypothesized by opponents of wind development can be ruled out as inconsistent with the data. While the coefficients are statistically insignificant, they are also consistently negative across the three specifications, which warrants updating the models in two or so years when there are more PC transactions. Results are qualitatively similar using distance bands with increment in thirds of a mile within 1 mile, but standard errors double, which leads to a larger range of possible impacts.

4.1 Repeat sales analysis

[10] A parsimonious model including just housing characteristics and DD variables was also estimated. Results suggested positive impacts of turbines, though we interpret this as a spurious correlation.

Table 5 presents results from a repeat sales analysis. Only properties that transact more than once are included in the sample, which decreases the sample by over half. The first column includes city by year-quarter fixed effects (akin to Column 1 in Table 4), and the second column additionally includes lot size-year interactions (akin to Column 3 in Table 4). Model 2 minimizes AIC, but both are presented for completeness and robustness.

Like Table 4, the results suggest that there is no significant difference in price changes between the 2-3 mile band and the 3-5 mile (control) band. In the 0.5-1 mile band, both columns suggest that house prices decreased PAPC, by 5.7% (statistically significant at the 5% level) in Model 2. The point estimates indicate larger impacts PC (-8.1% for Model 2), but are statistically insignificant. In contrast, the 0-0.5 mile band shows statistically insignificant price increases PAPC (8.1% for Model 2). The PC results for the 0-0.5 mile band are nearly identical to Table 4, indicating a 0.0% change in prices with a standard error of 3.7%.

It is difficult to draw conclusions from the results. On the one hand, the 0.5-1 mile band results indicate that turbines could have a negative and large impact on property values. On the other hand, the 0-0.5 mile band results, where the impacts should be strongest, are incongruent with the 0.5-1 mile results. It will be beneficial to update this analysis in two or so years with more PC transactions.

4.2 Heterogeneity by type of turbine and setting

As explained with Table 1, there is substantial heterogeneity among the Rhode Island turbines in terms of size and placement. The turbines range in size from 100 kW to 1.5 mW, and some are located near highways or industrial areas. The estimates presented thus far group all turbines together, but it is possible the price effects are different based on size and surroundings. Intuition suggests that price impacts would be more pronounced for larger turbines and turbines in primarily residential areas where other disamenities do not already exist.

Table 6 presents DD estimates, returning to Equation (1), for subsets of the data based on turbine characteristics. Columns 1 and 2 use only turbines with a capacity of 660 kW or more – these would be considered the industrial sized turbines. Columns 3 and 4 use only turbines in primarily residential areas. Similar to the repeat sales analysis, the large turbine analysis presents mixed evidence of price impacts. The results suggest negative price impacts of 3.6% PC in the 1-2 mile band and positive impacts of 8.4% PAPC in the 0-0.5 mile band. The point estimates for

PC in the 0-0.5 mile band are 4.3%, but insignificant. For the primarily residential locations analysis, all coefficients are statistically insignificant.

4.3 Viewshed

Beyond the size and location of a turbine, another source of heterogeneity is whether or not a house can actually see the turbine, and to what extent. This source of heterogeneity can occur within a group of houses matched to a single turbine, in contrast to the heterogeneity explored in Table 6, which occurs between turbines. Table 7 presents the results of three models exploring the impact of viewshed on prices. Models 1 and 2 match Columns 2 and 3 of Table 4, except additionally include indicator variables for each of the categories of view. Model 3 omits the DD variables from the model, to check if multicollinearity between viewshed and proximity affects coefficients on the viewshed variables. To be clear, only PC sales can be scored higher than 'no view' and the viewshed variables enter as an additive treatment effect, not interactive. Across the three models, the results suggest that view of the turbine has no statistical impact on property values. Further, the point estimates have a non-monotonic relationship with the extent of view and range from -5.2% to 7.9%.

5 Policy Perspective

The purpose of this paper is to quantify the negative externalities associated with wind turbine development in a population dense area. While a full cost-benefit analysis of wind energy is well beyond the scope of this paper, it is useful to consider the positive externalities derived from wind generation – specifically, reductions in CO_2 emissions – and weigh these against the negative. The following back-of-the-envelope calculations are not meant to be absolute, but to put perspective on the issue at hand and try to answer the question 'What loss in property values would offset gains from reduced CO_2?'

The turbines that enter this study have a nameplate capacity of 9.085 MW. Using a standard capacity factor of 0.25, we can expect these turbines to generate 19,896 MWh annually. The EPA estimates that each MWh produced in the US generates 0.706 tons of CO_2, which implies that 14,046.7 tons of CO2 are mitigated annually due to these turbines.[11] If the turbines last for 25 years, then a total 351,167 tons of CO_2 will be mitigated over the turbines lifetimes.

[11] http://www.epa.gov/cleanenergy/energy-resources/calculator.html

The EPA also estimates that the social cost of carbon (the marginal damage expected from each emitted ton of CO_2) is currently \$39, which yields a total monetary benefit of nearly \$13.7 million.[12] If we restrict attention to only the six industrial sized turbines, which have a combined nameplate capacity of 8.16, total monetary benefit is \$12.3 million.

Turning to the cost side, using the full dataset there are 910 single family, owner-occupied housing units within half a mile of a turbine site (over ten times what has transacted PC). The average selling price for these houses in 2012-2013 was \$260,162, and so we estimate a total value of this housing stock to be \$236.7 million. In order to offset the benefits, the housing stock would need to decline 5.8% is value. If we again restrict attention to industrial turbine sites only, we find 306 units worth an average of \$327,570 for a total value of \$100.2 million. These houses would need to decline in value by 12.3% to offset CO_2 benefits.

These calculations indicate two things. First, in Rhode Island, our results suggest that it is statistically improbable that the external benefits of wind generation are outweighed by the external costs to homeowners. Second, if we consider similar calculations for wind farms located in rural areas, it is impossible for prices to depreciate enough to overcome the benefits of CO_2 mitigation.[13]

6 Conclusion

This paper offers an econometrically sound analysis of the effect of wind turbines on property values in Rhode Island. With a sample of 48,554 transactions, we estimate a suite of DD models that examine property impacts due to proximity, viewshed, and type and location of turbine. Because our sample time period includes the housing boom and bust, we control for city-level price fluctuations and allow the implicit value of housing characteristics to vary by year and city, following the advice of Boyle et al. (2012). Broadly, the results suggest that there is no statistical evidence for negative property value impacts of wind turbines. Both the whole sample analysis and the repeat sales analysis indicate that houses within half a mile had essentially no price change PC. These results are consistent with Hoen et al. (2013), who examine impacts of large wind farms in nine states. However, the results are not unequivocal.

[12] http://www.epa.gov/climatechange/EPAactivities/economics/scc.html

[13] For example, Hoen et al. (2013) report an average of 12.3 sales within half a mile of wind farm with average capacity of 79 MW. Houses would need to depreciate over 1000% to outweigh the CO_2 mitigation benefits, but this of course is impossible.

First, some models do suggest negative impacts; however, these are often incongruent with other coefficient estimates in the same model. Second, many important coefficient estimates have large standard errors. As time goes on and there are more PC transactions observed, we hope to update this analysis and improve accuracy and consistency of the estimates.

In the past (and likely going forward), proposed wind energy projects have been fervently opposed by homeowners surrounding the turbine site. There are several possible reasons why these stated preferences may be different than preferences revealed through housing market choices, such as we found in this analysis. First, stated preference is completely in the abstract and losses and gains are never realized. Hence, people may behave strategically to try and influence outcomes even if they are not willing to pay for it. Lang (2014) finds a similar inconsistency with stated beliefs about climate change and what internet search records reveal about people's interests. Second, wind energy is still relatively new in the United States, especially farms and individual turbines that are in close proximity to residential development. It could be that local opposition is driven by fear of the unknown, but that once reality sets in (i.e., the turbines are built) people care much less. Third, there could be a process of preference-based sorting occurring in the housing market in which people who dislike the turbines move away and those that are indifferent or even enjoy the turbines move near.[14] Importantly, these location shifts of certain homeowners may not affect housing prices if there are enough potential buyers who are indifferent or prefer to live near turbines.

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[14] See, for example, Banzhaf and Walsh (2008), who examine preference-based sorting in response to toxic emissions from factories. One anecdote in support of this idea is that we talked with one recent home buyer, an engineer, who enjoyed watching a nearby turbine spin.

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Figure 1: Spatial distribution of sales and turbines

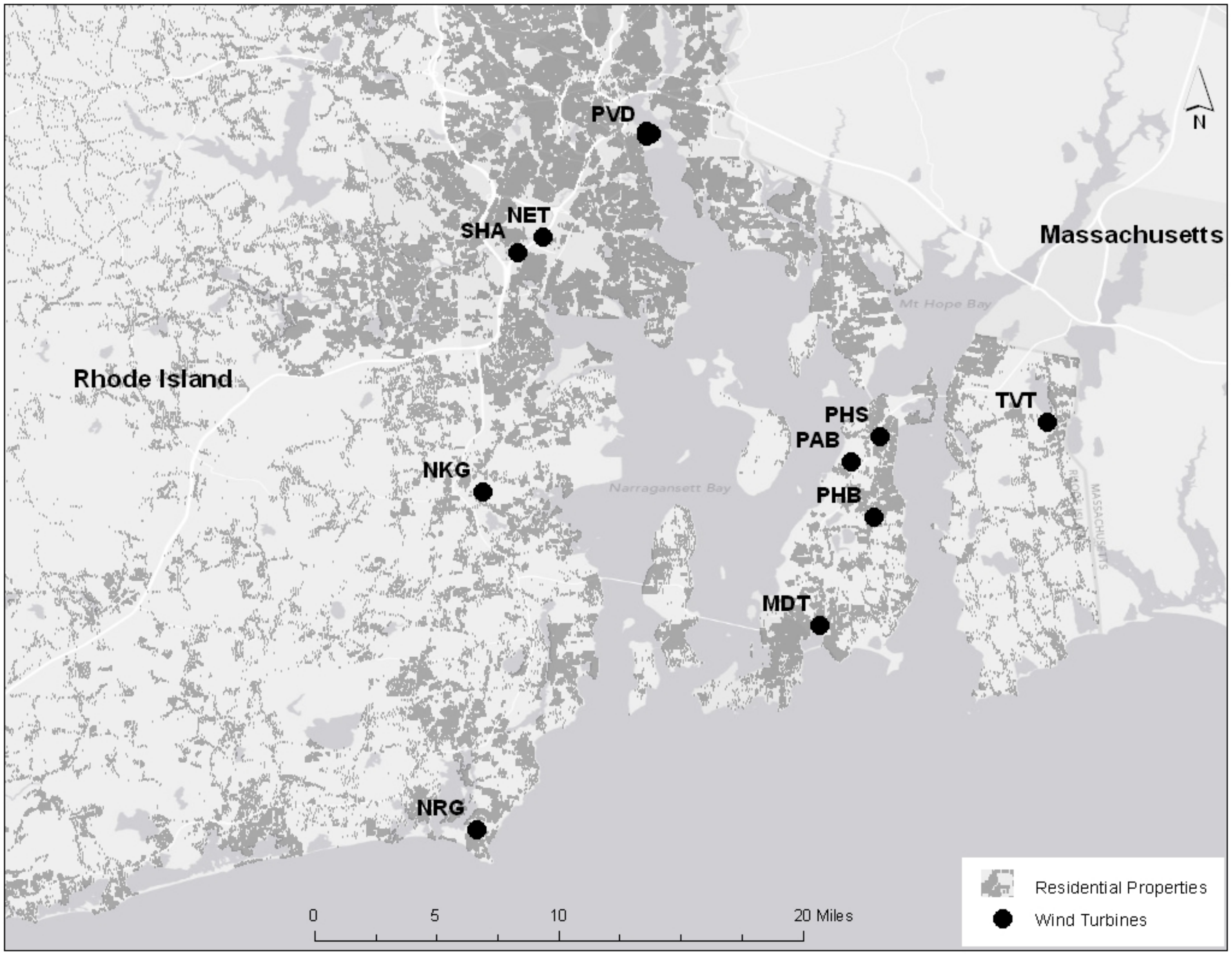

Figure 2: Proximity bands, viewshed, and shadow flicker, for post construction transactions around Portsmouth High School wind turbine

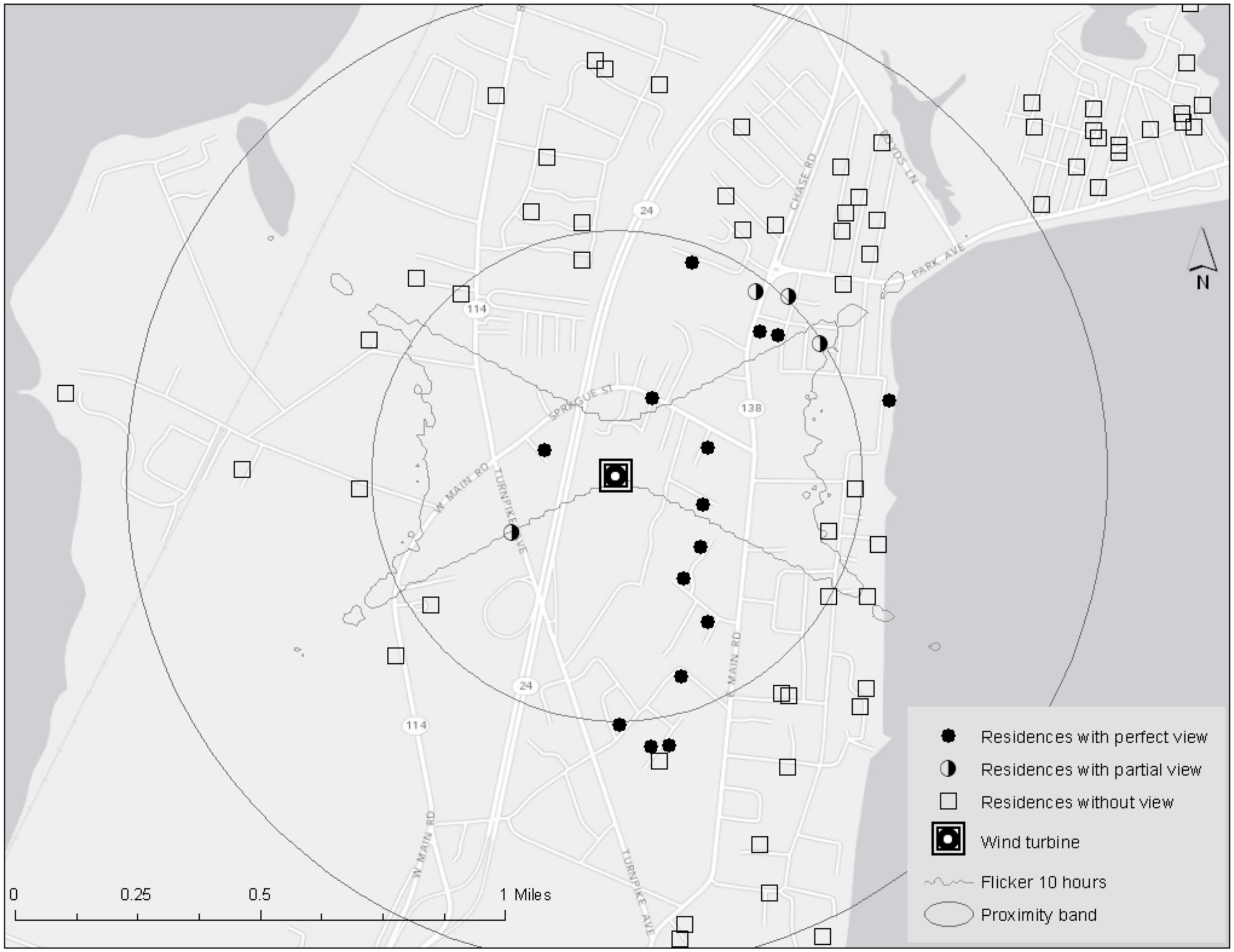

Table 1: Wind turbine characteristics for Rhode Island sample

Name	Abbreviation (match with Figure 1)	Nameplate capacity	Height (feet)	Announcement	Construction completed	Comments
Portsmouth Abbey	PAB	660 kW	240	12/15/2004*	3/27/2006	On grounds of a school/monastery; primarily residential surroundings
Portsmouth High School	PHS	1.5 mW	336	4/15/2006*	3/1/2009	On grounds of a public school; primarily residential surroundings
Tiverton Sandywoods Farm	TVT	275 kW	231	7/18/2006	3/23/2012	On grounds of communal residential development; primarily residential surroundings
Providence Narragansett Bay Commission (3 identical turbines)	PVD	1.5 mW each	360	9/26/2007	1/23/2012	On grounds of water treatment facility; mixed industrial/residential surroundings
Warwick New England Tech	NET	100 kW	157	10/9/2008	8/6/2009	On grounds of technical college, next to highway
Middletown Aquidneck Corporate Park	MDT	100 kW	157	4/13/2009	10/9/2009	Mixed residential/commercial surroundings
Narragansett Fishermen's Memorial State Park	NRG	100 kW	157	7/7/2009	9/19/2011	On grounds of state campground; primarily residential surroundings
Portsmouth Hodges Badge	PHB	250 kW	197	5/14/2009	1/4/2012	Mixed residential/commercial/agricultural surroundings
Warwick Shalom Housing	SHA	100 kW	157	8/6/2009	2/2/2011	On grounds of apartment complex, next to highway
North Kingstown Green	NKG	1.5 mW	402	9/15/2009	10/18/2012	Primarily residential surroundings

Notes: Height is hub height plus blade length. Dates of announcement and construction completed were gathered from personal requests for information and newspaper/online sources. Dates marked with * are approximate, sources could only identify a month and year that the announcement was made, and we chose to use the midpoint of the month.

Table 2: Transaction counts and proportions by distance and time period

Distance Interval (miles)	PA	PAPC	PC	**TOTAL**
0 - 0.5	435 1.2%	75 1.0%	74 1.4%	584 1.2%
0.5 - 1	1979 5.5%	353 4.9%	338 6.4%	2670 5.5%
1 - 2	6120 17.0%	1180 16.3%	942 17.8%	8242 17.0%
2 - 3	10116 28.1%	1877 25.9%	1599 30.3%	13592 28.0%
3 - 5	17375 48.2%	3765 51.9%	2326 44.1%	23466 48.3%
TOTAL	36025 100%	7250 100%	5279 100%	48554 100%

Notes: 'PA' stands for pre-announcement, 'PAPC' for post-announcement/pre-construction, and 'PC' for post-construction. The percentages are the proportion of all transactions for a given time period occurring in that distance band.

Table 3: Housing summary statistics

Variable	Full Sample	Pre-announcement 0 - 1 miles	Pre-announcement 3 - 5 miles	Difference/std. dev.
Price (000s)	305.8	330.8	323.4	0.03
Lot size (acres)	0.34	0.35	0.41	-0.06
Living area (square feet)	1559	1567	1600	-0.04
Bedrooms	3.03	3.07	3.03	0.06
Full bathrooms	1.49	1.55	1.51	0.06
Half bathrooms	0.45	0.44	0.46	-0.03
Fireplace (1=yes)	0.31	0.13	0.38	-0.44
Pool (1=yes)	0.04	0.03	0.05	-0.09
Air Conditioning (1=yes)	0.30	0.25	0.31	-0.15
Distance from coast (miles)	1.59	1.15	1.94	-0.49
Age at time of sale (years)	52.5	46.0	47.3	-0.04
Observations	48554	17375	2414	

Notes: Housing prices are brought to February 2013 levels using the monthly CPI. The final column equals the difference in means between the 0-1 mile set and the 3-5 mile set divided by their combined standard deviation.

Table 4: Difference-in-differences estimates of the impact of wind turbine proximity on housing prices

Variables		(1)	(2)	(3)
Distance (relative to 3-5 mile)				
2 - 3 miles		-0.008	-0.014	-0.014
		(0.023)	(0.023)	(0.023)
1 - 2 miles		-0.025	-0.030	-0.030
		(0.026)	(0.026)	(0.025)
0.5 - 1 miles		-0.048	-0.060	-0.059
		(0.022)**	(0.020)***	(0.020)***
0 - 0.5 miles		-0.090	-0.087	-0.087
		(0.033)**	(0.032)**	(0.032)**
Timeline (relative to PA)				
PAPC		-0.033	-0.035	-0.038
		(0.014)**	(0.014)**	(0.014)**
PC		-0.055	-0.060	-0.058
		(0.020)**	(0.020)***	(0.019)***
Difference-in-differences				
2 - 3 miles	PAPC	-0.008	-0.009	-0.008
		(0.020)	(0.020)	(0.018)
	PC	0.007	0.008	0.006
		(0.014)	(0.014)	(0.015)
1 - 2 miles	PAPC	-0.041	-0.040	-0.039
		(0.037)	(0.036)	(0.036)
	PC	-0.002	-0.009	-0.010
		(0.017)	(0.019)	(0.018)
0.5 - 1 miles	PAPC	-0.029	-0.032	-0.029
		(0.030)	(0.028)	(0.028)
	PC	-0.001	0.003	0.002
		(0.033)	(0.031)	(0.030)
0 - 0.5 miles	PAPC	-0.009	-0.001	-0.004
		(0.060)	(0.053)	(0.054)
	PC	-0.004	-0.001	-0.004
		(0.042)	(0.039)	(0.038)
City by year-quarter fixed effects		Y	Y	Y
Property-city interactions		N	Y	Y
Property-year interactions		N	N	Y
Observations		48554	48554	48554
R-squared		0.751	0.759	0.760
Akaike Information Criterion		12468.5	10933.5	10801.5

Notes: 'PA' stands for pre-announcement, 'PAPC' for post-announcement/pre-construction, and 'PC' for post-construction. Included in all regressions as control variables are lot size, lot size squared, living area, living area squared, number of bedrooms, full bathrooms, half bathrooms, indicator variables for the presence of a fireplace, pool, air conditioning, view of the water, within 0.25 miles of the coast, and within one mile of the coast, a set of dummy variables for the age of the house at purchase, a set of dummy variables for the subjective condition of the house, and tract fixed effects. Property-city interactions indicate that lot size, its square, and the two coast dummy variables are interacted with a full set of city dummies. Property-year interactions indicate that lot size and its square are interacted with year fixed effects. Standard errors are shown in parentheses and are estimated using the Eicker-White formula to correct for heteroskedasticity and are clustered at the city level. *, **, and *** indicate significance at 10%, 5% and 1%, respectively.

Table 5: Difference-in-differences estimates using repeat sales data

Variables		(1)	(2)
2 - 3 miles	PAPC	0.017	0.019
		(0.012)	(0.014)
	PC	0.032	0.032
		(0.027)	(0.027)
1 - 2 miles	PAPC	-0.067	-0.068
		(0.056)	(0.055)
	PC	-0.023	-0.024
		(0.041)	(0.041)
0.5 - 1 miles	PAPC	-0.058	-0.057
		(0.028)*	(0.027)**
	PC	-0.075	-0.081
		(0.054)	(0.052)
0 - 0.5 miles	PAPC	0.079	0.081
		(0.068)	(0.074)
	PC	0.006	-0.000
		(0.039)	(0.037)
City by year-quarter fixed effects		Y	Y
Property-year interactions		N	Y
Observations		21414	21414
Unique houses		9618	9618
R-squared		0.897	0.898
Akaike Information Criterion		-12939.7	-13058.9

Notes: Sample includes only properties that transact more than once during the sample timeframe. Standard errors are shown in parentheses and are estimated using the Eicker-White formula to correct for heteroskedasticity and are clustered at the city level. *, **, and *** indicate significance at 10%, 5% and 1%, respectively.

Table 6: Heterogeneity of impacts by turbine size and location

Variables		Capacity ≥ 660 kW		Primarily residential	
		(1)	(2)	(3)	(4)
2 - 3 miles	PAPC	0.003	0.002	-0.004	-0.011
		(0.016)	(0.016)	(0.075)	(0.061)
	PC	-0.011	-0.012	-0.045	-0.043
		(0.068)	(0.069)	(0.066)	(0.061)
1 - 2 miles	PAPC	-0.056	-0.057	0.048	0.046
		(0.053)	(0.052)	(0.037)	(0.031)
	PC	-0.038	-0.036	-0.022	-0.014
		(0.022)*	(0.019)*	(0.068)	(0.063)
0.5 - 1 miles	PAPC	-0.042	-0.042	0.023	0.022
		(0.041)	(0.038)	(0.048)	(0.036)
	PC	-0.047	-0.047	0.028	0.030
		(0.041)	(0.042)	(0.073)	(0.065)
0 - 0.5 miles	PAPC	0.084	0.084	-0.028	-0.034
		(0.044)*	(0.044)*	(0.124)	(0.126)
	PC	0.039	0.043	0.073	0.078
		(0.098)	(0.101)	(0.110)	(0.115)
City by year-quarter fixed effects		Y	Y	Y	Y
Property-city interactions		Y	Y	Y	Y
Property-year interactions		N	Y	N	Y
Observations		23776	23776	8206	8206
R-squared		0.775	0.776	0.726	0.729
Akaike Information Criterion		7107.2	7021.2	1929.2	1843.8

Notes: See notes to Table 4. The model used in Columns (1) and (3) is identical to that of Column (4) in Table 4, and the model used in Columns (2) and (4) is identical to that of Column (5) in Table 4. Columns (1) and (2) include turbines PAB, PHS, PVD, NKG. Columns (3) and (4) include PAB, PHS, TVT, NRG, NKG.

Table 7: The impact of viewshed on property values

	Variables	(1)	(2)	(3)
0 - 0.5 miles	PAPC	-0.001	-0.004	-
		(0.053)	(0.054)	-
	PC	0.007	0.003	-
		(0.061)	(0.059)	-
View of turbine	None (omitted)	-	-	-
		-	-	-
	Minor	0.028	0.021	0.020
		(0.067)	(0.072)	(0.066)
	Moderate	0.079	0.080	0.082
		(0.125)	(0.125)	(0.124)
	High	-0.052	-0.044	-0.042
		(0.177)	(0.172)	(0.144)
	Extreme	-0.019	-0.016	-0.012
		(0.071)	(0.069)	(0.050)
City by year-quarter fixed effects		Y	Y	Y
Property-city interactions		Y	Y	Y
Property-year interactions		N	Y	Y
R-squared		0.759	0.760	0.760
Akaike Information Criterion		10932.3	10800.4	10814.8

Notes: See notes to Table 4. The sample size in all columns is 48554. The model used in Column (1) is identical to that of Column (4) in Table 4, and the model used in Column (2) is identical to that of Column (5) in Table 4. Column (3) includes all control variables that Column (5) in Table 4, but does not include the interaction terms between proximity bands and time periods (i.e., the difference-in-differences terms). Columns (1) and (2) include all difference-in-difference variables shown in Table 4, though only the interaction between the 0-0.5 mile distance band and time period are displayed.

Exhibit A39-3

Relationship between Wind Turbines and Residential Property Values in Massachusetts

A Joint Report of University of Connecticut and Lawrence Berkeley National Laboratory

January 9, 2014

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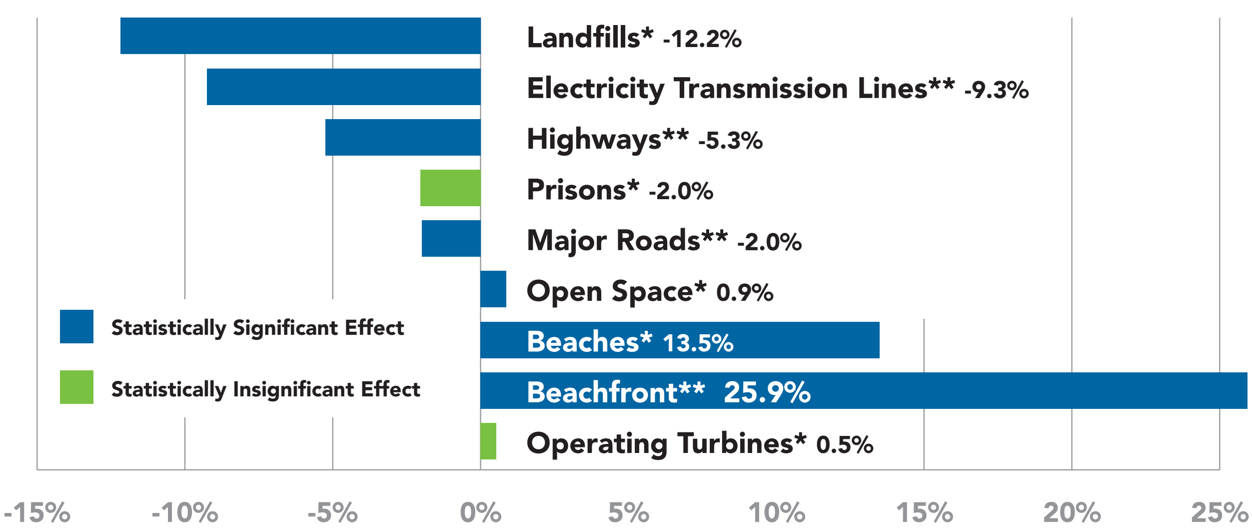
CONTENTS

EXECUTIVE SUMMARY

This study investigates a common concern of people who live near planned or operating wind developments: How might a home's value be affected by the turbines? Previous studies on this topic, which have largely coalesced around non-significant findings, focused on rural settings. Wind facilities in urban[1] locations could produce markedly different results. Nuisances from turbine noise and shadow flicker might be especially relevant in urban settings, where negative features, such as landfills or high voltage utility lines, have been shown to reduce home prices. To determine if wind turbines have a negative impact on property values in urban settings, this report analyzed more than 122,000 home sales, between 1998 and 2012, that occurred near the current or future location of 41 turbines in densely-populated Massachusetts communities.

The results of this study do not support the claim that wind turbines affect nearby home prices. Although the study found the effects from a variety of negative features (such as electricity transmission lines and major roads) and positive features (such as open space and beaches) generally accorded with previous studies, the study found no net effects due to the arrival of turbines in the sample's communities. Weak evidence suggests that the announcement of the wind facilities had a modest adverse impact on home prices, but those effects were no longer apparent after turbine construction and eventual operation commenced. The analysis also showed no unique impact on the rate of home sales near wind turbines. These conclusions were the result of a variety of model and sample specifications detailed later in this report.

Figure 1: Summary of Amenity, Disamenity and Turbine Home Price Impacts



*Distance to MA Homes: * within 1/2 mile; ** within 500 feet*

1 The term "urban" in this document includes both urban and suburban areas.

OVERVIEW

Wind power generation has grown rapidly in recent decades. In the United States, wind development centered initially on areas with relatively sparse populations in the Plains and West. Increasingly, however, wind development is occurring in more populous, urbanized areas, prompting additional concerns about the effects of wind turbine construction on residents in those areas.

One important concern is the potential for wind turbines to create a "nuisance stigma"—due to turbine-related noise, shadow flicker, or both—that reduces the desirability and thus value of nearby homes. Government officials who are called on to address this issue need additional reliable research to inform regulatory decisions, especially for understudied populous urban areas. Our study helps meet this need by examining the relationship between home prices and wind facilities in densely-populated Massachusetts.

A variety of methods can be used to explore the effects of wind turbines on home prices. Statistical analysis of home sales, using a hedonic model, is the most reliable methodology because it (a) uses actual housing market sales data rather than perceptions of potential impacts; (b) accounts for many of the other, potentially confounding, characteristics of the home, site, neighborhood and market; and (c) is flexible enough to allow a variety of potentially competing aspects of wind development and proximity to be tested simultaneously. Previous studies using this hedonic modeling method largely have agreed that post-construction home-price effects (i.e., changes in home prices after the construction of nearby wind turbines) are either relatively small or sporadic. A few studies that have used hedonic modeling, however, have suggested significant reductions in home prices after a nearby wind facility is announced but before it is built (i.e., post-announcement, pre-construction) owing to an "anticipation effect." Previous research in this area has focused on relatively rural residential areas and larger wind facilities with significantly greater numbers of turbines.

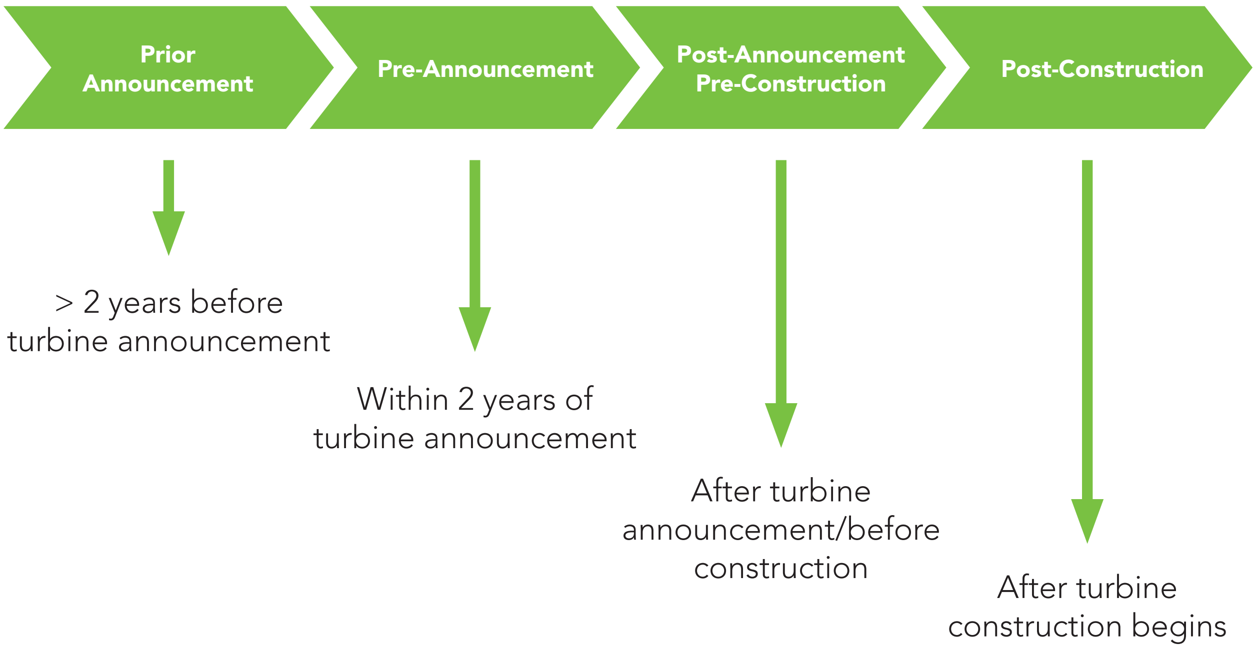
This previous research has done much to illuminate the effects of wind turbines on home prices, but a number of important knowledge gaps remain. Our study helps fill these gaps by exploring a large dataset of home sales occurring near wind turbine locations in Massachusetts. We analyze 122,198 arm's-length single-family home sales, occurring between 1998 and 2012, within 5 miles of 41 wind turbines in Massachusetts. The home sales analyzed in this study occurred in one of four periods based on the development schedule of the nearby turbines (see Figure 2).[2] To estimate the effect proximity to turbines has on home sale prices, we employ a hedonic pricing model in combination with a suite of robustness tests[3] that explore a variety of different model specifications and sample sets, organized around the following five research questions:

2 The analysis focuses on the 41 turbines in Massachusetts that are larger than 600 kilowatt and that were operating as of November 2012.

3 These tests included a comparison of a "base" model to a set of different models, each with slightly different assumptions, to explore the robustness of the study's findings.

Figure 2: Wind Turbine Development Periods Studied

Report Compares Transactions That Each Took Place in One of Four Development Periods



Q1) Have wind facilities in Massachusetts been located in areas where average home prices were lower than prices in surrounding areas (i.e., a "pre-existing price differential")?

Q2) Are post-construction (i.e., after wind-facility construction) home price impacts evident in Massachusetts and how do Massachusetts results contrast with previous results estimated for more rural settings?

Q3) Is there evidence of a post-announcement/pre-construction effect (i.e., an "anticipation effect")?

Q4) How do impacts near turbines compare to the impacts of amenities and disamenities also located in the study area, and how do they compare with previous findings?

Q5) Is there evidence that houses near turbines that sold during the post-announcement and post-construction periods did so at lower rates (i.e., frequencies) than during the pre-announcement period?

The study makes five major unique contributions:

1. It uses the largest and most comprehensive dataset ever assembled for a study linking wind facilities to nearby home prices.[4]

2. It encompasses the largest range of home sale prices ever examined.[5]

3. It examines wind facilities in urban areas (with relatively high-priced homes), whereas previous analyses have focused on rural areas (with relatively low-priced homes).

4. It largely focuses on wind facilities that contain fewer than three turbines, while previous studies have focused on large-scale wind facilities (i.e., wind farms).

5. Our modeling approach controls for seven environmental amenities and disamenities in the study area, allowing the effect of wind facilities to be compared directly to the effects of these other factors.

The models perform exceptionally well given the volatility in the housing market during the study period, with an adjusted-R^2 of approximately 0.80[6] and highly statistically significant[7] and appropriately signed controlling parameters (e.g., square feet, acres, and age of home at the time of sale). The amenity and disamenity variables (proximity to beaches, open space, electricity transmission lines, prisons, highways, major roads, and landfills) are significant in a large portion of the models and appropriately signed—indicating that the models discern a strong relationship between a home's environment and its selling price—and generally accord with the results of previous studies. To test whether the results of the analysis would change if the model was specified in a different way, or run using a differently-specified dataset, we ran a suite of robustness tests. The results generated from the robustness tests changed very little, suggesting that our approach is not dependent on the model specification or the data selection.

The results do not support the claim that wind turbines affect nearby home prices. Despite the consistency of statistical significance with the controlling variables, statistically significant results for the variables focusing on proximity to operating turbines are either too small or too sporadic to be apparent. Post-construction home prices within a half mile of a wind facility are 0.5% higher than they were more than 2 years before the facility was announced (after controlling for

4 Four of the most commonly cited previous studies (Carter, 2011; Heintzelman and Tuttle, 2012; Hinman, 2010; and Hoen et al., 2011) analyzed a *combined total* of 23,977 transactions, whereas the present study analyzes more than five times that number.

5 Existing studies analyzed the impact of wind turbines on homes with a median price of less than $200,000, whereas the current study examines houses with a median price of $265,000 for the 122,198 observations located within 5 miles of a wind turbine (with values ranging from $40,200 to $2,495,000).

6 In statistics, the coefficient of determination, denoted R^2 (pronounced "R squared"), indicates how well data points fit a line, curve or, in our case, a regression estimation. An R^2 of 1 indicates that the regression line perfectly fits the data.

7 Statistical significance allows one to gauge how likely sample data are to exhibit a definitive pattern rather than, instead, have occurred by chance alone. Significance is denoted by a *p*-value (or "probability" value) which can range between 0 and 1. A very low *p*-value, for example <0.001, is considered highly unlikely (in this case with a probability of less than 0.1%) to have occurred by chance. In general, an appropriate *p*-value is chosen by the researchers consistent with the area of research being conducted, under which results are considered "significant" and over which are considered "non-significant". For the purposes of this research, a *p*-value of 0.10 or below is considered "statistically significant", with *p*-values between 0.10 and 0.05 being "weakly statistically significant", between 0.05 and 0.01 being "significant", and below 0.01 being "highly statistically significant".

What Is a Hedonic Pricing Model?

Hedonic pricing models are frequently used by economists and real estate professionals to assess the impacts of house and community characteristics on property values by investigating the sales prices of homes. A house can be thought of as a bundle of characteristics (e.g., number of square feet, number of bathrooms, the size of the parcel). When a price is agreed upon by a buyer and seller there is an implicit understanding that those characteristics have value. When data from a large number of residential transactions are available, the individual marginal contribution to the sales price of each characteristic for an average home can be estimated with a hedonic regression model. Such a model can statistically estimate, for example, how much an additional bathroom adds to the sale price of an average home. A particularly useful application of the hedonic model is to value non-market goods—goods that do not have transparent and observable market prices. For this reason, the hedonic model is often used to derive value estimates of amenities such as wetlands or lake views, and disamenities such as proximity to and/or views of high voltage transmission lines, roads, cell phone towers, landfills. It should be emphasized that the hedonic model is not typically designed to appraise properties (i.e., to establish an estimate of the market value of one home at a specified point in time) as would a bank appraisal, which would generally be only applicable to that particular home. Instead, the typical goal of a hedonic model is to accurately estimate the marginal contribution of individual or groups of characteristics across a set of homes, which, in general, allows stakeholders to understand if widely applicable relationships exist.

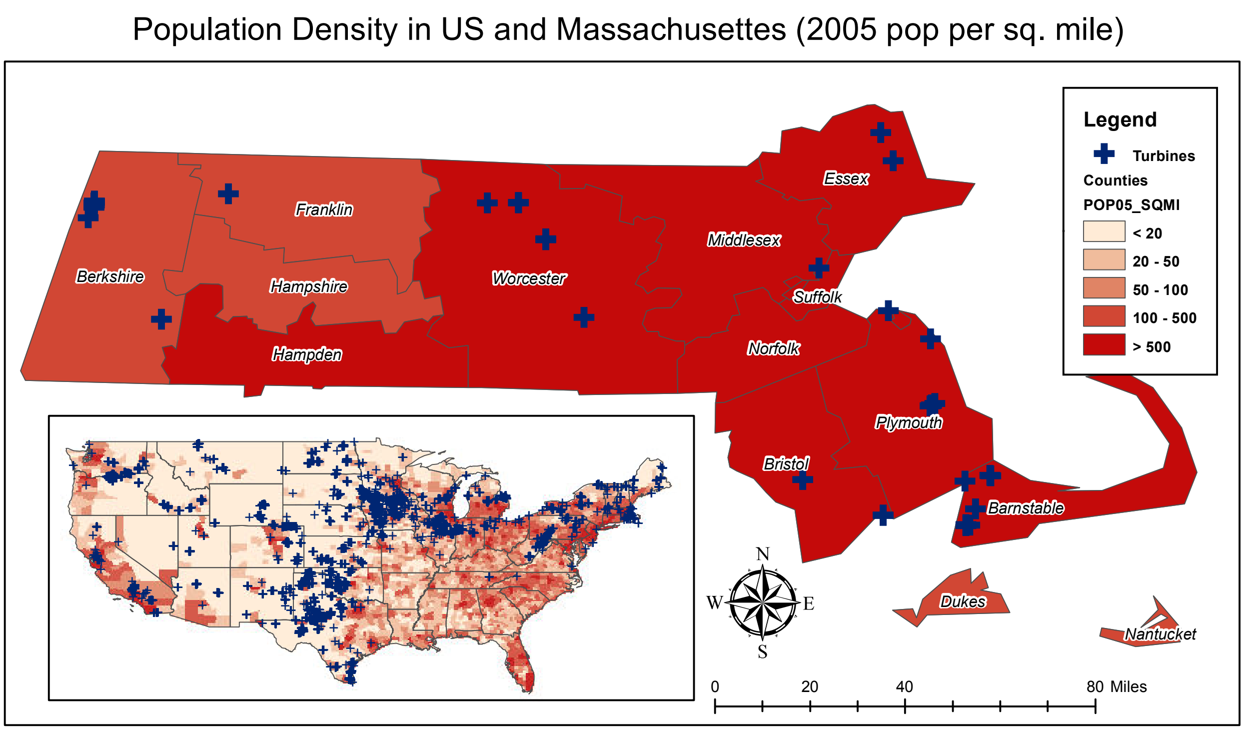
market inflation/deflation). This difference is not statistically significant. Post-announcement, pre-construction home prices within a half mile are 2.3% lower than their pre-announcement levels (after controlling for inflation/deflation), which is also a non-significant difference, though one of the robustness models suggests weak evidence that wind-facility announcement reduced home prices. An additional tangential, yet important, result of the analysis is the finding of a statistically significant "pre-existing price differential": prices of homes that sold more than 2 years before a future nearby wind facility was announced were 5.1% lower than the prices of comparable homes farther away from the future wind location. This indicates that wind facilities in Massachusetts are associated with areas where land values are lower than the surrounding areas, and, importantly, this "pre-existing price differential" needs to be accounted for in order to correctly measure the "post construction" impact of the turbines. Finally, our analysis finds no evidence of a lower rate (i.e., frequency) of home sales near the turbines.

As discussed in the literature review, the effects of wind turbines may be somewhat context specific. Nevertheless, the stability of the results across models and across subsets of the data, and the fact that they agree with the results of existing literature, suggests that the results may be generalizable to other U.S. communities, especially where wind facilities are located in more urban settings with relatively high-priced homes. These results should inform the debate on actual impacts to communities surrounding turbines. Additional research would augment the results of this study and previous studies, and our report concludes with recommendations for future work.

1. INTRODUCTION

Growing concern about global climate change and energy security are prompting reconsideration of how energy—particularly electricity—is generated, transmitted, and consumed in the United States and across the globe (Ekins, 2004; Devine-Wright, 2008; Pasqualetti, 2011). Internationally, greater use of renewable wind energy to mitigate the threat of climate change has broad-based support, primarily because, once facilities are constructed, wind power emits no greenhouse gases (Hasselmann et al., 2003; Watson, 2003; Jager-Waldau and Ossenbrink, 2004). Many jurisdictions have set ambitious renewable energy goals, targeting 20% to 33% of their electricity to be generated by renewable sources by 2020 (see for example, the European Union target of 20% EU, 2012 and California's updated RPS goal of 33%). Wind energy offers several advantages over other low-emission alternatives such as nuclear power and large-scale hydropower projects, but the siting of wind projects remains controversial in many countries (Firestone and Kempton, 2007; Moragues-Faus and Ortiz-Miranda, 2010; Nadai and van der Horst, 2010; Wolsink, 2010).

Figure 3: Map of Massachusetts Turbines included in study (through November 2012) and U.S. Wind Turbines through 2011 and population densities



Source: Lawrence Berkeley National Laboratory, FAA, Ventyx, US Census Bureau, MassCEC

In the United States, large-scale wind installations have tended to be built in sparsely populated locations in the Plains and West (Figure 3). Given that many existing turbines have been located in fairly rural areas, opposition to wind power has largely been attributed to concerns about the transformation of natural landscapes into "landscapes of power" (Pasqualetti et al., 2002 p. 3). Some have extended this place-based perspective and framed the wind-energy debate as being a new kind of environmental controversy, which divides environmentalists of different persuasions who attach contrasting priority to global and local concerns (see for example Warren et al., 2005). Others have delved more deeply into the discourse surrounding renewable energy projects in general, and wind-energy projects specifically, and pointed out that, depending on the narrative, they can be portrayed as representing either development or conservation, localization or globalization (van der Horst and Vermeylen, 2011).

Regardless of what is driving community attitudes towards wind power, government at all spatial scales needs to navigate the complex political terrain of introducing public policies that reduce carbon emissions and fossil fuel dependency in ways that simultaneously protect private property rights and meet with the community's approval (Jepson et al., 2012; Slattery et al., 2012). As such, one of the roles of government is to support independent research to characterize and communicate the potential impacts that public policy decisions, for example for wind facilities, may have on the price of surrounding private property. Existing studies of the effect that wind turbines have had on the price of residential properties have tended to focus on large-scale wind farms located in rural settings, because this is where the majority of projects have been developed. To date, no large-scale studies have focused on smaller-scale facilities in more urban settings, but Massachusetts affords such an opportunity. Massachusetts also has relatively high-priced homes near turbines compared to homes near turbines in other, less urban parts of the country.

Massachusetts has regions with substantial wind resources and strong policies that support the adoption of clean energy. Its first utility-scale (600 kW and larger) wind turbine was installed in Hull in 2001. Since then, wind generation capacity has increased substantially. As of January 2013, Massachusetts had 42 wind projects larger than 100 kW, consisting of 78 individual turbines totaling 99 MW of capacity. This compares to less than 3 MW in Rhode Island and Connecticut combined (Wiser and Bolinger, 2012). Turbines have been located in a variety of settings across the state, including the mountainous Berkshire East Ski Resort, heavily urbanized Charlestown, and picturesque Cape Cod. The average gross population density surrounding the Massachusetts turbines (approximately 416 persons per square mile, based on 2005 population levels and turbines as of 2012) far exceeds the national average of approximately 11 persons per square mile around turbines (Hoen, 2012).

In this study, we analyze the effect of Massachusetts' wind turbines larger than 600 kilowatts (kW) of rated capacity on nearby home prices to inform the debate about the siting and operation of smaller-scale, wind projects across a broad range of land use types in high-home-value areas of the United States. Our study makes five major unique contributions:

1. It uses the largest and most comprehensive dataset ever assembled for a study linking wind facilities to nearby home prices.[8]

2. It encompasses the largest range of home sale prices ever examined.[9]

3. It examines wind facilities in areas across a range of land use and zoning types from rural to urban/ industrial (with relatively high-priced homes), whereas previous analyses have focused on rural areas (with relatively low-priced homes).

4. It largely focuses on wind facilities that contain fewer than three turbines, while previous studies have focused on large-scale wind facilities.

5. Our modeling approach controls for seven environmental amenities and disamenities in the study area, allowing the effect of wind facilities to be compared directly to the effects of these other factors.

The remainder of this report is organized as follows. The next section (Section 2) reviews literature related to public opposition to and support for wind turbines, the hypothetical stigmas associated with turbines near homes, policies and guidelines which address the siting and operation of wind facilities, ways to quantify whether turbines are a disamenity, and the impact on home values of other types of environmental amenities and disamenities—followed by a discussion of gaps in the literature. Section 3 presents our empirical analysis, including descriptions of the study area, data, methods, and results. The final section (Section 4) discusses the findings, provides preliminary conclusions, and offers suggestions for future research.

8 Four of the most commonly cited previous studies (Carter, 2011; Heintzelman and Tuttle, 2012; Hinman, 2010; and Hoen et al., 2011) analyzed a *combined total* of 23,977 transactions, whereas the present study analyzes more than five times that number.

9 Existing studies analyzed the impact of wind turbines on homes with a median price of less than $200,000, whereas the current study examines houses with a median price of $265,000 for the 122,198 observations located within 5 miles of a wind turbine (with values ranging from $40,200 to $2,495,000) and a median price for the 312,674 observations located within 10 miles of a wind turbine of $287,000 (with values ranging from $41,100 to $2,499,000).

2. LITERATURE REVIEW

2.1 Public Acceptance of and Opposition to Wind Energy

Wind energy is one of the fastest growing sources of power generation in the world, and public and political support for it are generally strong (Ek, 2005; Graham et al., 2009). Despite this strong support, the construction of wind projects provokes concerns about local impacts (Toke et al., 2008; Jones and Eiser, 2009; Devine-Wright and Howes, 2010; Jones and Eiser, 2010; Moragues-Faus and Ortiz-Miranda, 2010; Wolsink, 2010; Pasqualetti, 2011). Thus, some researchers have studied the factors shaping public attitudes toward wind energy and renewable energy technologies in general (see for example Devine-Wright, 2005; Firestone and Kempton, 2007; Pedersen et al., 2007; Wolsink, 2007; Devine-Wright, 2009; Jones and Eiser, 2009; Devine-Wright and Howes, 2010; Jones and Eiser, 2010; Swofford and Slattery, 2010; Brannstrom et al., 2011; Devine-Wright, 2011). Others have downplayed the importance of local opposition to wind energy in hindering wind's expansion, pointing instead to hindrances related to institutional barriers, such as how wind energy projects are funded, and the heavy handedness of "legislate, announce, defend" approaches to siting turbines (Wolsink, 2000).

In the early stages of wind development, opposition to wind turbines was often simplistically conceptualized as NIMBY-ism, with NIMBY ("not in my backyard") referring to people opposing the local installation of technologies they otherwise support in principle (Devine-Wright, 2005; Wolsink, 2007; Devine-Wright, 2009). More recently, researchers have suggested that the factors shaping public sentiment towards renewable energy technologies are much more complex than the concept of NIMBY-ism suggests. Of note is the quantitative research aimed at understanding public attitudes towards wind farms in the Netherlands conducted by Wolsink (2007). His work, and the work of others (e.g., Devine-Wright, 2012), which is grounded in theories from social psychology, found that public attitudes towards wind projects were shaped by perceptions of risk and equity. Based on these findings, Wolsink concluded that a collaborative—rather than a "top-down"—approach to siting wind farms was the most likely to produce positive outcomes. These findings were echoed in an examination of public attitudes towards wind turbine construction in Sheffield, England, where researchers found little evidence of NIMBY-ism in respondents living close to proposed developments compared to a control group (Jones and Eiser, 2009). Rather, opposition could be attributed to uncertainty regarding the details of the facilities being constructed, which underscores the importance of continued and responsive community involvement in siting wind turbines.

Some researchers have studied whether communities are more accepting of wind turbines if the facilities are community owned (Warren and McFadyen, 2010). Comparing attitudes towards wind farms on two islands in Scotland, one community owned and one not, the researchers discovered that residents near the community owned facilities had a much more positive perception of the facilities. Locals affectionately referred to their wind turbines as "The Three

Dancing Ladies," which the researchers interpreted as indicating the positive psychological effects of community ownership. Warren and McFadyen (2010) concluded that a change of development model towards community ownership could improve public attitudes towards wind farms in Scotland.

Another strand of research has focused on community perceptions before and after wind-facility construction. Some studies showed that local people become more supportive of wind facilities after they have been constructed (Wolsink, 2007; Eltham et al., 2008; Walker et al., 2010) and that the degree of support increases with proximity to the facilities (Braunholtz and MORI, 2003; Warren et al., 2005; Slattery et al., 2012).

2.2 Hypothetical Stigmas Associated with Wind Turbines

To understand the basis of public opposition to wind facilities, researchers have hypothesized the existence of three types of stigma that might be associated with these facilities (Hoen et al., 2011). An "area stigma" would be a concern that wind-turbine construction will alter the rural sense of place; this resonates with the suggestion made by Pasqualetti et al. (2002) that people object to the creation of "landscapes of power." This is distinct from a "scenic vista stigma," the possible concern that homes might be devalued because of the view of a wind facility. Finally, a "nuisance stigma" would be associated with people located near turbines who might be affected by the turbines' noise and shadow flicker,[10] which fade quickly with distance. Our study focuses on the potential existence of a nuisance stigma by searching for turbine-related impacts on the sale of homes located a short distance away. However, if they exist, the effects of all three stigma types hypothetically could interact, and all are described briefly below.

The spatial and temporal combinations of community and wind-facility characteristics that might produce one or more of these stigmas are not entirely clear. Theoretically, an area stigma would have the largest geographic impact, although its exact reach would depend on the spatial distribution and types of land use in the surrounding area. In their comprehensive analysis, Hoen et al. (2009, 2011) were unable to uncover area stigma effects across their large set of U.S. wind facilities. Recent research has suggested, however, that this type of stigma depends on the "place identity" of local residents (Pedersen et al., 2007; Devine-Wright, 2009; Devine-Wright and Howes, 2010). For those who view the countryside as a place for economic activity and technological development or experimentation, which is potentially consistent with the locations studied in Hoen et al. (2009, 2011), wind turbines might not carry a stigma because they could represent a new use for the land, and the turbine sounds and sights might be insignificant in the context of existing machinery and land practices. Conversely, rural residents who view the countryside as a place for peace and restoration might oppose turbines even if they do not live near them. The "place identity" of the landscape likely varies among wind facility- locations and among individuals in those locations, making some local residents more accepting of turbines than others.

Acceptance of turbines might also relate to their economic benefits. For example, a study in West Texas and Iowa found that community members had positive impressions of large-scale wind facilities built to generate long-term social and economic benefits, including creation of a local industry that

10 Shadow flicker occurs when the sun is behind rotating turbine blades and produces an intermittent shadow.

brought jobs and increased property values as well as increased tax revenue that benefited the community and schools (Slattery et al., 2012; Kahn, 2013). These findings conform to other research suggesting that equitable distribution of economic benefits is a key method of increasing local support for turbines (Pasqualetti et al., 2002) and that the perception of how tax benefits will be shared locally can influence people's acceptance of wind projects (Toke, 2005; Brannstrom et al., 2011). Economic factors appear to be more of a consideration where the economy is perceived to be in decline (Toke et al., 2008); this finding is echoed in studies of other environmental disamenities that show that communities are more willing to accept facilities if jobs are associated with them (Braden et al., 2011). Many of these studies were conducted in rural areas, thus their findings may not be generalizable to more urban settings, where community reactions might be entirely different.

Similarly, if a scenic vista stigma exists, it might have different levels of impact depending on wind-facility locations, the place identity of nearby residents, and the distance of residents from the turbines. Hoen et al. (2009, 2011) meticulously examined effects from views of turbines at many different spatial scales and predicted levels of impacts in rural areas, but they found no evidence of impacts to support the scenic vista stigma claim. However, an urban setting might connote different landscape values and therefore generate different reactions to turbines and produce different effects on home values. For example, Sims et al. (2008) found weak evidence that a house's orientation to a wind facility (and therefore the prominence of the view of the turbines) affected its sales price in Cornwall, United Kingdom, an area of relatively high population.[11]

11 As of 2011, Cornwall had a population density of 390 persons per square mile. (See http://en.wikipedia.org/wiki/Cornwall)

More than the other stigma types, any potential wind-related nuisance stigma would depend on the close proximity of residents to turbines and likely would have the most constrained spatial scale. Two studies in Germany evaluated more than 200 participants living near wind turbines with regard to shadow flicker exposure, stress, behaviors, and coping and found that stress levels and annoyance increased the closer people were to wind turbines in all directions (Pohl et al., 1999, 2000). Similarly, wind turbine noise, which is less direction dependent than shadow flicker, might have an even greater impact on stress levels. Studies have shown that residents experience genuine annoyance and stress responses to "normal" turbine noise levels (Pedersen and Waye, 2007), perceiving the noise as an intrusion into their space and privacy, especially at night (van den Berg, 2004; Pedersen et al., 2007) and when the turbines can be seen (Pedersen and Waye, 2007). Governments around the world have addressed potential turbine-related nuisances via regulations and guidelines, which are discussed in the next subsection.

2.3 Policies and Guidelines Which Address the Siting and Operation of Wind Facilities

Noise is the most prominent potential nuisance associated with wind turbines and thus has been the focus of much regulatory effort. The quality and magnitude of sound produced by turbines results from the complex interaction of numerous variables, such as the size and design of the turbine as well as the wind speed and direction, temperature gradients that affect wind turbulence, and vertical and directional wind shear (Hubbard and Shepherd, 1991; Berglund et al., 1996; Oerlemans et al., 2006; Pedersen et al., 2010; Bolin et al., 2012; Wharton and Lundquist, 2012). For practical purposes, governments, both here in the U.S. and abroad, at a variety of spatial scales have tended to adopt setback metrics for the distance between a wind turbine and housing as a proxy for noise limits (NARUC, 2012). Very few countries have mandatory turbine setback distances beyond what would be required for safety in the event of a collapse (and therefore 1-1.5 times the turbines' height), nor do they often impose mandatory limits to shadow flicker; they do often have mandatory or, at least, stronger regulation of noise.

Although there is no worldwide standard limit for noise associated with wind turbines (Haugen, 2011), many European countries base their regulations on recommended noise limits published by the World Health Organization (WHO) Regional Office for Europe (WHO, 2011). The WHO recommends noise limits of 40 (A-weighted) decibels dB(A) for the average nighttime noise outside a dwelling, which translates to a noise limit of 30 dB(A) inside a bedroom.[12] These limits are based on noise levels that do not harm a person's sleep. Above these limits, it is believed, people have a lower amount and quality of sleep, which can lead to major health issues (WHO, 2011).

In the United States, turbine sound and setback regulation is limited: only "a handful of states have published setback standards, sound standards, or both" (NARUC, 2012, p. 15). Ten states have published voluntary guidelines for wind siting and zoning, and five have published model ordinances intended to guide local governments. Similar to other countries, required or recommended setbacks vary widely from state to state, both in terms of the distances cited and the legal weight they carry (some are formal limits while others are merely guidelines).

In Massachusetts, the Model Wind Bylaw and the Massachusetts Department of Environmental Protection (MADEP) Noise Policy provide guidelines and regulatory standards respectively for the siting and operation of wind facilities to address public safety and minimize local impacts. The former provides some guidance on setbacks from the nearest existing residential or commercial structure using a multiple (e.g., 3 times) of blade tip height (BTH) (i.e., the hub height plus the length of the blade) as a means to determine the project specific setback.[13] However, all of the wind turbines in the state have been permitted at the local level, with varying degrees of adherence to the guidance, while still others were permitted prior to the Model Bylaw's preparation, and still others have had few structures near the turbines from which to setback. Therefore, in practice, setbacks to the nearest structure have varied from as much as 4,679 feet (0.89 miles, 24.4 x BTH) to as little as 520 feet (0.1 miles, 1.3 x BTH), with an average Massachusetts project being 1,925 feet (0.36 miles, 5.9 x BTH) (Studds, 2013).[14] Because, in part, of the variety of ways in which the guidelines have been applied, setbacks remain one of the more controversial aspects of wind-facility siting. Also, adding to the controversy are the results of one recent study of two wind facilities in Maine that claimed noise effects are experienced as far as 1.4 kilometers (4,590 feet, 0.87 miles) from the turbines (Nissenbaum et al., 2012).

12 A-weighted decibels abbreviated to dBa, dBA or dB(a), are an expression of the relative loudness of sounds in air as perceived by the human ear. In the A-weighted system, the decibel values of sounds at low frequencies are reduced, compared with unweighted decibels, in which no correction is made for audio frequency (http://whatis.techtarget.com)

13 MA EEA/DOER Model Wind Bylaw. Accessed on 1/23/12 from: http://www.mass.gov/eea/docs/doer/gca/wind-not-by-right-bylaw-june13-2011.pdf. The Executive Office of Environmental Affairs, Department of Environmental Quality Engineering, Division of Air Quality Control, "DAQC Policy 90-001," February 1, 1990.

14 These setbacks do not include structures of participating landowners, that either might own the turbine, or are being compensated by the turbine owner.

Finally, in response to noise concerns, wind-technology developers are investigating numerous ways to suppress noise including passive noise reduction blade designs, active aerodynamic load control, new research on inflow turbulent and turbine wakes, low-noise brake linings, and cooling fan noise mufflers (Leloudas et al., 2009; Wilson et al., 2009; Barone, 2011; Petitjean et al., 2011), some of which have been shown to lower annoyance when applied (Hoen et al., 2010; Hessler, 2011). How these strategies might eventually affect setback and noise regulations and guidelines is unclear.

For the purposes of this study, suffice it to say that wind turbine setbacks vary, and they are often smaller than the distances at which (at least some) turbine noise effects have been claimed to exist. If a resulting nuisance stigma exists near turbines, it should be reflected in nearby home prices. By evaluating the relationship between wind turbines and home prices this study might help inform appropriate setbacks and noise recommendations in Massachusetts.

2.4 Methods to Quantify Whether Wind Turbines are a Disamenity

If a wind turbine near homes does produce a meaningful stigma, it could be considered a disamenity similar to other disamenities such as proximity to electricity transmission lines and major roads. A variety of research techniques can be used to determine the impact of wind energy projects on residential properties, including homeowner surveys, expert surveys (such as interviewing real estate appraisers), and statistical analysis of property transactions using cases studies or the well-established method of hedonic modeling (see e.g., Jackson, 2003). The latter technique is firmly established in the literature as the most reliable approach to determining the impact of a particular development on property prices, because it (a) uses transactions data that reflect actual sales in the housing market rather than perceptions of potential impacts; (b) controls for a set of potentially confounding home, site, neighborhood and market influences; and, (c) is flexible enough to allow a variety of potentially competing aspects of wind development and proximity to be tested simultaneously (Jackson, 2001).

An extensive meta-analysis of studies that had quantified the effect of environmental amenities and disamenities found that the use of case study techniques provide larger estimates of property losses associated with environmental disamenities than regression studies using hedonic models (Simons and Saginor, 2006). Simons and Saginor attributed this differential to the fact that case studies may be subjective based on the case researcher, and they argue that case study observations may even have been chosen because of their dramatic, atypical conditions. Surveys, which were generally based on respondents' estimates of impacts, were considered to suffer from similar bias due to the subjectivity of respondents and their potential lack of effect-estimation expertise.

The hedonic-modeling approach is based on the idea that any property's sales price is composed of a bundle of attributes, including the characteristics of the individual property and its location (Rosen, 1974). Sales can be compared to one another, taking into account the effects of time (i.e., inflation/deflation), to determine the value of any specific attribute (Butler, 1982; Clapp and Giaccotto, 1998; Jackson, 2001; Simons and Saginor, 2006; Jauregui and Hite, 2010; Kuminoff et al., 2010; Zabel and Guignet, 2012).

The approach has been used extensively to quantify the effects of public policies (specifically infrastructure) on home prices by examining the value associated with being close to a facility before and after it was constructed (see Atkinson-Palombo, 2010 and the extensive references therein). If the particular initiative being studied (for example, a transportation facility) is perceived as an amenity, it would be expected to increase property values, all else being equal. If the initiative is perceived as a disamenity, it would be expected to decrease property values. This hedonic method measures average impacts across the study area and therefore can help policy makers understand costs and benefits at a broad scale.

Our study uses the hedonic-modeling approach to quantify the effect of wind facilities on home values. This involves creating a statistical model with an expression of home price as the dependent variable and independent variables consisting of factors that influence home price. These independent variables include features of the specific housing unit, locational characteristics, a variable that represents distance to a wind turbine at discrete stages of the construction process, and various controls such as the time when a transaction took place to account for changes in the housing market over time (inflation and deflation). If a wind turbine creates a disamenity, then house prices closer to the turbine would be expected to decline (all else being equal) compared to their values before the turbine was installed and compared to the prices of houses farther away that sold during the same period.

The peer-reviewed, published studies that used hedonic modeling largely agree in finding non-significant post-construction effects (i.e., non-significant effects on home prices occurring after construction of wind turbines) (Sims et al., 2008; Hoen et al., 2011; Heintzelman and Tuttle, 2012), implying that average impacts in their study areas were either relatively small or sporadic near existing turbines. Three academic studies found similar results (Hoen, 2006; Hinman, 2010; Carter, 2011). The geographic extent of these studies varied from single counties (Hoen, 2006; Hinman, 2010; Carter, 2011), to three counties in New York (Heintzelman and Tuttle, 2012), to eight states (Hoen et al., 2011), showing that results have been robust to geographic scale. Although the academic and peer-reviewed literature has largely focused on post-construction impacts, some studies have found evidence of pre-construction yet post-announcement impacts (Hinman, 2010; Hoen et al., 2011; Heintzelman and Tuttle, 2012). This "anticipation effect" (Hinman, 2010) correlates with surveys of residents living near wind facilities that have found that once wind turbines are constructed, residents are more supportive of the facilities than they were when the construction of that facility was announced (Wolsink, 2007; Sims et al., 2008). Analysis of home prices related to other disamenities (e.g., incinerators) also has shown anticipation effects and post-construction rebounds in prices (Kiel and McClain, 1995).

2.5 General Literature on the Effects of Amenities and Disamenities on House Prices

While wind turbines are typically limited to high-wind-resource areas, disamenities such as highways, overhead electricity transmission lines, power plants, and landfills are ubiquitous in urban and semi-rural areas, and they have been the focus of many studies. This more established "disamenity literature" (see for example, Boyle and Kiel, 2001; Jackson, 2001; Simons and Saginor, 2006) helps frame the expected level of impact around turbines. For example, adverse home-price effects near electricity transmission lines, a largely visual disturbance, have ranged from 5% to 20%, fading quickly with distance and disappearing beyond 200 to 500 feet, and even in some cases, when afforded with access to the transmission line corridor, home-price effects have found to be positive signaling net benefits over costs of transmission line proximity (e.g., Des Rosiers, 2002). Landfills, which present smell and truck-activity nuisances and potential health risks from groundwater contamination, have been found to decrease adjacent property values by 13.7% on average, fading by 5.9% for each mile a home is further away for large-volume operations (that accept more than 500 tons per day). Lower-volume operations decreased adjacent property values by 2.7% on average, fading by 1.3% per mile, with 20% to 26% of the lower-volume landfills not significantly impacting values at all (Ready, 2010). Finally, a review of literature investigating impacts of road noise on house prices, which might be analogous to noise from turbines, found price decreases of 0.4% to 4% for houses adjacent to a busy road compared to those on a quiet street (see for example Bateman et al., 2001; Day et al., 2007; Kim et al., 2007; Andersson et al., 2010).

Community amenities also have been well studied. Open space (i.e., publicly accessible areas that are available for recreational purposes) has been found to increase surrounding prices (Irwin, 2002; Anderson and West, 2006a); Anderson and West estimated those premiums to be 0.1% to 5%, with an average of 2.6% for every mile that a home is closer to the open space. Proximity to (and access to and views of) water, especially oceans, has been found to increase values (e.g., Benson et al., 2000; Bond et al., 2002); for example, being on the waterfront increased values by almost 90% (Bond et al., 2002).

Although much of the literature on community perceptions of wind turbines suggests that local residents may see turbines as a disamenity, this is not always the case. As discussed above, perceptions about wind turbines are shaped by numerous factors that include the size of the turbine(s) or project, the sense of place of the local residents, the manner in which the planning process is conducted, and the ownership structure. In contrast to disamenities universally disliked by local residents (as discussed above), some literature suggests that wind turbines could be considered amenities (i.e., a positive addition to the community), particularly if benefits accrue to the local community. Thus, whether wind turbines increase or decrease surrounding home prices—and by how much—remains an open question.

The evidence discussed above suggests that any turbine-related disamenity impact likely would be relatively small, for example, less than 10%. If this were the case, tests to discover this impact would require correspondingly small margins of error, which in turn requires large amounts of data. Yet much of the literature has used relatively small numbers of transactions near turbines. For example, the largest dataset studied to date had only 125 post-construction sales within 1 mile of the turbines (Hoen et al., 2009, 2011), while others contained far fewer post-construction transactions within 1 mile: Heintzelman and Tuttle ($n \sim 35$), Hinman ($n \sim 11$), and Carter ($n \sim 41$). Although these numbers of observations might be adequate to examine large impacts (e.g., greater than 10%), they are less likely to discover smaller effects because of the size of the corresponding margins of error. Larger datasets of transactions would allow smaller effects to be discovered. Using results from Hoen at al. (2009) and the confidence intervals for the various fixed-effect variables in that study, we estimated the numbers of transactions needed to find effects of various sizes. Approximately 50 transactions are needed to find an effect of 10% or greater, 200 to find an effect of 5%, 500 to find an effect of 3.5%, and approximately 1,000 to find a 2.5% effect.

Additionally, there is evidence that wind facilities are sited in areas where property prices are lower than in surrounding areas—what we are referring to as a "pre-existing price differential". For example, Hoen et al. (2009) found significantly lower prices (-13%) for homes that sold more than 2 years prior to the wind facilities' announcements and were located within 1 mile of where the turbines were eventually located, as compared to homes that sold in the same period and were located outside of 1 mile. Hinman (2010) found a similar phenomenon that she labeled as a "location effect." To that end, Sims and Dent (2007), after their examination of three locations in Cornwall, United Kingdom, commented that the research "highlighted to some extent, wind farm developers are themselves avoiding the problem by locating their developments in places where the impact on prices is minimized, carefully choosing their sites to avoid any negative impact on the locality" (p. 5). Thus, further investigation of whether wind facilities are associated with areas with lower home values than surrounding areas would be worthwhile. It is important to emphasize that any "pre-existing price differential" does not exist because of the turbines, but instead is likely the result of the fact that wind turbines may be located in areas of relative disamenity. For example, in Massachusetts, wind turbines have typically been co-located with industrial facilities such as waste water treatment plants. While we included seven different amenities and disamenities in our model, we could not include all of them because of a lack of accurate data, especially for waste water treatment plants and industrial sites that may have been co-located with wind turbines. Some of the "pre-existing price differential" may therefore be attributable to other disamenities that have not been included in the model. Regardless of the reason, any "pre-existing price differential" needs to be taken into account in order to accurately calculate the net impacts that wind turbines may have on property prices.

Finally, there have been claims that the home sales rate (i.e., sales volume) near existing wind turbines is far lower than the rate in the same location before the turbines' construction and the rate farther away from the turbines, because homeowners near turbines cannot find buyers (see sales volume discussion in Hoen et al., 2009). Obviously, many homes near turbines have sold, as recorded in the literature. If it were true that homeowners near turbines have *chosen* to sell less often because of very low buyer bids, then sales that did take place near turbines should be similarly discounted on average, but evidence of large discounts has not emerged from the academic literature (as discussed above). Moreover, homes farther away from turbines would be taken off the market for similar reasons (sellers do not get offers they accept), thus the comparison group is potentially affected in a similar way. In any case, although Hoen et al. (2009) found no evidence of lower sales volumes near turbines, further investigations of this possible phenomenon using different datasets are warranted.

2.6 Gaps in the Literature

This literature review suggests several knowledge gaps that could be studied further: exploring wind turbine impacts on home prices in urban settings, where the "sense of place" might be different than in the previously studied rural areas; examining post-announcement/pre-construction impacts; testing for relatively small impacts using large datasets; determining whether wind facilities are sited in areas with lower home values; examining turbine impacts in concert with impacts from other disamenities and amenities; and investigating whether home sales volumes are different near existing wind turbines. Our study seeks to address each of these areas.

3. EMPIRICAL STUDY

Because of Massachusetts' density of urban homes near enough to wind turbines to produce potential nuisance effects, our study analyzes Massachusetts data to address gaps in knowledge about turbine effects on home prices. Specifically, the study seeks to answer the following five questions:

Q1) Have wind facilities in Massachusetts been located in areas where average home prices were lower than prices in surrounding areas (i.e., a "pre-existing price differential")?

Q2) Are post-construction (i.e., after wind-facility construction) home price impacts evident in Massachusetts, and how do Massachusetts results contrast with previous results estimated for more rural settings?

Q3) Is there evidence of a post-announcement/pre-construction effect (i.e., an "anticipation effect")?

Q4) How do impacts near turbines compare to the impacts of amenities and disamenities also located in the study area, and how do they compare with previous findings?

Q5) Is there evidence that houses near turbines that sold during the post-announcement and post-construction periods did so at lower rates (i.e., frequencies) than during the pre-announcement period?

The following subsections detail the study's hedonic-modeling process and base model, the extensive robustness tests used to determine the sensitivity of the base model, the study data, and the results.

3.1 Hedonic Base Model Specification

The price of a home can be expressed as follows:

$$P = f(L, N, A, E, T)$$

where L refers to lot-specific characteristics, N to neighborhood variables, A to amenity/disamenity variables, E to wind-turbine variables, and T to time-dependent variables.

Following from this basic formula, we estimate the following customarily used (see, e.g., Sirmans et al., 2005) semi-log base model to which the set of robustness models are compared.

$$\ln(P) = \beta_0 + \sum \beta_1 L \cdot D + \beta_2 N + \sum \beta_3 A \cdot D + \sum \beta_4 E \cdot D + \sum \beta_5 T + \varepsilon'$$

An explanation of this formula is as follows:

The dependent variable is the log of sales price (P).

L is the vector of lot-specific characteristics of the property, including living area (in thousands of square feet); lot size (in acres); lot size less than 1 acre (in acres if the lot size is less than 1, otherwise 1); effective age (sale year minus either the year built or, if available, the most recent renovation date); effective age squared; and number of bathrooms (the number of full bathrooms plus the number of half bathrooms multiplied by 0.5).

D is the nearest wind turbine's development period in which the sale occurred (e.g., if the sale occurred more than 2 years before the nearest turbine's development was announced, less than 2 years before announcement, after announcement but before construction, or after construction).

N is the U.S. census tract in which the sale occurred.

A is the vector of amenity/disamenity variables for the home, including the amenities: if the home is within a half mile from open space; is within 500 feet or is within a half mile but outside 500 feet of a beach; and, disamenities: is within a half mile of a landfill, and/or prison; and is within 500 feet of an electricity transmission line, highway and/or major road.[15]

T is the vector of time variables, including the year in which the sale occurred and the quarter in which the sale occurred.

E is a binary variable representing if the home is within a half mile from a turbine, and

ε is the error term.[16]

β_0, β_1, β_2, β_3, β_4, β_5 are coefficients for the variables.

The vectors of lot-specific and amenity/disamenity variables are interacted with the development period for three reasons: 1) to allow the covariates to vary over the study period, which will, for example, allow the relationship of living area and sale price to be different earlier in the study period, such as more than 2 years before announcement, than it is later in the study period, such as after construction of the nearest turbine;[17] 2) to ensure that the variables of interest do not absorb any of this variation and therefore bias the coefficients; and 3) to allow the examination of the amenity/disamenity variables for subsets of the data.[18]

The distance-to-the-nearest-turbine variable specified in the base model is binary: one if the home is within a half mile of a turbine and zero if not. The distance can be thought of as the distance, today, when all the turbines in the state have been built. Obviously, for some homes, such as those that sold before the wind facility was announced, there was no turbine nearby at the time of sale, so in those cases the distance variable represents the distance to where the turbine eventually was built. By interacting this distance variable with the turbine development period, we are able to examine how the distance effects might change over the periods and whether or not there was a pre-existing price differential between homes located near turbines and

15 Each of the amenity/disamenity variables are expressed as a binary variable: 1 if "yes," 0 if "no."

16 The error term (i.e., "unexplained variation" or "residual value") defines the portion of the change in the dependent variable (in this case the log of sale price) that cannot be explained by the differences in the combined set of independent variables (in this case the size and age of the home, the number of bathrooms, etc.). For example, a large portion of one's weight can be explained by one's gender, age and height, but differences (i.e., unexplained variation) in a sample of people's weight will still exist for random reasons. Regardless of how well a model performs, some portion of unexplained variation is expected.

17 As discussed in greater detail in the results, the coefficients for the variables of interest are quite small in magnitude, and therefore even a relatively small change in the size of the coefficients can be problematic to the correct interpretation of the results. Moreover, the lot-specific and amenity/disamenity variables vary over the development periods, further reinforcing the need to interact them with period. The results for the wind turbine variables presented herein are robust to alternative specifications without these interactions.

18 While the coefficients associated with the amenity/disamenity variables interacted with the facility development periods are not particularly meaningful, creating the subsets enables examination of the data represented by the different wind turbine development periods and shows how stable the amenity/disamenity variables are within these subsets of data.

those farther away that existed even before the turbines were announced.

Further, we used a binary variable as opposed to other forms used to capture distance. For example, other researchers investigating wind turbine effects have commonly used continuous variables to measure distance such as linear distance (Sims et al., 2008; Hoen et al., 2009), inverse distance (Heintzelman and Tuttle, 2012; Sunak and Madlener, 2013), or mutually exclusive non-continuous distance variables (Hoen et al., 2009; Hinman, 2010; Carter, 2011; Hoen et al., 2011; Heintzelman and Tuttle, 2012; Sunak and Madlener, 2013). We preferred the binary variable because we believe the other forms have limitations. Using the linear or inverse continuous forms necessarily forces the model to estimate effects at the mean distance. In some of these cases those means can be quite far from the area of expected impact. For example, Heintzelman and Tuttle (2012) estimated an inverse distance effect using a mean distance of over 10 miles from the turbines, while Sunak and Madlener (2013) used a mean distance of approximately 1.9 miles. Using this approach makes the model less able to quantify the effect near the turbines, where they are likely to be stronger. More importantly, this method encourages researchers to extrapolate their findings to the ends of the distance curve, near the turbines, despite having few data in this distance band. This was the case for Heintzelman and Tuttle (2010), who had less than 10 sales within a half mile in the two counties where effects were found and only a handful of sales in those counties after the turbines were built. Yet they extrapolated their findings to a quarter mile and even a tenth of a mile, where they had very few, if any, cases. Similarly, Sunak and Madlener (2013) had only six (post-construction) sales within a half mile, yet they extrapolated their findings to this distance band.

One method to avoid using a single continuous function to describe effects at all distances is to use a spline model, which breaks the distances into continuous groups (Hoen et al., 2011), but this still imposes some structure on the data that might not actually exist. By far the most transparent method is to use binary variables for discrete distances that therefore impose only slight structure on the data (Hoen et al., 2009; Hinman, 2010; Hoen et al., 2011). Although this method has been used in existing studies, because of a paucity of data, margins of error for the estimates were large (e.g., 7% to 10% for Hoen et al. 2011). However, as discussed above, the extensive dataset for Massachusetts allows this approach to be taken while maintaining relatively small margins of error. Moreover, although others have estimated effects for multiple distance bins out to 5 or 10 miles, we have focused our estimates on the group of homes that are within a half mile of a turbine—although other groups, such as those within a quarter of a mile and between one half and one mile, are explored in the robustness models. The homes within a half mile of turbines are most likely to be impacted and are, therefore, the first and best place to look for impacts. Further, we use the entire group of homes outside of a half mile as the reference category, which gives us a large heterogeneous comparison group and therefore one that is likely *not* correlated with omitted variables—although we also explore other comparison groups in the robustness tests.

3.2 Robustness Tests

Models are built on assumptions and therefore practitioners often test those assumptions by trying multiple model forms. As was the case for this research, a "base" model is compared to a set of "robustness" models, each with slightly different assumptions, to explore the robustness of the study's findings.

The suite of robustness tests explored changes in: 1) the spatial extent at which both the effect and the comparable data are specified; 2) the variables used to describe fixed effects; 3) the screens that are used to select the final dataset as well as outliers and influencers; 4) the inclusion of spatially and temporally lagged variables to account for the presence of spatial autocorrelation; and 5) the inclusion of additional explanatory variables that are not populated across the whole dataset. Each will be described below.

3.2.1 Varying the Distance to Turbine

The base model tests for effects on homes sold within a half mile of a turbine (and compares the sales to homes located outside of a half mile and inside 5 miles of a turbine). Conceivably, effects are stronger the nearer homes are to turbines and weaker the further they are away—because that roughly corresponds to the nuisance effects (e.g., noise and shadow flicker) that we are measuring—but the base model does not explore this. Therefore, this set of robustness models investigates effects within a quarter mile as well as between a half and 1 mile. It is assumed that effects will be larger within a quarter mile and smaller outside of a half mile.

Additionally, the basis of comparison could be modulated as well. The base model compares homes within a half mile to those outside of a half mile and inside of 5 miles, most of which are between 3 and 5 miles. Conceivably, homes immediately outside of a half mile are also affected by the presence of the turbines, which might bias down the comparison group and therefore bias down the differences between it and the target group inside of a half mile. Therefore, two additional comparison groups are explored: 1) those outside of a half mile and inside of 10 miles, and 2) those outside of 5 miles and inside of 10 miles. It is assumed that effects from turbines are not experienced outside of 5 miles from the nearest turbine.

3.2.2 Fixed Effects

A large variety of neighborhood factors might influence a home price (e.g., the quality of the schools, the crime rate, access to transportation corridors, local tax rates), many of which cannot be adequately measured and controlled for in the model specifically. Thus, practitioners use a "fixed effect" to adjust prices based on the neighborhood, which accounts for all the differences between neighborhoods simultaneously. Examples of these fixed effects, moving from larger and less precise geographic areas to smaller and more precise areas are: zip code; census tract; and, census block group.

The base model uses census tract boundaries as the geographic extent of fixed effects, aiming to capture "neighborhood" effects throughout the sample area. Because this delineation is both arbitrary (a census tract does not necessarily describe a neighborhood) and potentially too broad (multiple neighborhoods might be contained in one census tract), the census block group is used in a robustness test. This is expected to allow a finer adjustment to the effects of individual areas of the sample and therefore be a more accurate control for neighborhood effects. The drawback is that the variables of interest (e.g., within a half mile and the development-period variables) might vary less within the block group, and therefore the block group will absorb the effects of the turbines, biasing the results for the variables of interest.

3.2.3 Screens, Outliers, and Influencers

As described below, to ensure that the data used for the analysis are representative of the sample in Massachusetts and do not contain exceptionally high- or low-priced homes or homes with incorrect characteristics, a number of screens are applied for the analysis dataset. To explore what effect these screens have on the results, they are relaxed for this set of robustness tests. Additionally, a selection of outliers (based on the 1 and 99 percentile of sale price) and influencers (based on a Cook's Distance of greater than 1[19]) might bias the results, and therefore a model is estimated with them removed.

3.2.4 Spatially and Temporally Lagged Nearest-Neighbor Data

The value of a given house is likely impacted by the characteristics of neighboring houses (i.e., local spatial spillovers, defined empirically as W_x) or the neighborhood itself. For example, a house in a neighborhood with larger parcels (e.g., 5 acres lots), might be priced higher than an otherwise identical home in a neighborhood with smaller parcels (e.g., 1 acre lots).

If statistical models do not adequately account for these spatial spillovers, the effects are relegated to the unexplained component of the results contained in the error term, and therefore the other coefficients could be biased. If this occurs, then the error terms exhibit spatial autocorrelation (i.e., similarity on the basis of proximity). Often, in the hedonic literature, more concern is paid to unobserved (and spatially correlated) neighborhood factors in the model.[20]

A common approach for controlling for the unobserved neighborhood factors is to include neighborhood fixed effects (see for example Zabel and Guignet, 2012), which is the approach we took in the base model. To additionally control for the characteristics of neighboring houses a model can be estimated that includes spatial lags of their characteristics as covariates in the hedonic model, as is done for this robustness test. Neighboring houses are determined by a set of *k*-nearest neighbors (*k*, in this case, equals 5), though alternative methods could have been used (Anselin, 2002). Further, although dependence often focuses on spatial proximity, it is also likely that sales are "temporally correlated," with nearby houses selling in the same period (e.g., within the previous 6 months) being more correlated than nearby houses selling in earlier periods (e.g., within the previous 5 years). To account for both of these possible correlations, we include a spatially <u>and</u> temporally lagged set of *k*-nearest neighbor data in a robustness model.

These spatially and temporally lagged variables were created using the set of the five nearest neighbors that sold within the 6 months preceding the sale of each house. These variables contained the average living area, lot size, age, and age squared of the "neighbors."

19 According to Cook, R. D. (1977) Detection of Influential Observations in Linear Regression. Technometrics. 19(1): 15-18.

20 LeSage and Pace (2009) have argued that including an expression of neighboring observations (i.e., a spatial lag, know as Wy) of the dependent variable (i.e., sale price) in the model is appropriate for dealing with these omitted variables. They show that spatially dependent omitted variables generate a model that contains spatial lags of the dependent and exogenous variables, known as the spatial Durbin model (Anselin, 1988). Ideally, we would have estimated these models, but this was not possible because of computing limitations.

3.2.5 Inclusion of Additional Explanatory Variables

Although the base model includes a suite of controlling variables that encompasses a wide range of home and site characteristics, the dataset contains additional variables not fully populated across the dataset that might also help explain price differences between homes. They include the style of the home (e.g., cape, ranch, colonial) and the type of heat the home has (e.g., forced air, baseboard, and steam). Therefore, an additional robustness model is estimated that includes these variables but uses a slightly smaller dataset for which these variables are fully populated.

Combined, it is assumed that the set of robustness tests will provide additional context and possibly bound the results from the base model. We now turn to the data used for the analysis.

3.3 Data Used For Analysis

To conduct the analysis, a rich set of four types of data was obtained from a variety of sources in Massachusetts, including 1) wind turbine data, 2) single-family-home sale and characteristic data, 3) U.S. Census data, and 4) amenities and disamenities data. From these, three other sets of variables were created: distance-to-turbine data, time-of-sale period relative to announcement and construction dates of nearby turbines, and spatially and temporally lagged nearest-neighbor characteristics. Each is discussed below.

3.3.1 Wind Turbines

Using data from the Massachusetts Clean Energy Center (MassCEC), every wind turbine in Massachusetts that had been commissioned as of November 2012 with a nameplate capacity of at least 600 kW was identified and included in the analysis. This generated a dataset of 41 turbines located in a variety of settings across Massachusetts, ranging in scope from a single turbine to a maximum of 10 turbines, with blade tip heights ranging from 58.5 meters (192 feet) to 390 meters (1,280 feet), with an average of approximately 120 meters (394 feet) (Table 1 and Figure 4). Spatial data for every turbine (e.g., x and y coordinates), derived from MassCEC records and a subsequent visual review of satellite imagery, were added, and wind turbine announcement and construction dates were populated by MassCEC. Announcement date is assumed to be the first instance when news of the projects enters the public sphere via a variety of sources including a news article, the filing of a permit application, or release of a Request for Proposals. Dates were identified in consultation with project proponents, developers or using Google News searches.

3.3.2 Single-Family-Home Sales and Characteristics

A set of arm's-length, single-family-home sales data for all of Massachusetts from 1998 to November 2012 was purchased from the Warren Group.[21] Any duplicate observations, cases where key information was missing (e.g., living area, lot size, year built), or observations where the data appeared to be erroneous (e.g., houses with no bathrooms) were removed from the dataset. These data included the following variables (and are abbreviated as follows in parentheses): sale date (*sd*), sale price (*sp*), living

21 See http://www.thewarrengroup.com/. The Warren Group identified all transactions that were appropriate for analysis. As discussed later, we used additional screens to ensure that they were representative of the population of homes. Single-family homes, as opposed to multi-family or condominiums, were selected because condos and multi-family properties constitute different markets and are generally not analyzed together (Goodman and Thibodeau, 1998; Lang, 2012).

Table 1: List of Locations, Key Project Metrics and Dates of Massachusetts Turbines Analyzed

Project Name	Number of Turbines	Capacity per Turbine (kW)	Project Nameplate Capacity (MW)	Blade Tip Height (meters)	Announcement Date	Construction Date	Commission Date	Wastewater or Water Treatment	Industrial Site	Landfill	Located at a School
Berkshire East Ski Resort	1	900	0.9	87	12/16/08	7/12/10	10/31/10				
Berkshire Wind	10	1500	15	118.5	1/12/01	6/1/09	5/28/11				
Fairhaven	2	1500	3	121	5/1/04	11/1/11	5/1/12	X			
Falmouth Wastewater 1	1	1650	1.65	121	4/1/03	11/1/09	3/23/10	X			
Falmouth Wastewater 2	1	1650	1.65	121	11/1/09	4/5/10	2/14/12	X			
Holy Name Central Catholic Jr/Sr HS	1	600	0.6	73.5	9/21/06	3/21/08	10/4/08				X
Hull 1	1	660	0.66	73.5	10/1/97	11/1/01	12/27/01				X
Hull 2	1	1800	1.8	100	1/1/03	12/1/05	5/1/06			X	
Ipswich MLP	1	1600	1.6	121.5	3/1/03	10/1/10	5/15/11				
Jiminy Peak Mountain Resort	1	1500	1.5	118.5	11/1/05	6/25/07	8/3/07				
Kingston Independence	1	2000	2	123	6/1/06	9/23/11	5/11/12				
Lightolier	1	2000	2	126.5	12/14/06	11/1/11	4/20/12		X		
Mark Richey Woodworking	1	600	0.6	89	11/10/07	11/1/08	2/22/09		X		
Mass Maritime Academy	1	660	0.66	73.5	1/31/05	4/12/06	6/14/06				X
Mass Military Reservation 1	1	1500	1.5	118.5	11/8/04	8/1/09	7/30/10		X		
Mass Military Reservation 2	1	1500	1.5	121	10/1/09	10/1/10	10/28/11		X		
Mass Military Reservation 3	1	1500	1.5	121	10/1/09	10/1/10	10/28/11		X		
Mt Wachusett Community College	2	1650	3.3	121	8/18/08	1/28/11	4/27/11				X
MWRA - Charlestown	1	1500	1.5	111	1/24/10	3/25/10	10/1/11	X			
MWRA - Deer Island	2	600	1.2	58.5	6/1/08	8/1/09	11/15/10	X			
No Fossil Fuel (Kingston)	3	2000	6	125	3/1/10	11/16/11	1/25/12		X		
NOTUS Clean Energy	1	1650	1.65	121	8/31/07	4/1/10	7/28/10		X		
Princeton MLP	2	1500	3	105.5	12/18/99	9/9/09	1/12/10				
Scituate	1	1500	1.5	111	3/15/08	2/15/12	3/15/12	X			
Templeton MLP	1	1650	1.65	118.5	7/24/09	2/1/10	9/1/10				
Williams Stone	1	600	0.6	88.5	1/11/08	5/1/08	5/27/09		X		
Total: 26 projects	**41**							**6**	**8**	**1**	**4**

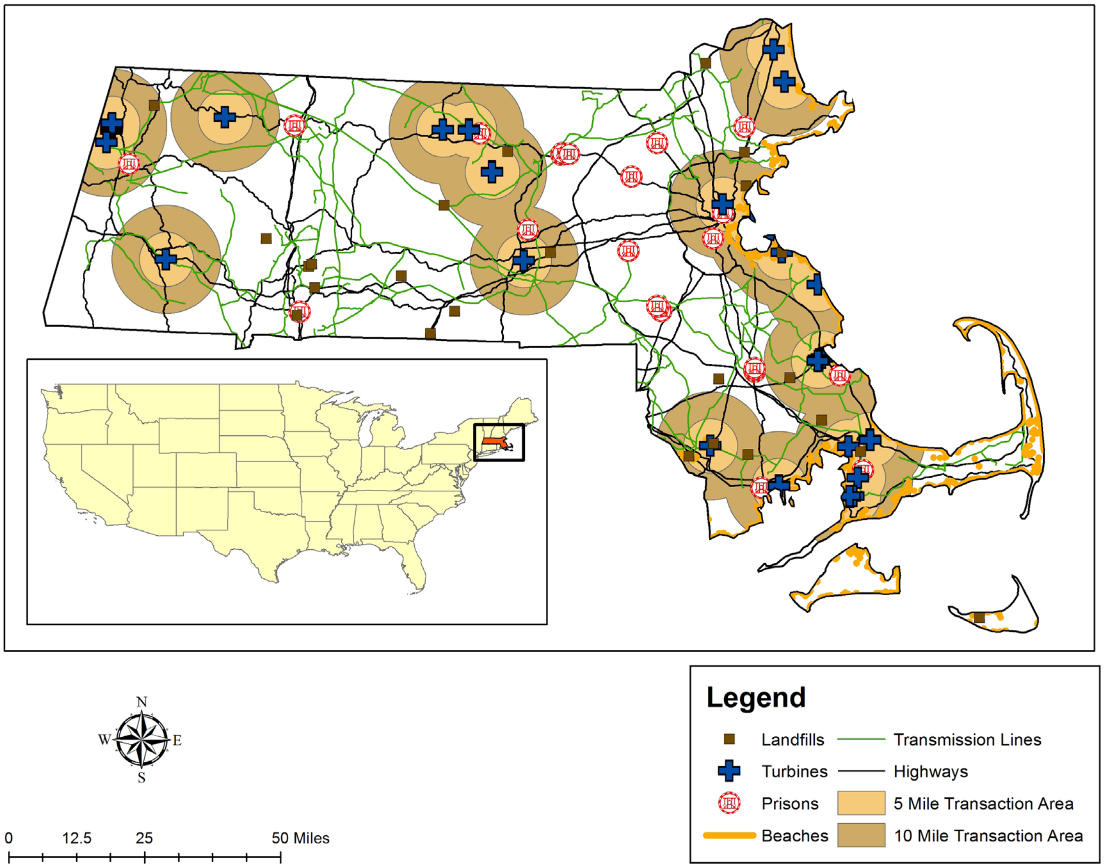
area in thousands of square feet (*sfla1000*), lot size in acres (*acres*), year the home was built (*yb*), most recent renovation year (*renoyear*), the number of full (*fullbath*) and half (*halfbath*) bathrooms, the style of the home (e.g., colonial, cape, ranch) (*style*), the heat type (e.g., forced air, baseboard, steam) (*heat*), and the x and y coordinates of the home.[22] From these, the following variables were calculated: natural log of sale price (*lsp*), sale year (*sy*), sale quarter (*sq*), age of the home at the time of sale (*age = sy – (yb or renoyear)*), age of the home at the time of sale squared (*agesqr = age × age*), lot size less than 1 acre (*acrelt1*), bathrooms (*bath = fullbath + (halfbath × 0.5)*).[23]

To ensure a relatively homogenous set of data, without outlying observations that could skew the results, the following criteria were used to screen the dataset: sale price between $40,000 and $2,500,000; less than 12 bathrooms or bedrooms; lot size less than 25 acres; and sale price per square foot between $30 and $1,250. As detailed below, these screens

22 The style is used in a robustness test.

23 Geocoding of x-y coordinates can have various levels of accuracy, including block level (a centroid of the block), street level (the midpoint of two ends of a street), address level (a point in front of the house – usually used for Google maps etc.), and house level (a point over the roof of the home). Warren provided x and y coordinates that were accurate to the street level or block level but not accurate to the house level. All homes that were within 2 miles of a turbine were corrected to the house level by Melissa Data. See: www.MelissaData.com. This was important to ensure that accurate measurements of distance to the nearest turbine were possible.

Figure 4: Locations of Massachusetts Wind Turbines Included in Study



were relaxed for a robustness test, and no significant alteration to the results was discovered.

3.3.3 Distance to Turbine

Geographic information system (GIS) software was used to calculate the distance between each house and the nearest wind turbine in the dataset (*tdis*) and to identify transactions within a 10-mile radius of a wind turbine. Transactions inside 5 miles were used for the base model, while those outside of 5 miles were retained for the robustness tests. This resulted in a total of 122,198 transactions within 5 miles of a turbine (and 312,677 within 10 miles of a turbine). Additionally, a binary variable was created if a home was within a half mile of a turbine or not (*halfmile*), which was used in the base model. As discussed above, the robustness models used additional distance variables, including if a home was within a quarter mile of a turbine (*qtrmile*) and if a home was outside a half mile but within 1 mile (*outsidehalf*).

3.3.4 Time of Sale Relative to Announcement and Construction Dates of Nearby Turbines

Using the announcement and construction dates of the turbine nearest a home and the sale date of the home, the facility development period (*fdp*) was assigned one of four values: the sale was more than 2 years before the wind facility was announced

Table 2: Distribution of Transaction Data Across Distance and Period Bins

	prioranc	*preanc*	*postanc-precon*	*postcon*	***all periods***
0-0.25mile	60	9	14	38	121
	0.04%	*0.02%*	*0.03%*	*0.06%*	*0.04%*
0.25-0.5mile	434	150	210	192	986
	0.25%	*0.39%*	*0.47%*	*0.33%*	*0.32%*
0.5-1mile	3,190	805	813	1,273	6,081
	1.9%	*2.1%*	*1.8%*	*2.2%*	*1.9%*
1-5mile	62,967	14,652	17,086	20,305	115,010
	37%	*38%*	*38%*	*34%*	*37%*
5-10mile	104,188	22,491	26,544	37,256	190,479
	61%	*59%*	*59%*	*63%*	*61%*
Total	**170,839**	**38,107**	**44,667**	**59,064**	**312,677**
	100%	*100%*	*100%*	*100%*	*100%*

(*prioranc*),[24] the sale was less than 2 years before the facility was announced (*preanc*), the sale occurred after facility announcement but prior to construction commencement (*postancprecon*), or the sale occurred after construction commenced (*postcon*). We are assuming that once construction was completed, the turbine went into operation. See Table 2 for the distribution of the 312,677 sales within 10 miles across the distance and period bins.

3.3.5 U.S. Census

Using GIS software, the U.S. Census tract and block group of each home were determined. The tract delineation was used for the base model, and the block group was used for one of the robustness tests. In both cases, the Census designations were used to control for "neighborhood" fixed effects across the sample.

3.3.6 Amenity and Disamenity Variables

Data were obtained from the Massachusetts Office of Geographic Information (MassGIS) on the location of beaches, open space,[25] electricity transmission lines, prisons, highways, and major roads.[26] As discussed above, these variables were included in the model to control for and allow comparisons to amenities and disamenities in the study areas near

24 This first period, more than two years before announcement, was used to ensure that these transactions likely occurred before the community was aware of the development. Often prior to the announcement of the project, wind developers are active in the area, potentially, arranging land leases and testing/measuring wind speeds, which can occur in the two years before an official announcement is made.

25 The protected and recreational open space data layer contains the boundaries of conservation land and outdoor recreational facilities in Massachusetts.

26 Office of Geographic Information (MassGIS), Commonwealth of Massachusetts, Information Technology Division. (www.mass.gov/mgis).

turbines. Based on the data, variables were assigned to each home in the dataset using GIS software. If a home was within 500 feet of a beach, it was assigned the variable *beach500ft*, and if a home was outside of 500 feet but inside of a half mile from a beach it was assigned the variable *beachhalf*. Similarly, variables were assigned to homes within a half mile of a publicly accessible open space with a minimum size of 25 acres (*openhalf*), a currently operating landfill (*fillhalf*), or a prison containing at least some maximum-security inmates (*prisonhalf*). Variables were also assigned to homes within 500 feet of an electricity transmission line (*line500ft*), a highway (*hwy500ft*) or otherwise major road (*major500ft*).[27] Figure 4 shows the location of these amenities and disamenities (except open space and major roads) across Massachusetts.

3.3.7 Spatially and Temporally Lagged Nearest-Neighbor Characteristics

Using the data obtained from Warren Group for the home and site characteristics, x/y coordinates and the sale date, a set of spatially and temporally lagged nearest neighbor variables were prepared to be used in a robustness test. For each transaction the five nearest neighbors were selected that: transacted

Table 3: Summary of Characteristics of Base Model Dataset

Variable	Description	Mean	Std. Dev.	Min	Median	Max
sp	sale price	$322,948	$238,389	$40,200	$265,000	$2,495,000
lsp	log of sale price	12.49	0.60	10.6	12	14.72
sd	sale date	10/19/04	1522	3/3/98	2/6/05	11/23/12
sy	sale year	2004	4	1998	2004	2012
syq	sale year and quarter (e,g., 20042 = 2004, 2nd quarter)	20042	42	19981	20043	20124
sfla1000	square feet of living area (1000s of square feet)	1.72	0.78	0.41	1.6	9.9
acre*	number of acres	0.51	1.1	0.0054	0.23	25
acrelt1*	the number of acres less than one	-0.65	0.31	-0.99	-0.77	0
age	age of home at time of sale	54	42	-1	47	359
agesq	age of home squared	4671	4764	0	3474	68347
bath**	the number of bathrooms	1.9	0.79	0.5	1.5	10.5
wtdis	distance to nearest turbine (miles)	3.10	1.20	0.098	3.2	5
fdp	wind facility development period	1.95	1.18	1	1	4
annacre	average nearest neighbor's acres	0.51	0.93	0.015	0.25	32
annage	average nearest neighbor's age	53.71	30.00	-0.8	52	232
annagesq	average nearest neighbor's agesq	4672	4766	0	3474	68347
annsfla1000	average nearest neighbor's sfla1000	1.72	0.53	0.45	1.6	6.8

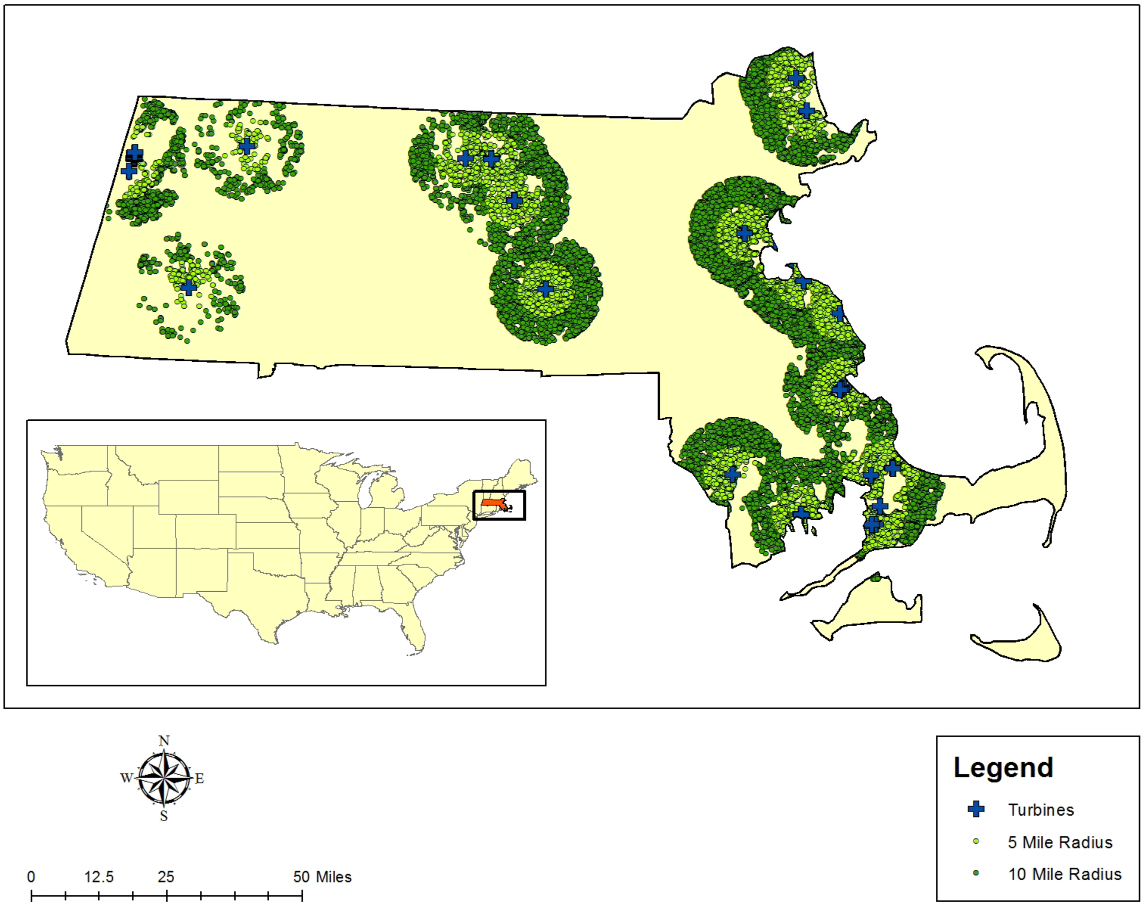
Note: Sample size for the full dataset is 122,198

* Together acrelt1 and acre are entered into the model as a spline function with acrelt1 applying to values from 0 to 1 acres (being entered as values from -1 to 0, respectively) and acre applying to values from 1 to 25 acres.

** Bath is calculated as follows: number of bathrooms + (number of half bathrooms *0.5)

27 Highways and majors road are mutually exclusive by our definition despite the fact that highways are also considered major roads.

Figure 5: Locations of Houses in Relation to Wind Turbines



within the preceding 6 months and were the closest in terms of Euclidian distance. Using those five transactions, average 1000s of square feet of living space (*annsfla1000*), average acres (*annacre*), average age (*annage*), and age squared (*annagesq*) of the neighbors were created for each home. These four variables were used in the robustness test.

3.3.8 Summary Statistics

The base model dataset includes all home sales within 5 miles of a wind turbine, which are summarized in Table 2. The average home in the dataset of 122,198 sales from 1998 to 2012 has a sale price of $322,948, sold in 2004, in the 2nd quarter, has 1,728 square feet of living area, is on a parcel with a lot size of 0.51 acres, is 54 years old, has 1.9 bathrooms, and is 3.1 miles from the nearest turbine. As summarized in Table 2, of the 122,198 sales within 5 miles of a turbine, 7,188 (5.9%) are within 1 mile of a turbine, 1,107 (approximately 0.9%) are within a half mile, and 121 (0.1%) are within a quarter mile. In the post-construction period, 1,503 sales occurred within 1 mile of a turbine, and 230 occurred within a half mile. These totals are well above those collected for other analyses and are therefore ample to discover considerably smaller effects. For example, as discussed in Section 2.5 above, an effect larger than 2.5% should be detectable within 1 mile, and an effect larger than approximately 4% should be detectable within a half mile, given the number of transactions that we are analyzing. Figure 5 shows the spatial distribution of sales throughout the sample area.

3.4 Results

3.4.1 Base Model Results

The base model results for the turbine, amenity, and disamenity variables are presented in Table 4 (with full results in the Appendix). The base model has a high degree of explanatory power, with an adjusted-R^2 of 0.80, while the controlling variables are all highly significant and conform to the *a priori* assumption as far as sign and magnitude (e.g., Sirmans et al., 2006).[28] The model interacts the four wind-facility periods with each of the controlling variables to test the stability of the controlling variables across the periods (and the subsamples they represent) and to ensure that the coefficients for the wind turbine distance variables, which are also interacted with the periods, do not absorb any differences in the controlling variables across the periods.[29] The controlling variables do vary across the periods, although they are relatively stable. For example, each additional thousand square feet of living area adds 21%–24% to a home's value in each of the four periods; the first acre adds 14%–22% to home value, while each additional acre adds 1%–2%; each year a home ages reduces the home's value by approximately 0.2% and each bathroom adds 6%–11% to the value. Additionally, the sale years are highly statistically significant compared to the reference year of 2012; prices in 1998 are approximately 52% lower, and prices in 2005 and 2006 are approximately 31% and 28% higher, after which prices decline to current levels. Finally, there is considerable seasonality in the transaction values. Compared to the reference third quarter, prices in the first quarter are approximately 7% lower, while prices in the second and fourth are about 1%–2% lower (see Appendix for full results).

Similar to the controlling variables, the coefficients for the amenity and disamenity parameters are, for the most part, of the correct sign and within the range of findings from previous studies. For example, being within 500 feet of a beach increases a home's value by 21%-30%, while being outside of 500 feet but within a half mile of a beach increases a home's value by 5%–13%, being within 500 feet of a highway reduces value by 5%–7%, and being within 500 feet of a major road reduces value by 2%–3%. Being within a half mile of a prison reduces value by 6%, but this result is only apparent in one of the periods. Similarly, being within a half mile of a landfill reduces value by 12% in only one of the periods, and being within a half mile of open space increases value by approximately 1% in two of the periods. Finally, being within 500 feet of an electricity transmission line reduces value by 3%-9% in two of the four periods. As noted above, the wind development periods are not meaningful as it relates to the amenity/disamenity variables, because they all likely existed well before this sample period began, and therefore the turbines. That said, they do represent different data groups across the dataset (one for each wind development period), and therefore are illustrative of the consistency of findings for these variables, with beaches, highways and major roads showing very consistent results, while electricity transmission lines, open space, landfills and prisons showing more sporadic results.

Turning now to the variables that capture the effects in our sample, for being within a half mile of a turbine, we find interesting results (see Table

28 All models are estimated using the .areg procedure in Stata MP 12.1 with robust estimates, which corrects for heteroskedasticity. The effects of the census tracts are absorbed. Results are robust to an estimation using the .reg procedure.

29 The results are robust to the exclusion of these interactions, but theoretically we believe this model is the most appropriate, so it is presented here.

Table 4. Selected Results from Base Model

		Wind Facility Development Period			
		prioranc	*preanc*	*postanc-precon*	*postcon*
Variables	**Description**	**coefficient** / *p-value*	**coefficient** / *p-value*	**coefficient** / *p-value*	**coefficient** / *p-value*
halfmile	within a half mile of a wind turbine	**-5.1%*****	**-7.1%*****	**-7.4%*****	**-4.6%***
		0.000	*0.002*	*0.000*	*0.081*
	Net Difference Compared to *prioranc* Period			**-2.3%**	**0.5%**
				0.264	*0.853*
beach500ft	within 500 feet of a beach	**20.8%*****	**30.4%*****	**25.3%*****	**25.9%*****
		0.000	*0.000*	*0.000*	*0.000*
beachhalf	within a half mile and outside of 500 feet of a beach	**5.3%*****	**8.8%*****	**8.7%*****	**13.5%*****
		0.000	*0.000*	*0.000*	*0.000*
openhalf	within a half mile of open space	**0.6%****	**0.1%**	**0.1%**	**0.9%***
		0.021	*0.729*	*0.903*	*0.062*
line500ft	within 500 feet of a electricity transmission line	**-3%*****	**-0.9%**	**-0.9%**	**-9.3%*****
		0.001	*0.556*	*0.522*	*0.000*
prisonhalf	within a half mile of a prison	**-5.9%*****	**2.6%**	**2.8%**	**-2.3%**
		0.001	*0.291*	*0.100*	*0.829*
hwy500ft	within 500 feet of a highway	**-7.3%*****	**-5.2%*****	**-3.7%*****	**-5.3%*****
		0.000	*0.000*	*0.000*	*0.000*
major500ft	within 500 feet of a major road	**-2.8%*****	**-2.3%*****	**-2.5%*****	**-2%*****
		0.000	*0.000*	*0.000*	*0.000*
fillhalf	within a half mile of a landfill	**1.8%**	**-0.9%**	**1%**	**-12.2%*****
		0.239	*0.780*	*0.756*	*0.002*
sfla1000	living area in thousands of square feet	**22.9%*****	**21.4%*****	**22.6%*****	**23.5%*****
		0.000	*0.000*	*0.000*	*0.000*
acre	lot size in acres	**1.1%*****	**1.9%*****	**1.3%*****	**-0.02%**
		0.000	*0.000*	*0.000*	*0.863*
acrelt1	lot size less than 1 acre	**21.7%*****	**17.2%*****	**14.7%*****	**22.1%*****
		0.000	*0.000*	*0.000*	*0.000*
age	age of the home at time of sale	**-0.2%*****	**-0.2%*****	**-0.2%*****	**-0.2%*****
		0.000	*0.000*	*0.000*	*0.000*
agesq*	age of the home at time of sale squared*	**0.6%*****	**0.5%*****	**0.6%*****	**0.8%*****
		0.000	*0.000*	*0.000*	*0.000*
bath	number of bathrooms	**6.4%*****	**7.9%*****	**8.4%*****	**11.1%*****
		0.001	*0.556*	*0.522*	*0.000*

Coefficients *represent the percentage change in price for every unit of change in the characteristic. For example, the model estimates that price increases by approximately 23% for every 1000 additional square feet. Coefficient values are reported as percentages, although the actual conversion is 100*(exp(b)-1)% (Halvorsen and Palmquist, 1980). In most cases, the differences between the two are de minimis, though, larger coefficient values would be slightly larger after conversion.*

p-value *is a measure of how likely the estimate is different from zero (i.e., no effect) by chance. The lower the p-value, the more likely the estimate is expected to be different from zero. A p-value of less than 0.10 is considered statistically significant, with higher levels of significance being denoted as follows: * 0.10, ** 0.05, ***0.01.*

** coefficient values are multiplied by 1000 for reporting purposes only*

4). The coefficients for the *halfmile* variable over the four periods are as follows: *prioranc* (sale more than 2 years before the nearest wind turbine was announced) -5.1%, *preanc* (less than 2 years before announcement) -7.1%, *postancprecon* (after announcement but before the nearest turbine construction commenced) -7.4%, and *postcon* (after construction commenced) -4.6%.[30] Importantly, our model estimates that home values within a half mile of a future turbine were lower than in the surrounding area even before wind-facility announcement. In other words, wind facilities in Massachusetts are associated with areas with relatively low home values, at least compared to the average values of homes more than a half mile but less than 5 miles away from the turbines. Moreover, when we determine if there has been a "net" effect from the arrival of the turbines, we must account for this preexisting *prioranc* difference. The net *postancprecon* effect is -2.3% ([-7.4%] - [-5.1%] = -2.3%; *p*-value 0.26). The net *postcon* effect is 0.5% ([-4.6%] - [-5.1%] = 0.5%: *p*-value 0.85).[31] Therefore, after accounting for the "pre-existing price differential" that predates the turbine's development, there is no evidence of an additional impact from the turbine's announcement or eventual construction.

3.4.2 Robustness Test Results

To test and possibly bound the results from the base model, several robustness tests were explored (Section 3.2):

1. Impacts within a quarter mile
2. Impacts between a half and 1 mile
3. Impacts inside of a half mile when data between a half mile and 10 miles were used as a reference category
4. Impacts inside of a half mile when data between 5 miles 10 miles were used as a reference category
5. The inclusion of style (of the home) and heat (type of the home) variables
6. The use of the census block group as the fixed effect instead of census tract
7. Relaxing the screens (e.g., sale price between $40,000 and $2,500,000) used to create the analysis dataset
8. The removal of outliers and influential cases from the analysis dataset
9. The inclusion of spatially/temporally lagged variables to account for the presence of spatial autocorrelation.

Table 5 shows the robustness test results and the base model results for comparison (the robustness models are numbered in the table as they are above). For brevity only the "net" differences in value for the *postancprecon* and *postcon* periods are shown that quantify the *postancprecon* and *postcon* effects after deducting the difference that existed in the Prior period.[32] Throughout the rest of this section, those effects will be referred to as net *postancprecon* and net *postcon.*

There are a number of key points that arise from the results that have implications for stakeholders involved in wind turbine siting. For example, the effects for both the net *postancprecon* and net *postcon* periods for sales within a quarter mile of a turbine are positive and non-significant (which is believed to be a circumstance of the small dataset

30 Although a post-construction effect is shown here and for all other models, a post-operation (after the turbine was commissioned and began operation) effect was also estimated and was no different than this post-construction effect.

31 These linear combinations are estimated using the post-estimation .lincom test in Stata MP 12.1.

32 The full set of robustness results is available upon request.

Exhibit A39-3

Table 5: Robustness Results

#	Model Name	n	Adj R^2	Prior Announcement Turbine Effect			"Net" Post Announcement Pre Construction Turbine Effect			"Net" Post Construction Turbine Effect		
				inside 1/4 mile	inside 1/2 mile	between 1/2 and 1 mile	inside 1/4 mile	inside 1/2 mile	between 1/2 and 1 mile	inside 1/4 mile	inside 1/2 mile	between 1/2 and 1 mile
				coef / *p-value*	**coef** / *p-value*	**coef** / *p-value*	**coef** / *p-value*	**coef** / *p-value*	**coef** / *p-value*	**coef** / *p-value*	**coef** / *p-value*	**coef** / *p-value*
	Base Model	122,198	0.80		**-5.1%*****			**-2.3%**			**0.5%**	
					0.000			*0.264*			*0.853*	
1	Inside 1/4 mile	122,198	0.80	**-5.3%**			**12.7%**			**0.7%**		
				0.260			*0.118*			*0.916*		
2	Between 1/2 and 1 Mile	122,198	0.80		**-5.0%*****	**-0.4%**		**-2.0%**	**1.4%**		**1.0%**	**1.3%**
					0.000	*0.536*		*0.336*	*0.225*		*0.715*	*0.288*
3	All Sales Out to 10 Miles	312,677	0.82		**-5.8%*****			**-3.0%**			**1.0%**	
					0.000			*0.886*			*0.724*	
4	Using Outside of 5 Miles as Reference	312,677	0.82		**-7.6%*****			**1.6%**			**1.1%**	
					0.000			*0.435*			*0.695*	
5	Including Style & Heat Variables	120,292	0.81		**-3.8%*****			**-3.3%**			**2.8%**	
					0.004			*0.114*			*0.336*	
6	Using Block Group	122,198	0.81		**-3.1%*****			**-1.3%**			**-2.6%**	
					0.024			*0.554*			*0.324*	
7	No Screens	123,555	0.73		**-4.0%*****			**-4.6%***			**-0.8%**	
					0.003			*0.072*			*0.800*	
8	Removing Outliers and Influencers	119,623	0.79		**-4.3%*****			**-2.6%**			**0.04%**	
					0.001			*0.205*			*0.989*	
9	Including Spatial Variables	122,198	0.80		**-5.3%*****			**-1.5%**			**1.4%**	
					0.000			*0.467*			*0.621*	

*Statistical Significance: * 0.10, ** 0.05, ***0.01. Note: For simplicity, coefficient values are reported as percentages, although the actual conversion is 100*(exp(b)-1)% (Halvorsen and Palmquist, 1980). In most cases, the differences between the two are de minimis, though, larger coefficient values would be slightly larger after conversion.*

in that distance range, see Table 2), providing no evidence of a large negative effect near the turbines. Further, there are weakly significant net *postancprecon* impacts for relaxing the screens (-4.6%), indicating a possible effect associated with turbine announcement that disappears after turbine construction. Finally, and most importantly, no model specification uncovers a statistically significant net *postcon* impact, bolstering the base model results. Moreover, all net *postcon* estimates for homes within a half mile of a turbine fall within a relatively narrow band that equally spans zero (-2.6% to 2.8%), further reinforcing the non-significant results from the base model.

4. DISCUSSION AND CONCLUSIONS

The study estimated a base hedonic model along with a large set of robustness models to test and bound the results. These results are now applied to the research questions listed in Section 3.

4.1 Discussion of Findings in Relation to Research Questions

Q1) Have wind facilities in Massachusetts been located in areas where average home prices were lower than prices in surrounding areas (i.e., a "pre-existing price differential")?

To test for this, we examined the coefficient in the *prioranc* period, in which sales occurred more than 2 years before a nearby wind facility was announced. The -5.1% coefficient for the *prioranc* period (for home sales within a half mile of a turbine compared to the average prices of all homes between a half and 5 miles) is highly statistically significant (p-value < 0.000). This clearly indicates that houses near where turbines eventually are located are depressed in value relative to their comparables further away. Other studies have also uncovered this phenomenon (Hoen et al., 2009; Hinman, 2010; Hoen et al., 2011). If the wind development is not responsible for these lower values, what is?

Examination of turbine locations reveals possible explanations for the lower home prices. Six of the turbines are located at wastewater treatment plants, and another eight are located on industrial sites (Table 1). Some of these locations (for example, Charlestown) have facilities that generate large amounts of hazardous waste regulated by Massachusetts and/or the U.S. Environmental Protection Agency and use large amounts of toxic substances that must be reported to the Massachusetts Department of Environmental Protection.[33] Regardless of the reason for this "pre-existing price differential" in Massachusetts, the effect must be factored into estimates of impacts due to the turbines' eventual announcement and construction, as this analysis does.

Q2) Are post-construction (i.e., after wind-facility construction) home price impacts evident in Massachusetts, and how do Massachusetts results contrast with previous results estimated for more rural settings?

To test for these effects, we examine the "net" *postcon* effects (*postcon* effects minus *prioranc* effects), which account for the "pre-existing price differential" discussed above. In the base model, with a *prioranc* effect of -5.1% and a *postcon* effect of -4.6%, the "net" effect is 0.5% and not statistically significant. Similarly, none of the robustness models reveal a statistically significant "net" effect, and the range of estimates from those models is -2.6% to 2.8%, effectively bounding the results from the base model. Therefore, in our sample of more than 122,000 sales, of which more than 21,808 occurred

33 See, e.g., http://www.mass.gov/anf/research-and-tech/it-serv-and-support/application-serv/office-of-geographic-information-massgis/datalayers/dep-bwp-major-facilities-.html

after nearby wind-facility construction began (with 230 sales within a half mile), no evidence emerges of a *postcon* impact. This collection of *postcon* data within a half mile (and that within 1 mile: n = 1,503) is orders of magnitude larger than had been collected in previous studies and is large enough to find effects of the magnitude others have claimed to have found (e.g., Heintzelman and Tuttle, 2012; Sunak and Madlener, 2012).[34] Therefore, if effects are captured in our data, they are either too small or too sporadic to be identified.

These *postcon* results conform to previous analyses (Hoen, 2006; Sims et al., 2008; Hoen et al., 2009; Hinman, 2010; Carter, 2011; Hoen et al., 2011). Our study differed from previous analyses because it examined sales near turbines in more urban settings than had been studied previously. Contrary to what might have been expected, there do not seem to be substantive differences between our results and those found by others in more rural settings, thus it seems possible that turbines, on average, are viewed similarly (i.e., with only small differences) across these urban and rural settings.

Q3) Is there evidence of a post-announcement/pre-construction effect (i.e., an "anticipation effect")?

To answer this question, we examine the "net" *postancprecon* effect (*postancprecon* effect of -7.4% minus *prioranc* effect of -5.1%), which is -2.3% and not statistically significant. This base model result is bounded by robustness-model *postancprecon* effects ranging from -4.6% to 1.6%. One of the robustness models reveals a weakly statistically significant effect of -4.6% (p-value 0.07) when the set of data screens is relaxed. It is unclear, however, whether these statistically significant findings result from spurious data or multi-collinear parameters, examination of which is outside the scope of this research. Still, it is reasonable to say that these *postancprecon* results, which find some effects, *might* conform to effects found by others (Hinman, 2010), and, to that extent, they *might* lend credence to the "anticipation effect" put forward by Hinman and others (e.g., Wolsink, 2007; Sims et al., 2008; Hoen et al., 2011), especially if future studies also find such an effect. For now, we can only conclude that there is weak and sporadic evidence of a *postancprecon* effect in our sample.

Q4) How do impacts near turbines compare to the impacts of amenities and disamenities also located in the study area, and how do they compare with previous findings?

The effects on house prices of our amenity and disamenity variables are remarkably consistent with a priori expectations and stable throughout our various specifications. The results clearly show that home buyers and sellers accounted for the surrounding environment when establishing home prices. Beaches (adding 20% to 30% to price when within 500 feet, and adding 5% to 13% to price when within a half mile), highways (reducing price 4% to 8% when within 500 feet), and major roads (reducing price 2% to 3% when within 500 feet) affected home prices consistently in all models. Open space (adding 0.6%-0.9% to price when within a half mile), prisons (reducing price 6% when within a half mile), landfills (reducing price 13% when within a half mile) and electricity transmission lines (reducing price 3%-9% when within 500 feet) affected home prices in some models.

34 Though, as discussed earlier, their findings might be the result of their continuous distance specification and not the result of the data, moreover, although Heintzelman & Tuttle claim to have found a *postcon* effect, their data primary occurred prior to construction.

Our disamenity findings are in the range of findings in previous studies. For example, Des Rosiers (2002) found price reduction impacts ranging from 5% to 20% near electricity transmission lines; although those impacts faded quickly with distance. Similarly, the price reduction impacts we found near highways and major roads appear to be reasonable, with others finding impacts of 0.4% to 4% for homes near "noisy" roads (Bateman et al., 2001; Andersson et al., 2010; Blanco and Flindell, 2011; Brandt and Maennig, 2011). Further, although sporadic, the large price reduction impact we found for homes near a landfill is within the range of impacts in the literature (Ready, 2010), although this range is categorized by volume: an approximately 14% home-price reduction effect for large-volume landfills and a 3% effect for small-volume landfills. The sample of landfills in our study does not include information on volume, thus we cannot compare the results directly.

Our amenity results are also consistent with previous findings. For example, Anderson and West (2006b) found that proximity to open space increased home values by 2.6% per mile and ranged from 0.1% to 5%. Others have found effects from being on the waterfront, often with large value increases, but none have estimated effects for being within 500 feet or outside of 500 feet and within a half mile of a beach, as we did, and therefore we cannot compare results directly.

Clearly, home buyers and sellers are sensitive to the home's environment in our sample, consistently seeing more value where beaches, and open space are near and less where highways and major roads are near—with sporadic value distinctions where landfills, prisons and electricity line corridors are near. This observation not only supports inclusion of these variables in the model—because they control for potentially collinear aspects of the environment—but it also strengthens the claim that the market represented by our sample does account for surrounding amenities and disamenities which are reflected in home prices. Therefore, buyers and sellers in the sample should also have accounted for the presence of wind turbines when valuing homes.

Q5) Is there evidence that houses that sold during the post-announcement and post-construction periods did so at lower rates than during the pre-announcement period?

To test for this sales-volume effect, we examine the differences in sales rate in fixed distances from the turbines over the various development periods (Table 2). Approximately 0.29% percent of all homes in our sample (i.e., inside of 10 miles from a turbine) that sold in the *prioranc* period were within a half mile of a turbine. That percentage increases to 0.50% in the *postancprecon* period and then drops to 0.39% in the *postcon* period for homes within a half mile of a turbine. Similarly, homes located between a half mile and 1 mile sold, as a percentage of all sales out to 10 miles, at 1.9% in the *prioranc* period, 1.8% in the *postancprecon* period, and 2.2% in the *postcon* period (and similar results are apparent for those few homes within a quarter mile). Neither of these observations indicates that the rate of sales near the turbines is affected by the announcement and eventual construction of the turbines, thus we can conclude that there is an absence of evidence to support the claim that sales rate was affected by the turbines.[35]

35 This conclusion was confirmed with Friedman's two-way Analysis of Variance for related samples using period as the ranking factor, which confirmed that the distributions of the frequencies across periods was statistically the same.

4.2 Conclusion

This study investigates a common concern of people who live near planned or operating wind developments: How might a home's value be affected by the turbines? Previous studies on this topic, which have largely coalesced around non-significant findings, focused on rural settings. Wind facilities in urban locations could produce markedly different results. Nuisances from turbine noise and shadow flicker might be especially relevant in urban settings where other negative features, such as landfills or high voltage utility lines, have been shown to reduce home prices. To determine if wind turbines have a negative impact on property values in urban settings, this report analyzed more than 122,000 home sales, between 1998 and 2012, that occurred near the current or future location of 41 turbines in densely-populated Massachusetts.

The results of this study do not support the claim that wind turbines affect nearby home prices. Although the study found the effects on home prices from a variety of negative features (such as electricity transmission lines, landfills, prisons and major roads) and positive features (such as open space and beaches) that accorded with previous studies, the study found no net effects due to the arrival of turbines in the sample's communities. Weak evidence suggests that the announcement of the wind facilities had an adverse impact on home prices, but those effects were no longer apparent after turbine construction and eventual operation commenced. The analysis also showed no unique impact on the rate of home sales near wind turbines. These conclusions were the result a variety of model and sample specifications.

4.3 Suggestions for Future Research

Although our study is unparalleled in its methodological scope and dataset compared to the previous literature in the subject area, we recommend a number of areas for future work. Because much of the existing work on wind turbines has focused on rural areas—which is where most wind facilities have been built—there is no clear understanding of how residents would view the introduction of wind turbines in landscapes that are already more industrialized. Therefore, investigating residents' perceptions, through survey instruments, of wind turbines in more urbanized settings may be helpful. Policy-makers may also be interested in understanding the environmental attitudes and perceptions towards wind turbines of people who purchase houses near wind turbines after they have been constructed. Also, our study has aggregated the effects of wind turbines on the price of single-family houses for the study area as a whole. Although the data span an enormous range of sales prices, and contain the highest mean value of homes yet studied, it might be fruitful to analyze impacts partitioned by sales price or neighborhood to discover whether the effects vary with changes in these factors.

Finally, in our study we did not investigate the ownership structure of the turbines (i.e., in Massachusetts some projects benefit town budgets while others are owned by private entities) and assess whether any benefits accrued to surrounding communities, factors that the existing literature suggests are important determinants of community perceptions. This was considered beyond the scope of the existing study, but could be addressed in future research.

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APPENDIX: BASE MODEL FULL RESULTS

	Coef	SE	t	p-value
Intercept	12.15	0.01	1133.88	0.000
within a half mile of a wind turbine				
prioranc	-0.051	0.01	-3.95	0.000
preanc	-0.071	0.02	-3.08	0.002
postancprecon	-0.074	0.02	-4.34	0.000
postcon	-0.046	0.03	-1.74	0.081
Net Difference Compared to prioranc Period—within a half mile of a wind turbine				
postancprecon	-0.023	0.02	-1.12	0.264
postcon	0.005	0.03	0.19	0.853
within 500 feet of a electricity transmission line				
prioranc	-0.030	0.01	-3.41	0.001
preanc	-0.009	0.02	-0.59	0.556
postancprecon	-0.009	0.01	-0.64	0.522
postcon	-0.093	0.02	-4.79	0.000
within 500 feet of a highway				
prioranc	-0.073	0.01	-14.28	0.000
preanc	-0.052	0.01	-4.57	0.000
postancprecon	-0.037	0.01	-4.16	0.000
postcon	-0.053	0.01	-3.95	0.000
within 500 feet of a major road				
prioranc	-0.028	0.00	-12.18	0.000
preanc	-0.023	0.00	-5.05	0.000
postancprecon	-0.025	0.00	-5.43	0.000
postcon	-0.020	0.00	-4.01	0.000
within a half mile of a landfill				
prioranc	0.018	0.02	1.18	0.239
preanc	-0.009	0.03	-0.28	0.780
postancprecon	0.010	0.03	0.31	0.756
postcon	-0.122	0.04	-3.08	0.002
within a half mile of a prison				
prioranc	-0.059	0.02	-3.38	0.001
preanc	0.024	0.02	1.05	0.291
postancprecon	0.028	0.02	1.64	0.100
postcon	-0.020	0.09	-0.22	0.829

	Coef	SE	t	p-value
within 500 feet of a beach				
prioranc	0.208	0.02	12.71	0.000
preanc	0.304	0.03	12.09	0.000
postancprecon	0.253	0.02	12.72	0.000
postcon	0.259	0.02	16.95	0.000
within a half mile and outside of 500 feet of a beach				
prioranc	0.053	0.01	10.07	0.000
preanc	0.088	0.01	10.52	0.000
postancprecon	0.087	0.01	11.99	0.000
postcon	0.135	0.01	17.30	0.000
within a half mile of open space				
prioranc	0.006	0.00	2.31	0.021
preanc	0.001	0.00	0.35	0.729
postancprecon	0.001	0.00	0.12	0.903
postcon	0.009	0.00	1.87	0.062
living area in thousands of square feet				
prioranc	0.229	0.00	86.37	0.000
preanc	0.214	0.01	41.62	0.000
postancprecon	0.226	0.00	48.41	0.000
postcon	0.235	0.01	46.58	0.000
lot size in acres				
prioranc	0.011	0.00	6.67	0.000
preanc	0.019	0.00	6.51	0.000
postancprecon	0.013	0.00	4.17	0.000
postcon	-0.001	0.00	-0.17	0.863
lot size less than 1 acre				
prioranc	0.217	0.01	34.79	0.000
preanc	0.172	0.01	18.45	0.000
postancprecon	0.147	0.01	16.03	0.000
postcon	0.221	0.01	21.71	0.000
age of the home at time of sale				
prioranc	-0.0016	0.00	-21.87	0.000
preanc	-0.0016	0.00	-11.33	0.000
postancprecon	-0.0020	0.00	-13.99	0.000
postcon	-0.0025	0.00	-16.47	0.000

	Coef	SE	t	p-value
age of the home at time of sale squared				
prioranc	0.000006	0.00	28.55	0.000
preanc	0.000005	0.00	17.03	0.000
postancprecon	0.000006	0.00	20.01	0.000
postcon	0.000008	0.00	26.4	0.000
number of bathrooms				
prioranc	0.064	0.00	29.22	0.000
preanc	0.079	0.00	17.98	0.000
postancprecon	0.084	0.00	20.31	0.000
postcon	0.111	0.00	25.54	0.000
sale year				
1998	-0.52	0.007	-73.48	0.000
1999	-0.41	0.007	-58.44	0.000
2000	-0.26	0.007	-37.59	0.000
2001	-0.13	0.007	-18.03	0.000
2002	0.02	0.007	2.33	0.020
2003	0.14	0.007	21.26	0.000
2004	0.24	0.007	37.05	0.000
2005	0.31	0.006	49.32	0.000
2006	0.28	0.006	43.94	0.000
2007	0.23	0.006	37.58	0.000
2008	0.12	0.006	18.43	0.000
2009	0.04	0.006	7.29	0.000
2010	0.04	0.006	6.15	0.000
2011	-0.02	0.006	-3.74	0.000
2012	Omitted			
sale quarter				
1	-0.07	0.002	-28.05	0.000
2	-0.02	0.002	-9.56	0.000
3	Omitted			
4	-0.01	0.002	-3.03	0.002

n	**122,198**
R^2	**0.80**
Adj R^2	**0.80**
F	**2418**

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A Spatial Hedonic Analysis of the Effects of Wind Energy Facilities on Surrounding Property Values in the United States

Ben Hoen, Jason P. Brown, Thomas Jackson, Ryan Wiser, Mark Thayer and Peter Cappers

Environmental Energy Technologies Division

August 2013

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Abstract

Previous research on the effects of wind energy facilities on surrounding home values has been limited by small samples of relevant home-sale data and the inability to account adequately for confounding home-value factors and spatial dependence in the data. This study helps fill those gaps. We collected data from more than 50,000 home sales among 27 counties in nine states. These homes were within 10 miles of 67 different wind facilities, and 1,198 sales were within 1 mile of a turbine—many more than previous studies have collected. The data span the periods well before announcement of the wind facilities to well after their construction. We use OLS and spatial-process difference-in-difference hedonic models to estimate the home-value impacts of the wind facilities; these models control for value factors existing before the wind facilities' announcements, the spatial dependence of unobserved factors effecting home values, and value changes over time. A set of robustness models adds confidence to our results. Regardless of model specification, we find no statistical evidence that home values near turbines were affected in the post-construction or post-announcement/pre-construction periods. Previous research on potentially analogous disamenities (e.g., high-voltage transmission lines, roads) suggests that the property-value effect of wind turbines is likely to be small, on average, if it is present at all, potentially helping to explain why no evidence of an effect was found in the present research.

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Figures

1. Introduction

In 2012, approximately 13 gigawatts (GW) of wind turbines were installed in the United States, bringing total U.S. installed wind capacity to approximately 60 GW from more than 45,000 turbines (AWEA, 2013). Despite uncertainty about future extensions of the federal production tax credit, U.S. wind capacity is expected by some to continue growing by approximately 5–6 GW annually owing to state renewable energy standards and areas where wind can compete with natural gas on economics alone (Bloomberg, 2013); this translates into approximately 2,750 turbines per year.[1] Much of that development is expected to occur in relatively populated areas (e.g., New York, New England, the Mid-Atlantic and upper Midwest) (Bloomberg, 2013).

In part because of the expected wind development in more-populous areas, empirical investigations into related community concerns are required. One concern is that the values of properties near wind developments may be reduced; after all, it has been demonstrated that in some situations market perceptions about an area's disamenities (and amenities)[2] are capitalized into home prices (e.g., Boyle and Kiel, 2001; Jackson, 2001; Simons and Saginor, 2006). The published research about wind energy and property values has largely coalesced around a finding that homes sold after nearby wind turbines have been constructed do not experience statistically significant property value impacts. Additional research is required, however, especially for homes located within about a half mile of turbines, where impacts would be expected to be the largest. Data and studies are limited for these proximate homes in part because setback requirements generally result in wind facilities being sited in areas with relatively few houses, limiting available sales transactions that might be analyzed.

This study helps fill the research gap by collecting and analyzing data from 27 counties across nine U.S. states, related to 67 different wind facilities. Specifically, using the collected data, the study constructs a pooled model that investigates average effects near the turbines across the sample while controlling for the local effects of many potentially correlated independent variables. Property-value effect estimates are derived from two types of models: (1) an ordinary

[1] Assuming 2-MW turbines, the 2012 U.S. average (AWEA, 2013), and 5.5 GW of annual capacity growth.
[2] Disamenities and amenities are defined respectively as disadvantages (e.g., a nearby noxious industrial site) and advantages (e.g., a nearby park) of a location.

least squares (OLS) model, which is standard for this type of disamenity research (see, e.g., discussion in Jackson, 2003; Sirmans et al., 2005), and (2) a spatial-process model, which accounts for spatial dependence. Each type of model is used to construct a difference-in-difference (DD) specification—which simultaneously controls for preexisting amenities or disamenities in areas where turbines were sited and changes in the community after the wind facilities' construction was announced—to estimate effects near wind facilities after the turbines were announced and, later, after the turbines were constructed.[3]

The remainder of the report is structured as follows. Section 2 reviews the current literature. Section 3 details our methodology. Section 4 describes the study data. Section 5 presents the results, and Section 6 provides a discussion and concluding remarks.

2. Previous Literature

Although the topic is relatively new, the peer-reviewed literature investigating impacts to home values near wind facilities is growing. To date, results largely have coalesced around a common set of non-significant findings generated from home sales after the turbines became operational. Previous Lawrence Berkeley National Laboratory (LBNL) work in this area (Hoen et al., 2009, 2011) found no statistical evidence of adverse property-value effects due to views of and proximity to wind turbines after the turbines were constructed (i.e., post-construction or PC). Other peer-reviewed and/or academic studies also found no evidence of PC effects despite using a variety of techniques and residential transaction datasets. These include homes surrounding wind facilities in Cornwall, United Kingdom (Sims and Dent, 2007; Sims et al., 2008); multiple wind facilities in McLean County, Illinois (Hinman, 2010); near the Maple Ridge Wind Facility in New York (Heintzelman and Tuttle, 2011); and, near multiple facilities in Lee County, Illinois (Carter, 2011). Analogously, a 2012 Canadian case found a lack of evidence near a wind facility in Ontario to warrant the lowering of surrounding assessments (Kenney v MPAC, 2012). In contrast, one recent study did find impacts to land prices near a facility in North Rhine-Westphalia, Germany (Sunak and Madlener, 2012). Taken together, these results imply that the

[3] Throughout this report, the terms "announced/announcement" and "constructed/construction" represent the dates on which the proposed wind facility (or facilities) entered the public domain and the dates on which facility construction began, respectively. Home transactions can either be pre-announcement (PA), post-announcement/pre-construction (PAPC), or post-construction (PC).

PC effects of wind turbines on surrounding home values, if they exist, are often too small for detection or sporadic (i.e., a small percentage overall), or appearing in some communities for some types of properties but not others.

In the post-announcement, pre-construction period (i.e., PAPC), however, recent analysis has found more evidence of potential property value effects: by theorizing the possible existence of, but not finding, an effect (Laposa and Mueller, 2010; Sunak and Madlener, 2012); potentially finding an effect (Heintzelman and Tuttle, 2011)[4]; and, consistently finding what the author terms an "anticipation stigma" effect (Hinman, 2010). The studies that found PAPC property-value effects appear to align with earlier studies that suggested lower community support for proposed wind facilities before construction—potentially indicating a risk-averse (i.e., fear of the unknown) stance by community members—but increased support after facilities began operation (Gipe, 1995; Palmer, 1997; Devine-Wright, 2005; Wolsink, 2007; Bond, 2008, 2010). Similarly, researchers have found that survey respondents who live closer to turbines support the turbines more than respondents who live farther away (Braunholtz and MORI Scotland, 2003; Baxter et al., 2013), which could also indicate more risk-adverse / fear of the unknown effects (these among those who live farther away). Analogously, a recent case in Canada, although dismissed, highlighted the fears that nearby residents have for a planned facility (Wiggins v. WPD Canada Corporation, 2013)

Some studies have examined property-value conditions existing before wind facilities were announced (i.e., pre-announcement or PA). This is important for exploring correlations between wind facility siting and pre-existing home values from an environmental justice perspective and also for measuring PAPC and PC effects more accurately. Hoen et al. (2009, 2011) and Sims and Dent (2007) found evidence of depressed values for homes that sold before a wind facility's announcement and were located near the facility's eventual location, but they did not adjust their PC estimates for this finding. Hinman (2010) went further, finding value reductions of 12%–20% for homes near turbines in Illinois, which sold prior to the facilities' announcements; then using these findings to deflate their PC home-value-effect estimates.

[4] Heintzelman and Tuttle do not appear convinced that the effect they found is related to the PAPC period, yet the two counties in which they found an effect (Clinton and Franklin Counties, NY) had transaction data produced almost entirely in the PAPC period.

Some research has linked wind-related property-value effects with the effects of better-studied disamenities (Hoen et al., 2009). The broader disamenity literature (e.g., Boyle and Kiel, 2001; Jackson, 2001; Simons and Saginor, 2006) suggests that, although property-value effects might occur near wind facilities as they have near other disamenities, those effects (if they do exist) are likely to be relatively small, are unlikely to persist some distance from a facility, and might fade over time as home buyers who are more accepting of the condition move into the area (Tiebout, 1956).

For example, a review of the literature investigating effects near high-voltage transmission lines (a largely visual disturbance, as turbines may be for many surrounding homes) found the following: property-value reductions of 0%–15%; effects that fade with distance, often only affecting properties crossed by or immediately adjacent to a line or tower; effects that can increase property values when the right-of-way is considered an amenity; and effects that fade with time as the condition becomes more accepted (Kroll and Priestley, 1992). While potentially much more objectionable to residential communities than turbines, a review of the literature on landfills (which present odor, traffic, and groundwater-contamination issues) indicates effects that vary by landfill size (Ready, 2010). Large-volume operations (accepting more than 500 tons per day) reduce adjacent property values by 13.7% on average, fading to 5.9% one mile from the landfill. Lower-volume operations reduce adjacent property values by 2.7% on average, fading to 1.3% one mile away, with 20%–26% of lower-volume landfills not having any statistically significant impact. A study of 1,600 toxic industrial plant openings found adverse impacts of 1.5% within a half mile, which disappeared if the plants closed (Currie et al., 2012). Finally, a review of the literature on road noise (which might be analogous to turbine noise) shows property-value reductions of 0% –11% (median 4%) for houses adjacent to a busy road that experience a 10-dBA noise increase, compared with houses on a quiet street (Bateman et al., 2001).

It is not clear where wind turbines might fit into these ranges of impacts, but it seems unlikely that they would be considered as severe a disamenity as a large-volume landfill, which present odor, traffic, and groundwater-contamination issues. Low-volume landfills, with an effect near 3%, might be a better comparison, because they have an industrial (i.e., non-natural) quality, similar to turbines, but are less likely to have clear health effects. If sound is the primary concern, a 4% effect (corresponding to road noise) could be applied to turbines, which might correspond to a 10-dBA increase for houses within a half mile of a turbine (see e.g., Hubbard and Shepherd, 1991). Finally, as with transmission lines, if houses are in sight but not within sound distance of turbines, there may be no property-value effects unless those homes are immediately adjacent to the turbines. In summary, assuming these potentially analogous disamenity effects can be entirely transferred, turbine impacts might be 0%–14%, but more likely might coalesce closer to 3%–4%.

Of course, wind turbines have certain positive qualities that landfills, transmission lines, and roads do not always have, such as mitigating greenhouse gas emissions. no air or water pollution, no use of water during the generation of energy, and no generation of solid or hazardous waste that requires permanent storage/disposal (IPCC, 2011). Moreover, wind facilities can, and often do, provide economic benefits to local communities (Lantz and Tegen, 2009; Slattery et al., 2011; Brown et al., 2012; Loomis et al., 2012), which might not be the case for all other disamenities. Similarly, wind facilities can have direct positive effects on local government budgets through property tax or other similar payments (Loomis and Aldeman, 2011), which might, for example, improve school quality and thus increase nearby home values (e.g., Haurin and Brasington, 1996; Kane et al., 2006). These potential positive qualities might mitigate potential negative wind effects somewhat or even entirely. Therefore for the purposes of this research we will assume 3-4% is a maximum possible effect.

The potentially small average property-value effect of wind turbines, possibly reduced further by wind's positive traits, might help explain why effects have not been discovered consistently in previous research. To discover effects with small margins of error, large amounts of data are needed. However, previous datasets of homes very near turbines have been small. Hoen et al. (2009, 2011) used 125 PC transactions within a mile of the turbines, while others used far fewer PC transactions within a mile: Heintzelman and Tuttle (2012) (n ~ 35); Hinman (2010) (n ~ 11), Carter (2011) (n ~ 41), and Sunak and Madlener (2012) (n ~ 51). Although these numbers of observations are adequate to examine large impacts (e.g., over 10%), they are less likely to reveal small effects with any reasonable degree of statistical significance. Using results from Hoen et al. (2009) and the confidence intervals for the various fixed-effect variables in that study, estimates for the numbers of transactions needed to find effects of various sizes were obtained.

Approximately 50 cases are needed to find an effect of 10% and larger, 100 cases for 7.5%, 200 cases for 5%, 350 cases for 4%, 700 cases for 3%, and approximately 1,000 cases for a 2.5% effect.[5] Therefore, in order to detect an effect in the range of 3%–4%, a dataset of approximately 350–700 cases within a mile of the turbines will be required to detect it statistically, a number that to-date has not been amassed by any of the previous studies.

As discussed above, in addition to being relatively small on average, impacts are likely to decay with distance. As such, an appropriate empirical approach must be able to reveal spatially diminishing effects. Some researchers have used continuous variables to capture these effects, such as linear distance (Hoen et al., 2009; Sims et al., 2008) and inverse distance (Heintzelman and Tuttle, 2012; Sunak and Madlener, 2012), but doing so forces the model to estimate effects at the mean distance. In some cases, those means can be far from the area of expected impact. For example, Heintzelman and Tuttle (2012) estimated an inverse distance effect using a mean distance of more than 10 miles from the turbines, while Sunak and Madlener (2012) used a mean distance of approximately 1.9 miles. Using this approach weakens the ability of the model to quantify real effects near the turbines, where they are likely to be stronger. More importantly, this method encourages researchers to extrapolate their findings to the ends of the distance curve, near the turbines, despite having few data at those distances to support these extrapolations. This was the case for Heintzelman and Tuttle (2012), who had fewer than 10 cases within a half mile in the two counties where effects were found and only a handful that sold in those counties after the turbines were built, yet they extrapolated their findings to a quarter mile and even a tenth of a mile, where they had very few (if any) cases. Similarly, Sunak and Madlener (2012) had only six PC sales within a half mile and 51 within 1 mile, yet they extrapolated their findings to these distance bands.

One way to avoid using a single continuous function to estimate effects at all distances is to use a spline model, which breaks the distances into continuous groups (Hoen et al., 2011), but this method still imposes structure on the data by forcing the ends of each spline to tie together. A second and more transparent method is to use fixed-effect variables for discrete distances, which imposes little structure on the data (Hoen et al., 2009; Hinman, 2010; Carter, 2011; Hoen et al.,

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[5] This analysis is available upon request from the authors.

2011). Although this latter method has been used in a number of studies, because of a paucity of data, the resulting models are often ineffective at detecting what might be relatively small effects very close to the turbines. As such, when using this method (or any other, in fact) it is important that the underlying dataset is large enough to estimate the anticipated magnitude of the effect sizes.

Finally, one rarely investigated aspect of potential wind-turbine effects is the possibly idiosyncratic nature of spatially averaged transaction data used in the hedonic analyses. Sunak and Madlener (2012) used a geographically weighted regression (GWR), which estimates different regressions for small clusters of data and then allows the investigation of the distribution of effects across all of the clusters. Although GWR can be effective for understanding the range of impacts across the study area, it is not as effective for determining an average effect or for testing the statistical significance of the range of estimates. Results from studies that use GWR methods are also sometimes counter-intuitive.[6] As is discussed in more detail in the methodology section, a potentially better approach is to estimate a spatial-process model that is flexible enough to simultaneously control for spatial heterogeneity and spatial dependence, while also estimating an average effect across fixed discrete effects.

In summary, building on the existing literature, further research is needed on property-value effects in particularly close proximity to wind turbines. Specifically, research is needed that uses a large set of data near the turbines, accounts for home values before the announcement of the facility (as well as after announcement but before construction), accounts for potential spatial dependence in unobserved factors effecting home values, and uses a fixed-effect distance model that is able to accurately estimate effects near turbines.

3. Methodology

The present study seeks to respond to the identified research needs noted above, with this section describing our methodological framework for estimating the effects of wind turbines on the value of nearby homes in the United States.

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[6] For example, Sunak and Madlener (2012) find larger effects related to the turbines in a city that is farther from the turbines than they find in a town which is closer. Additionally, they find stronger effects in the center of a third town than they do on the outskirts of that town, which do not seem related to the location of the turbines.

3.1. Basic Approach and Models

Our methods are designed to help answer the following questions:

1. Did homes that sold prior to the wind facilities' announcement (PA)—and located within a short distance (e.g., within a half mile) from where the turbines were eventually located—sell at lower prices than homes located farther away?
2. Did homes that sold after the wind facilities' announcement but before construction (PAPC)—and located within a short distance (e.g., within a half mile)—sell at lower prices than homes located farther away?
3. Did homes that sold after the wind facilities' construction (PC)—and located within a short distance (e.g., within a half mile)—sell at lower prices than homes located farther away?
4. For question 3 above, if no statistically identifiable effects are found, what is the likely maximum effect possible given the margins of error around the estimates?

To answer these questions, the hedonic pricing model (Rosen, 1974; Freeman, 1979) is used in this paper, as it has been in other disamenity research (Boyle and Kiel, 2001; Jackson, 2001; Simons and Saginor, 2006). The value of this approach is that is allows one to disentangle and control for the potentially competing influences of home, site, neighborhood, and market characteristics on property values, and to uniquely determine how home values near announced or operating facilities are affected.[7] To test for these effects, two pairs of "base" models are estimated, which are then coupled with a set of "robustness" models to test and bound the estimated effects. One pair is estimated using a standard OLS model, and the other is estimated using a spatial-process model. The models in each pair are different in that one focuses on all homes within 1 mile of an existing turbine (*one-mile* models), which allows the maximum number of data for the fixed effect to be used, while the other focuses on homes within a half mile (*half-mile* models), where effects are more likely to appear but fewer data are available. We assume that, if effects exist near turbines, they are larger for the *half-mile* models than the *one-mile* models.

[7] See Jackson (2003) for a further discussion of the Hedonic Pricing Model and other analysis methods.

As is common in the literature (Malpezzi, 2003; Sirmans et al., 2005), a semi-log functional form of the hedonic pricing model is used for all models, where the dependent variable is the natural log of sales price. The OLS *half-mile* model form is as follows:

$$\ln(SP_i) = \alpha + \sum_a \beta_1(T_i \bullet S_i) + \beta_2(W_i) + \sum_b \beta_3(X_i \bullet C_i) + \beta_4(D_i \bullet P_i) + \varepsilon_i \quad (1)$$

where

SP_i represents the sale price for transaction *i*,

α is the constant (intercept) across the full sample,

T_i is a vector of time-period dummy variables (e.g., sale year and if the sale occurred in winter) in which transaction *i* occurred,

S_i is the state in which transaction *i* occurred,

W_i is the census tract in which transaction *i* occurred,

X_i is a vector of home, site, and neighborhood characteristics for transaction *i* (e.g., square feet, age, acres, bathrooms, condition, percent of block group vacant and owned, median age of block group),[8]

C_i is the county in which transaction *i* occurred,

D_i is a vector of four fixed-effect variables indicating the distance (to the nearest turbine) bin (i.e., group) in which transaction *i* is located (e.g., within a half mile, between a half and 1 mile, between 1 and 3 miles, and between 3 and 10 miles),

P_i is a vector of three fixed-effect variables indicating the wind project development period in which transaction *i* occurred (e.g., PA, PAPC, PC),

B_{1-3} is a vector of estimates for the controlling variables,

B_4 is a vector of 12 parameter estimates of the distance-development period interacted variables of interest,

ε_i is a random disturbance term for transaction *i*.

This pooled construction uses all property transactions in the entire dataset. In so doing, it takes advantage of the large dataset in order to estimate an average set of turbine-related effects across all study areas, while simultaneously allowing for the estimation of controlling characteristics at

[8] A "block group" is a US Census Bureau geographic delineation that contains a population between 600 to 3000 persons.

the local level, where they are likely to vary substantially across the study areas.[9] Specifically, the interaction of county-level fixed effects (C_i) with the vector of home, site, and neighborhood characteristics (X_i) allows different slopes for each of these independent variables to be estimated for each county. Similarly, interacting the state fixed-effect variables (S_i) with the sale year and sale winter fixed effects variables (T_i) (i.e., if the sale occurred in either Q1 or Q4) allows the estimation of the respective inflation/deflation and seasonal adjustments for each state in the dataset.[10] Finally, to control for the potentially unique collection of neighborhood characteristics that exist at the micro-level, census tract fixed effects are estimated.[11] Because a pooled model is used that relies upon the full dataset, smaller effect sizes for wind turbines will be detectable. At the same time, however, this approach does not allow one to distinguish possible wind turbine effects that may be larger in some communities than in others.

As discussed earlier, effects might predate the announcement of the wind facility and thus must be controlled for. Additionally, the area surrounding the wind facility might have changed over time simultaneously with the arrival of the turbines, which could affect home values. For example, if a nearby factory closed at the same time a wind facility was constructed, the influence of that factor on all homes in the general area would ideally be controlled for when estimating wind turbine effect sizes.

To control for both of these issues simultaneously, we use a difference-in-difference (*DD)* specification (see e.g., Hinman, 2010; Zabel and Guignet, 2012) derived from the interaction of

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[9] The dataset does not include "participating" landowners, those that have turbines situated on their land, but does include "neighboring" landowners, those adjacent to or nearby the turbines. One reviewer notes that the estimated average effects also include any effects from payments "neighboring" landowners might receive that might transfer with the home. Based on previous conversations with developers (see Hoen et al, 2009), we expect that the frequency of these arrangements is low, as is the right to transfer the payments to the new homeowner. Nonetheless, our results should be interpreted as "net" of any influence whatever "neighboring" landowner arrangements might have.

[10] Unlike the vector of home, site, and neighborhood characteristics, sale price inflation/deflation and seasonal changes were not expected tovary substantially across various counties in the same states in our sample and therefore the interaction was made at the state level. This assumption was tested as part of the robustness tests though, where they are interacted at the county level and found to not affect the results.

[11] In part because of the rural nature of many of the study areas included in the research sample, these census tracts are large enough to contain sales that are located close to the turbines as well as those farther away, thereby ensuring that they do not unduly absorb effects that might be related to the turbines. Moreover each tract contains sales from throughout the study periods, both before and after the wind facilities' announcement and construction, further ensuring they are not biasing the variables of interest.

the spatial (D_i) and temporal (P_i) terms. These terms produce a vector of 11 parameter estimates (β_4) as shown in Table 1 for the *half-mile* models and in Table 2 for the *one-mile* models. The omitted (or reference) group in both models is the set of homes that sold prior to the wind facilities' announcement and which were located more than 3 miles away from where the turbines were eventually located (A3). It is assumed that this reference category is likely not affected by the imminent arrival of the turbines, although this assumption is tested in the robustness tests.

Using the *half-mile* models, to test whether the homes located near the turbines that sold in the PA period were uniquely affected (*research question 1*), we examine A0, from which the null hypothesis is A0=0. To test if the homes located near the turbines that sold in the PAPC period were uniquely affected (*research question 2*), we first determine the difference in their values as compared to those farther away (B0-B3), while also accounting for any pre-announcement (i.e., pre-existing) difference (A0-A3) and any change in the local market over the development period (B3-A3). Because all covariates are determined in relation to the omitted category (A3), the null hypothesis collapses B0-A0-B3=0. Finally, in order to determine if homes near the turbines that sold in the PC period were uniquely affected (*research question 3*), we test if C0-A0-C3=0. Each of these *DD* tests are estimated using a linear combination of variables that produces the "net effect" and a measure of the standard error and corresponding confidence intervals of the effect, which enables the estimation of the maximum (and minimum) likely impacts for each research question. We use 90% confidence intervals both to determine significance and to estimate maximum likely effects (*research question 4*).

Following the same logic as above, the corresponding hypothesis tests for the *one-mile* models are as follows: *PA*, A1=0; *PAPC*, B1-A1-B3=0; and, *PC*, C1-A1-C3=0.

Table 1: Interactions between Wind Facility Development Periods and Distances – ½ Mile

	Distances to Nearest Turbine			
Wind Facility Development Periods	Within 1/2 Mile	Between 1/2 and 1 Mile	Between 1 and 3 Miles	Outside of 3 Miles
Prior to Announcement	A0	A1	A2	A3 (Omitted)
After Announcement but Prior to Construction	B0	B1	B2	B3
Post Construction	C0	C1	C2	C3

Table 2: Interactions between Wind Facility Development Periods and Distances - 1 Mile

	Distances to Nearest Turbine		
Wind Facility Development Periods	Within 1 Mile	Between 1 and 3 Miles	Outside of 3 Miles
Prior to Announcement	A1	A2	A3 (Omitted)
After Announcement but Prior to Construction	B1	B2	B3
Post Construction	C1	C2	C3

3.2. Spatial Dependence

As discussed briefly above, a common feature of the data used in hedonic models is the spatially dense nature of the real estate transactions. While this spatial density can provide unique insights into local real estate markets, one concern that is often raised is the impact of potentially omitted variables given that this is impossible to measure all of the local characteristics that affect housing prices. As a result, spatial dependence in a hedonic model is likely because houses located closer to each other typically have similar unobservable attributes. Any correlation between these unobserved factors and the explanatory variables used in the model (e.g., distance to turbines) is a source of omitted-variable bias in the OLS models. A common approach used in the hedonic literature to correct this potential bias is to include local fixed effects (Hoen et al., 2009, 2011; Zabel and Guignet, 2012), which is our approach as described in formula (1).

In addition to including local fixed effects, spatial econometric methods can be used to help further mitigate the potential impact of spatially omitted variables by modeling spatial dependence directly. When spatial dependence is present and appropriately modeled, more accurate (i.e., less biased) estimates of the factors influencing housing values can be obtained. These methods have been used in a number of previous hedonic price studies; examples include the price impacts of wildfire risk (Donovan et al., 2007), residential community associations (Rogers, 2006), air quality (Anselin and Lozano-Gracia, 2009), and spatial fragmentation of land use (Kuethe, 2012). To this point, however, these methods have not been applied to studies of the impact of wind turbines on property values.

Moran's I is the standard statistic used to test for spatial dependence in OLS residuals of the hedonic equation. If the Moran's I is statistically significant (as it is in our models – see Section 5.1.2), the assumption of spatial independence is rejected. To account for this, in spatial-process models, spatial dependence is routinely modeled as an additional covariate in the form of a spatially lagged dependent variable *Wy*, or in the error structure $\mu = \lambda W\mu + \varepsilon$, where ε is an identically and independently distributed disturbance term (Anselin, 1988). Neighboring criterion determines the structure of the spatial weights matrix *W*, which is frequently based on contiguity, distance criterion, or *k*-nearest neighbors (Anselin, 2002). The weights in the spatial-weights matrix are typically row standardized so that the elements of each row sum to one.

The spatial-process model, known as the SARAR model (Kelejian and Prucha, 1998)[12], allows for both forms of spatial dependence, both as an autoregressive process in the lag-dependent and in the error structure, as shown by:

$$\begin{aligned} y &= \rho W y + X\beta + \mu, \\ \mu &= \lambda W \mu + \varepsilon. \end{aligned} \tag{2}$$

[12] SARAR refers to a "spatial-autoregressive model with spatial autoregressive residuals".

Equation (2) is often estimated by a multi-step procedure using generalized moments and instrumental variables (Arraiz et al., 2009), which is our approach. The model allows for the innovation term ε in the disturbance process to be heteroskedastic of an unknown form (Kelejian and Prucha, 2010). If either λ or ρ are not significant, the model reduces to the respective spatial lag or spatial error model (SEM). In our case, as is discussed later, the spatial process model reduces to the SEM, therefore both *half-mile* and *one-mile* SEMs are estimated, and, as with the OLS models discussed above, a similar set of *DD* "net effects" are estimated for the PA, PAPC, and PC periods. One requirement of the spatial model is that the x/y coordinates be unique across the dataset. However, the full set of data (as described below) contains, in some cases, multiple sales for the same property, which consequently would have non-unique x/y coordinates.[13] Therefore, for the spatial models, only the most recent sale is used. An OLS model using this limited dataset is also estimated as a robustness test.

In total, four "base" models are estimated: an OLS *one-mile* model, a SEM *one-mile* model, an OLS *half-mile* model, and a SEM *half-mile* model. In addition, a series of robustness models are estimated as described next.

3.3. Robustness Tests

To test the stability of and potentially bound the results from the four base models, a series of robustness tests are conducted that explore: the effect that outliers and influential cases have on the results; a micro-inflation/deflation adjustment by interacting the sale-year fixed effects with the county fixed effects rather than state fixed effects; the use of only the most recent sale of homes in the dataset to compare results to the SEM models that use the same dataset; the application of a more conservative reference category by using transactions between 5 and 10 miles (as opposed to between 3 and 10 miles) as the reference; and a more conservative

[13] The most recent sale weights the transactions to those occurring after announcement and construction, that are more recent in time. One reviewer wondered if the frequency of sales was affected near the turbines, which is also outside the scope of the study, though this "sales volume" was investigated in Hoen et al. (2009), where no evidence of such an effect was discovered. Another correctly noted that the most recent assessment is less accurate for older sales, because it might overestimate some characteristics of the home (e.g., sfla, baths) that might have changed (i.e., increased) over time. This would tend to bias those characteristics' coefficients downward. Regardless, it is assumed that this occurrence is not correlated with proximity to turbines and therefore would not bias the variables of interest.

reference category by using transactions more than 2 years PA (as opposed to simply PA) as the reference category. Each of these tests is discussed in detail below.

3.3.1. Outliers and Influential Cases

Most datasets contain a subset of observations with particularly high or low values for the dependent variables, which might bias estimates in unpredictable ways. In our robustness test, we assume that observations with sales prices above or below the 99% and 1% percentile are potentially problematic outliers. Similarly, individual sales transactions and the values of the corresponding independent variables might exhibit undue influence on the regression coefficients. In our analysis, we therefore estimate a set of Cook's Distance statistics (Cook, 1977; Cook and Weisberg, 1982) on the base OLS *half-mile* model and assume any cases with an absolute value of this statistic greater than one to be potentially problematic influential cases. To examine the influence of these cases on our results, we estimate a model with both the outlying sales prices and Cook's influential cases removed.

3.3.2. Interacting Sale Year at the County Level

It is conceivable that housing inflation and deflation varied dramatically in different parts of the same state. In the base models, we interact sale year with the state to account for inflation and deflation of sales prices, but a potentially more-accurate adjustment might be warranted. To explore this, a model with the interaction of sale year and county, instead of state, is estimated.

3.3.3. Using Only the Most Recent Sales

The dataset for the base OLS models includes not only the most recent sale of particular homes, but also, if available, the sale prior to that. Some of these earlier sales occurred many years prior to the most recent sale. The home and site characteristics (square feet, acres, condition, etc.) used in the models are populated via assessment data for the home. For some of these data, only the most recent assessment information is available (rather than the assessment from the time of sale), and therefore older sales might be more prone to error as their characteristics might have changed since the sale.[14] Additionally, the SEMs require that all x/y coordinates entered into the model are unique; therefore, for those models only the most recent sale is used. Excluding older sales therefore potentially reduces measurement error, and also enables a more-direct comparison of effects between the base OLS model and SEM results.

3.3.4. Using Homes between 5 and 10 Miles as Reference Category

The base models use the collection of homes between 3 and 10 miles from the wind facility (that sold before the announcement of the facility) as the reference category in which wind facility effects are not expected. However, it is conceivable that wind turbine effects extend farther than 3 miles. If homes outside of 3 miles are affected by the presence of the turbines, then effects estimated for the target group (e.g., those inside of 1 mile) will be biased downward (i.e., smaller) in the base models. To test this possibility and ensure that the results are not biased, the group of homes located between 5 and 10 miles is used as a reference category as a robustness test.

3.3.5. Using Transactions Occurring More than 2 Years before Announcement as Reference Category

The base models use the collection of homes that sold before the wind facilities were announced (and were between 3 and 10 miles from the facilities) as the reference category, but, as discussed in Hoen et al. (2009, 2011), the announcement date of a facility, when news about a facility enters the public domain, might be after that project was known in private. For example, wind facility developers may begin talking to landowners some time before a facility is announced, and these landowners could share that news with neighbors. In addition, the developer might erect an anemometer to collect wind-speed data well before the facility is formally “announced,” which might provide concrete evidence that a facility may soon to be announced. In either case, this news might enter the local real estate market and affect home prices before the formal facility announcement date. To explore this possibility, and to ensure that the reference category

[14] As discussed in more detail in the Section 4, approximately 60% of all the data obtained for this study (that obtained from CoreLogic) used the most recent assessment to populate the home and site characteristics for all transactions of a given property.

is unbiased, a model is estimated that uses transactions occurring more than 2 years before the wind facilities were announced (and between 3 and 10 miles) as the reference category.

Combined, this diverse set of robustness tests allows many assumptions used for the base models to be tested, potentially allowing greater confidence in the final results.

4. Data

The data used for the analysis are comprised of four types: wind turbine location data, real estate transaction data, home and site characteristic data, and census data. From those, two additional sets of data are calculated: distance to turbine and wind facility development period. Each data type is discussed below. Where appropriate, variable names are shown in *italics*.

4.1. Wind Turbine Locations

Location data (i.e., x/y coordinates) for installed wind turbines were obtained via an iterative process starting with Federal Aviation Administration obstacle data, which were then linked to specific wind facilities by Ventyx[15] and matched with facility-level data maintained by LBNL. Ultimately, data were collected on the location of almost all wind turbines installed in the U.S. through 2011 (n ~ 40,000), with information about each facility's announcement, construction, and operation dates as well as turbine nameplate capacity, hub height, rotor diameter, and facility size.

4.2. Real Estate Transactions

Real estate transaction data were collected through two sources, each of which supplied the home's sale price (*sp*), sale date (*sd*), x/y coordinates, and address including zip code. From those, the following variables were calculated: natural log of sale price (*lsp*), sale year (*sy*), if the sale occurred in winter (*swinter*) (i.e., in Q1 or Q4).

The first source of real estate transaction data was CoreLogic's extensive dataset of U.S. residential real estate information.[16] Using the x/y coordinates of wind turbines, CoreLogic

[15] See the EV Energy Map, which is part of the Velocity Suite of products at www.ventyx.com.
[16] See www.corelogic.com.

selected all arms-length single-family residential transactions between 1996 and 2011 within 10 miles of a turbine in any U.S. counties where they maintained data (not including New York – see below) on parcels smaller than 15 acres.[17] The full set of counties for which data were collected were then winnowed to 26 by requiring at least 250 transactions in each county, to ensure a reasonably robust estimation of the controlling characteristics (which, as discussed above, are interacted with county-level fixed effects), and by requiring at least one PC transaction within a half mile of a turbine in each county (because this study's focus is on homes that are located in close proximity to turbines).

The second source of data was the New York Office of Real Property Tax Service (NYORPTS),[18] which supplied a set of arms-length single-family residential transactions between 2001 and 2012 within 10 miles of existing turbines in any New York county in which wind development had occurred prior to 2012. As before, only parcels smaller than 15 acres were included, as were a minimum of 250 transactions and at least one PC transaction within a half mile of a turbine for each New York county. Both CoreLogic and NYORPTS provided the most recent home sale and, if available, the prior sale.

4.3. Home and Site Characteristics

A set of home and site characteristic data was also collected from both data suppliers: 1000s of square feet of living area (*sfla1000*), number of acres of the parcel (*acres*), year the home was built (or last renovated, whichever is more recent) (*yrbuilt*), and the number of full and half bathrooms (*baths*).[19] Additional variables were calculated from the other variables as well: log of 1,000s of square feet (*lsfla1000*),[20] the number of acres less than 1 (*lt1acre)*,[21] age at the time of sale (*age*), and age squared (*agesqr*).[22]

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[17] The 15 acre screen was used because of a desire to exclude from the sample any transaction of property that might be hosting a wind turbine, and therefore directly benefitting from the turbine's presence (which might then increase property values). To help ensure that the screen was effective, all parcels within a mile of a turbine were also visually inspected using satellite and ortho imagery via a geographic information system.

[18] See www.orps.state.ny.us

[19] *Baths* was calculated in the following manner: full bathrooms + (half bathrooms x 0.5). Some counties did not have *baths* data available, so for them *baths* was not used as an independent variable.

[20] The distribution of *sfla1000* is skewed, which could bias OLS estimates, thus *lsfla1000* is used instead, which is more normally distributed. Regression results, though, were robust when *sfla1000* was used instead.

Regardless of when the sale occurred, CoreLogic supplied the related home and site characteristics as of the most recent assessment, while NYORPTS supplied the assessment data as of the year of sale.[23]

4.4. Census Information

Each of the homes in the data was matched (based on the x/y coordinates) to the underlying census block group and tract via ArcGIS. Using the year 2000 block group census data, each transaction was appended with neighborhood characteristics including the median age of the residents (*medage*), the total number of housing units (*units*), the number vacant (*vacant*) homes, and the number of owned (*owned*) homes. From these, the percentages of the total number of housing units in the block group that were vacant and owned were calculated, i.e., *pctvacant* and *pctowned*.

4.5. Distances to Turbine

Using the x/y coordinates of both the homes <u>and</u> the turbines, a Euclidian distance (in miles) was calculated for each home to the nearest wind turbine (*tdis*), regardless of when the sale occurred (e.g., even if a transaction occurred prior to the wind facility's installation).[24] These were then broken into four mutually exclusive distance bins (i.e., groups) for the base *half-mile* models: inside a half mile, between a half and 1 mile, between 1 and 3 miles, and between 3 and 10 miles. They were broken into three mutually exclusive bins for the base *one-mile* models: inside 1 mile, between 1 and 3 miles, and between 3 and 10 miles.

4.6. Wind Facility Development Periods

After identifying the nearest wind turbine for each home, a match could be made to Ventyx' dataset of facility-development announcement and construction dates. These facility-development dates in combination with the dates of each sale of the homes determined in which

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[21] This variable allows the separate estimations of the 1st acre and any additional acres over the 1st.

[22] *Age* and *agesqr* together account for the fact that, as homes age, their values usually decrease, but further increases in age might bestow countervailing positive "antique" effects.

[23] See footnote 13.

[24] Before the distances were calculated, each home inside of 1 mile was visually inspected using satellite and ortho imagery, with x/y coordinates corrected, if necessary, so that those coordinates were on the roof of the home.

of the three facility-development periods (*fdp*) the transaction occurred: *pre-announcement* (PA), *post-announcement-pre-construction* (PAPC), or *post-construction* (PC).

4.7. Data Summary

After cleaning to remove missing or erroneous data, a final dataset of 51,276 transactions was prepared for analysis.[25] As shown in the map of the study area (Figure 1), the data are arrayed across nine states and 27 counties (see Table 4), and surround 67 different wind facilities.

Table 3 contains a summary of those data. The average unadjusted sales price for the sample is $122,475. Other average house characteristics include the following: 1,600 square feet of living space; house age of 48 years[26]; land parcel size of 0.90 acres; 1.6 bathrooms; in a block group in which 74% of housing units are owned, 9% are vacant, and the median resident age is 38 years; located 4.96 miles from the nearest turbine; and sold at the tail end of the PA period.

The data are arrayed across the temporal and distance bins as would be expected, with smaller numbers of sales nearer the turbines, as shown in Table 5. Of the full set of sales, 1,198 occurred within 1 mile of a then-current or future turbine location, and 376 of these occurred post construction; 331 sales occurred within a half mile, 104 of which were post construction. Given these totals, the models should be able to discern a post construction effect larger than ~3.5% within a mile and larger than ~7.5% within a half mile (see discussion in Section 2). These effects are at the top end of the expected range of effects based on other disamenities (high-voltage power lines, roads, landfills, etc.).

[25] Cleaning involved the removal of all data that did not have certain core characteristics (sale date, sale price, *sfla*, *yrbuilt*, *acres*, *median age*, etc.) fully populated as well as the removal of any sales that had seemingly miscoded data (e.g., having a *sfla* that was greater than *acres*, having a *yrbuilt* more than 1 year after the sale, having less than one *bath*) or that did not conform to the rest of the data (e.g., had *acres* or *sfla* that were either larger or smaller, respectively, than 99% or 1% of the data). OLS models were rerun with those "nonconforming" data included with no substantive change in the results in comparison to the screened data presented in the report.

[26] Age could be as low as -1(for a new home) for homes that were sold before construction was completed.

Figure 1: Map of Transactions, States, and Counties

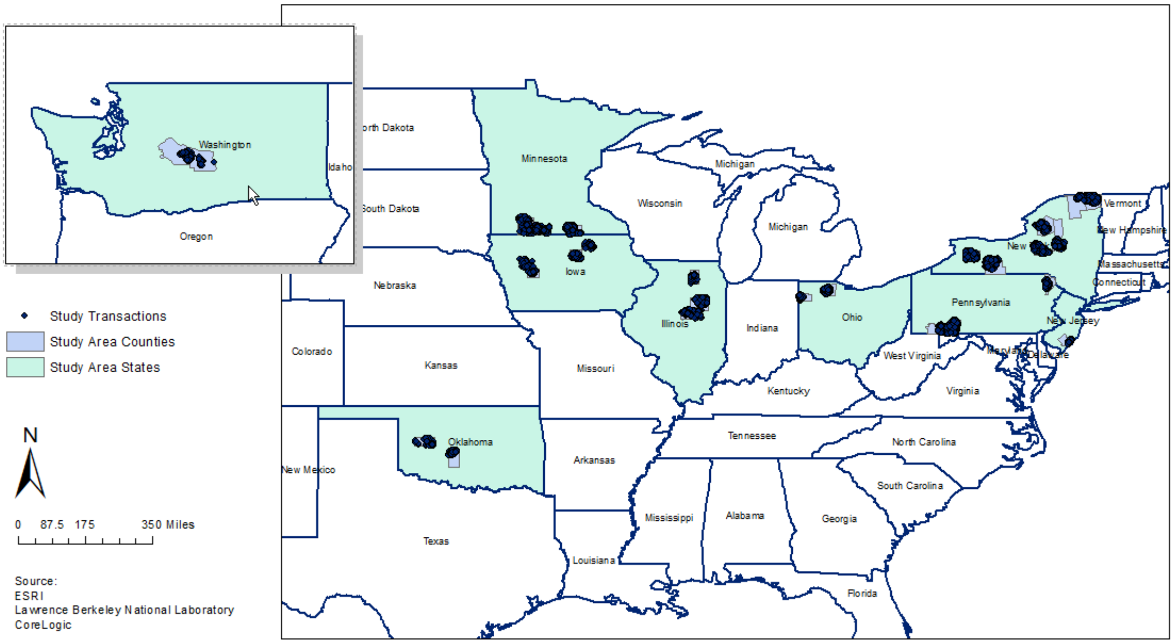


Table 3: Summary Statistics

Variable	Description	Mean	Std. Dev.	Min	Max
sp	sale price in dollars	$ 122,475	$ 80,367	$ 9,750	$ 690,000
lsp	natural log of sale price	11.52	0.65	9.19	13.44
sd	sale date	1/18/2005	1,403 days	1/1/1996	9/30/2011
sy	sale year	2005	3.84	1996	2011
sfla1000	living area in 1000s of square feet	1.60	0.57	0.60	4.50
lsfla1000	natural log of sfla1000	0.41	0.34	-0.50	1.50
acres	number of acres in parcel	0.90	1.79	0.03	14.95
acreslt1*	acres less than 1	-0.58	0.34	-0.97	0.00
age	age of home at time of sale	48	37	-1	297
agesq	age squared	3689	4925	0	88209
baths**	number of bathrooms	1.60	0.64	1.00	5.50
pctowner	fraction of house units in block group that are owned (as of 2000)	0.74	0.17	0.63	0.98
pctvacant	fraction of house units in block group that are vacant (as of 2000)	0.09	0.10	0.00	0.38
med_age	median age of residents in block group (as of 2000)	38	6	20	63
tdis	distance to nearest turbine (as of December 2011) in miles	4.96	2.19	0.09	10.00
fdp***	facility development period of nearest turbine at time of sale	1.94	0.87	1.00	3.00
Note: The number of cases for the full dataset is 51,276					
** acreslt1 is calculated as follows: acres (if less than 1) * - 1*					
*** Some counties did not have bathrooms populated; for those, these variables are entered into the regression as 0.*					
**** fdp periods are: 1, pre-announcement,; 2, post-announcement-pre-construction; and, 3, post-construction.*					

Table 4: Summary of Transactions by County

County	State	<1/2 mile	1/2-1 mile	1-3 miles	3-10 miles	Total
Carroll	IA	12	56	331	666	1,065
Floyd	IA	3	2	402	119	526
Franklin	IA	8	1	9	322	340
Sac	IA	6	77	78	485	646
DeKalb	IL	4	8	44	605	661
Livingston	IL	16	6	237	1,883	2,142
McLean	IL	18	88	380	4,359	4,845
Cottonwood	MN	3	10	126	1,012	1,151
Freeborn	MN	17	16	117	2,521	2,671
Jackson	MN	19	28	36	149	232
Martin	MN	7	25	332	2,480	2,844
Atlantic	NJ	34	96	1,532	6,211	7,873
Paulding	OH	15	58	115	309	497
Wood	OH	5	31	563	4,844	5,443
Custer	OK	45	24	1,834	349	2,252
Grady	OK	1	6	97	874	978
Fayette	PA	1	2	10	284	297
Somerset	PA	23	100	1,037	2,144	3,304
Wayne	PA	4	29	378	739	1,150
Kittitas	WA	2	6	61	349	418
Clinton	NY	4	6	49	1,419	1,478
Franklin	NY	16	41	75	149	281
Herkimer	NY	3	17	354	1,874	2,248
Lewis	NY	5	6	93	732	836
Madison	NY	5	26	239	3,053	3,323
Steuben	NY	5	52	140	1,932	2,129
Wyoming	NY	50	50	250	1,296	1,646
Total		331	867	8,919	41,159	51,276

Table 5: Frequency Crosstab of Wind Turbine Distance and Development Period Bins

	<1/2 mile	1/2-1 mile	1-3 miles	3-10 miles	total
PA	143	383	3,892	16,615	21,033
PAPC	84	212	1,845	9,995	12,136
PC	104	272	3,182	14,549	18,107
total	331	867	8,919	41,159	51,276

As shown in Table 6, the home sales occurred around wind facilities that range from a single-turbine project to projects of 150 turbines, with turbines of 290–476 feet (averaging almost 400 feet) in total height from base to tip of blade and with an average nameplate capacity of 1,637 kW. The average facility was announced in 2004 and constructed in 2007, but some were announced as early as 1998 and others were constructed as late as 2011.

Table 6: Wind Facility Summary

	mean	min	25th percentile	median	75th percentile	max
turbine rotor diameter (feet)	262	154	253	253	269	328
turbine hub height (feet)	256	197	256	262	262	328
turbine total height (feet)	388	290	387	389	397	476
turbine capacity (kW)	1637	660	1500	1500	1800	2500
facility announcement year	2004	1998	2002	2003	2005	2010
facility construction year	2007	2000	2004	2006	2010	2011
number of turbines in facility	48	1	5	35	84	150
nameplate capacity of facility (MW)	79	1.5	7.5	53	137	300

Note: The data correspond to 67 wind facilities located in the study areas. Mean values are rounded to integers

4.8. Comparison of Means

To provide additional context for the analysis discussed in the next section, we further summarize the data here using four key variables across the sets of development period (*fdp*) and distance bins (*tdis*) used in the *one-mile* models.[27] The variables are the dependent variable log of sale price *(lsp)* and three independent variables: *lsfla100*, *acres*, and *age*. These summaries are provided in Table 7; each sub-table gives the mean values of the variables across the three *fdp* bins and three *tdis* bins, and the corresponding figures plot those values.

The top set of results are focused on the log of the sales price, and show that, based purely on price and not controlling for differences in homes, homes located within 1 mile of turbines had lower sale prices than homes farther away; this is true across all of the three development periods. Moreover, the results also show that, over the three periods, the closer homes appreciated to a somewhat lesser degree than homes located farther from the turbines. As a result, focusing only on the post-construction period, these results might suggest that home prices near turbines are

[27] Summaries for the *half-mile* models reveal a similar relationship, so only the *one-mile* model summaries are shown here.

adversely impacted by the turbines. After all, the logarithmic values for the homes within a mile of the turbines (11.39) and those outside of a three miles (11.72) translate into an approximately 40% difference, in comparison to an 21% difference before the wind facilities were announced (11.16 vs. 11.35).[28] Focusing on the change in average values between the pre-announcement and post-construction periods might also suggest an adverse effect due to the turbines, because homes inside of 1 mile appreciated more slowly (11.16 to 11.39, or 25%) than those outside of 3 miles (11.35 to 11.72, or 45%). Both conclusions of adverse turbine effects, however, disregard other important differences between the homes, which vary over the periods and distances. Similarly, comparing the values of the PA inside 1 mile homes (11.16) and the PC outside of 3 miles homes (11.72), which translates into a difference of 75%, and which is the basis for comparison in the regressions discussed below, but also ignores any differences in the underlying characteristics.

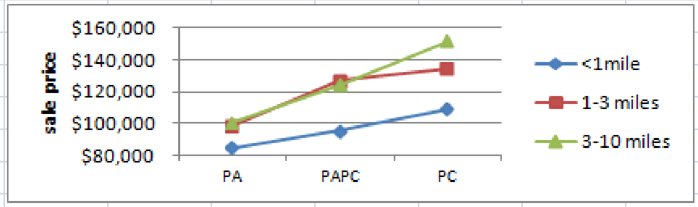
The remainder of Table 7, for example, indicates that, although the homes that sold within 1 mile are lower in value, they are also generally (in all but the PA period) smaller, on larger parcels of land, and older. These differences in home size and age across the periods and distances might explain the differences in price, while the differences in the size of the parcel, which add value, further amplifying the differences in price. Without controlling for these possible impacts, one cannot reliably estimate the impact of wind turbines on sales prices.

In summary, focusing solely on trends in home price (or price per square foot) alone, and for only the PC period, as might be done in a simpler analysis, might incorrectly suggest that wind turbines are affecting price when other aspects of the markets, and other home and sites characteristic differences, could be driving the observed price differences. This is precisely why researchers generally prefer the hedonic model approach to control for such effects, and the results from our hedonic OLS and spatial modeling detailed in the next section account for these and many other possible influencing factors.

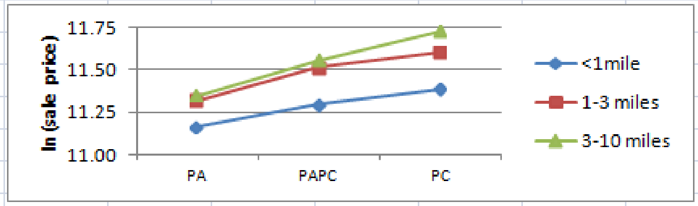
[28] Percentage differences are calculated as follows: exp(11.72-11.39)-1=0.40 and exp(11.35-11.16)-1=0.21.

Table 7: Dependent and Independent Variable Means

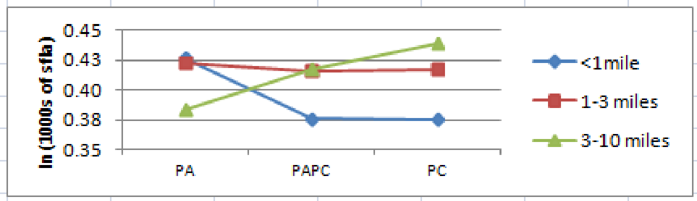
Sale Price	<1mile	1-3 miles	3-10 miles
PA	$ 84,830	$ 98,676	$100,485
PAPC	$ 95,223	$127,054	$124,532
PC	$109,133	$134,647	$151,559



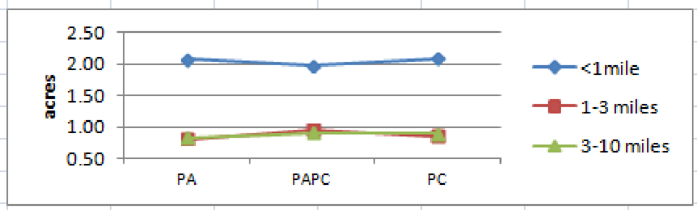
Log of Sale Price	<1mile	1-3 miles	3-10 miles
PA	11.16	11.32	11.35
PAPC	11.30	11.52	11.56
PC	11.39	11.61	11.72



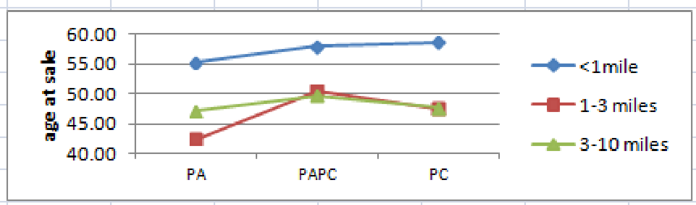
Log of Square Feet (in 1000s)	<1mile	1-3 miles	3-10 miles
PA	0.43	0.42	0.38
PAPC	0.38	0.42	0.42
PC	0.38	0.42	0.44



Number of Acres	<1mile	1-3 miles	3-10 miles
PA	2.08	0.80	0.83
PAPC	1.98	0.94	0.90
PC	2.09	0.84	0.89



Age at the Time of Sale	<1mile	1-3 miles	3-10 miles
PA	55.32	42.34	47.19
PAPC	58.01	50.34	49.73
PC	58.63	47.39	47.73



5. Results

This section contains analysis results and discussion for the four base models, as well as the results from the robustness models.

5.1. Estimation Results for Base Models

Estimation results for the "base" models are shown in Table 8 and Table 9.[29] In general, given the diverse nature of the data, the models perform adequately, with adjusted R^2 values ranging from 0.63 to 0.67 (bottom of Table 9).

5.1.1. Control Variables

The controlling home, site, and block group variables, which are interacted at the county level, are summarized in Table 8. Table 8 focuses on only one of the base models, the *one-mile* OLS model, but full results from all models are shown in the Appendix. [30] To concisely summarize results for all of the 27 counties, the table contains the percentage of all 27 counties for which each controlling variable has statistically significant (at or below the 10% level) coefficients for the *one-mile* OLS model. For those controlling variables that are found to be statistically significant, the table further contains mean values, standard deviations, and minimum and maximum levels.

Many of the county-interacted controlling variables (e.g., *lsfla1000, lt1acre, age, agesqr, baths,* and *swinter*) are consistently (in more than two thirds of the counties) statistically significant (with a p-value < 0.10) and have appropriately sized mean values. The seemingly spurious minimum and maximum values among some of the county-level controlling variables (e.g., *lt1acre* minimum of -0.069) likely arise when these variables in particular counties are highly correlated with other variables, such as square feet (*lsfla1000*), and also when sample size is limited.[31] The other variables (*acres* and the three block group level census variables: *pctvacant, pctowner,* and *med_age*) are statistically significant in 33-59% of the counties. Only one variable's mean value—the percent of housing units vacant in the block group as of the 2000 census (*pctvacant*)—was counterintuitive. In that instance, a positive coefficient was estimated, when in fact, one would expect that increasing the percent of vacant housing would lower prices;

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[29] The OLS models are estimated using the areg procedure in Stata with robust (White's corrected) standard errors (White, 1980). The spatial error models are estimated using the *gstslshet* routine in the sphet package in R, which also allows for robust standard errors to be estimated. See: http://cran.r-project.org/web/packages/sphet/sphet.pdf

[30] The controlling variables' coefficients were similar across the base models, so only the *one-mile* results are summarized here.

[31] The possible adverse effects of these collinearities were fully explored both via the removal of the variables and by examining VIF statistics. The VOI results are robust to controlling variable removal and have relatively low (< 5) VIF statistics.

this counter-intuitive effect may be due to collinearity with one or more of the other variables, or possible measurement errors.[32]

The sale year variables, which are interacted with the state, are also summarized in Table 8, with the percentages indicating the number of states in which the coefficients are statistically significant. The inclusion of these sale year variables in the regressions control for inflation and deflation across the various states over the study period. The coefficients represent a comparison to the omitted year, which is 2011. All sale year state-level coefficients are statistically significant in at least 50% of the states in all years except 2010, and they are significant in two thirds of the states in all except 3 years. The mean values of all years are appropriately signed, showing a monotonically ordered peak in values in 2007, with lower values in the prior and following years. The minimum and maximum values are similarly signed (negative) through 2003 and from 2007 through 2010 (positive), and are both positive and negative in years 2003 through 2006, indicating the differences in inflation/deflation in those years across the various states. This reinforces the appropriateness of interacting the sale years at the state level. Finally, although not shown, the model also contains 250 fixed effects for the census tract delineations, of which approximately 50% were statistically significant.

[32] The removal of this, as well as the other block group census variables, however, did not substantively influence the results of the VOI.

Table 8: Levels and Significance for County- and State-Interacted Controlling Variables[33]

Variable	% of Counties/States Having Significant (*p* -value <0.10) Coefficients	Statistics for Significant Variables Mean	St Dev	Min	Max
lsfla1000	100%	0.604	0.153	0.332	0.979
acres	48%	0.025	0.035	-0.032	0.091
lt1acre	85%	0.280	0.170	-0.069	0.667
age	81%	-0.006	0.008	-0.021	0.010
agesqr	74%	-0.006	0.063	-0.113	0.108
*baths**	85%	0.156	0.088	0.083	0.366
pctvacant	48%	1.295	3.120	-2.485	9.018
pctowner	33%	0.605	0.811	-0.091	2.676
med_age	59%	-0.016	0.132	-0.508	0.066
swinter	78%	-0.034	0.012	-0.053	-0.020
sy1996	100%	-0.481	0.187	-0.820	-0.267
sy1997	100%	-0.448	0.213	-0.791	-0.242
sy1998	100%	-0.404	0.172	-0.723	-0.156
sy1999	100%	-0.359	0.169	-0.679	-0.156
sy2000	88%	-0.298	0.189	-0.565	-0.088
sy2001	88%	-0.286	0.141	-0.438	-0.080
sy2002	67%	-0.261	0.074	-0.330	-0.128
sy2003	67%	-0.218	0.069	-0.326	-0.119
sy2004	75%	-0.084	0.133	-0.208	0.087
sy2005	67%	0.082	0.148	-0.111	0.278
sy2006	67%	0.128	0.158	-0.066	0.340
sy2007	67%	0.196	0.057	0.143	0.297
sy2008	56%	0.160	0.051	0.084	0.218
sy2009	50%	0.138	0.065	0.071	0.219
sy2010	33%	0.172	0.063	0.105	0.231

** % of counties significant is reported only for counties that had the baths variable populated (17 out of 27 counties)*

5.1.2. Variables of Interest

The variables of interest, the interactions between the *fdp* and *tdis* bins, are shown in Table 9 for the four base models. The reference (i.e., omitted) case for these variables are homes that sold prior to the wind facilities' announcement (PA) and are located between 3 and 10 miles from the

[33] Controlling variable statistics are provided for only the *one-mile* OLS model but did not differ substantially for other models. All variables are interacted with counties, except for sale year (sy), which is interacted with the state.

wind turbines' eventual locations. In relation to that group of transactions, three of the eight interactions in the *one-mile* models and four of the 11 interactions in the *half-mile* models produce coefficients that are statistically significant (at the 10% level).

Across all four base models none of the PA coefficients show statistically significant differences between the reference category (outside of 3 miles) and the group of transactions within a mile for the *one-mile* models (OLS: -1.7%, *p*-value 0.48; SEM: -0.02%, *p*-value 0.94)[34] or within a half- or between one-half and one-mile for the *half-mile* models (OLS inside a half mile: 0.01%, *p*-value 0.97; between a half and 1 mile: -2.3%, *p*-value 0.38; SEM inside a half mile: 5.3%, *p*-value 0.24; between a half and 1 mile: -1.8%, *p*-value 0.60). Further, none of the coefficients are significant, and all are relatively small (which partially explains their non-significance). Given these results, we find an absence of evidence of a PA effect for homes close to the turbines (*research question 1*). These results can be contrasted with the differences in prices between within-1-mile homes and outside-of-3-miles homes as summarized in Section 4.8 when no differences in the homes, the local market, the neighborhood, etc. are accounted for. The approximately 75% difference in price (alone) in the pre-announcement period 1-mile homes, as compared to the PC 3-mile homes, discussed in Section 4.8, is largely explained by differences in the controlling characteristics, which is why the pre-announcement distance coefficients shown here are not statistically significant.

Turning to the PAPC and PC periods, the results also indicate statistically insignificant differences in average home values, all else being equal, between the reference group of transactions (sold in the PA period) and those similarly located more than 3 miles from the turbines but sold in the PAPC or PC periods. Those differences are estimated to be between -0.8% and -0.5%.

The results presented above, and in Table 8, include both OLS and spatial models. Prior to estimating the spatial models, the Moran's I was calculated using the residuals of an OLS model that uses the same explanatory variables as the spatial models and the same dataset (only the most recent transactions). The Moran's I statistic (0.133) was highly significant (*p*-value 0.00),

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[34] p-values are not shown in the table can but can be derived from the standard errors, which are shown.

which allows us to reject the hypothesis that the residuals are spatially independent. Therefore, there was justification in estimating the spatial models. However, after estimation, we determined that only the spatial error process was significant. As a result, we estimated spatial error models (SEMs) for the final specification. The spatial autoregressive coefficient, lambda (bottom of Table 9), which is an indication of spatial autocorrelation in the residuals, is sizable and statistically significant in both SEMs (0.26, *p*-value 0.00). The SEM models' variable-of-interest coefficients are quite similar to those of the OLS models. In most cases, the coefficients are the same sign, approximately the same level, and often similarly insignificant, indicating that although spatial dependence is present it does not substantively bias the variables of interest. The one material difference is the coefficient size and significance for homes outside of 3 miles in the PAPC and PC periods, 3.3% (*p*-value 0.000) and 3.1% (*p*-value 0.008), indicating there are important changes to home values over the periods that must be accounted for in the later DD models in order to isolate the potential impacts that occur due to the presence of wind turbines.

Table 9: Results of Interacted Variables of Interest: *fdp* and *tdis*

		one-mile	*one-mile*	*half-mile*	*half-mile*
		OLS	SEM	OLS	SEM
fdp	tdis	β (se)	β (se)	β (se)	β (se)
PA	< 1 mile	-0.017	0.002		
		(0.024)	*(0.031)*		
PA	1-2 miles	-0.015	0.008		
		(0.011)	*(0.016)*		
PA	> 3 miles	Omitted	Omitted		
		n/a	*n/a*		
PAPC	< 1 mile	-0.035	-0.038		
		(0.029)	*(0.033)*		
PAPC	1-2 miles	-0.001	-0.033.		
		(0.014)	*(0.018)*		
PAPC	> 3 miles	-0.006	-0.033***		
		(0.008)	*(0.01)*		
PC	< 1 mile	0.019	-0.022		
		(0.026)	*(0.032)*		
PC	1-2 miles	0.044***	-0.001		
		(0.014)	*(0.019)*		
PC	> 3 miles	-0.005	-0.031**		
		(0.010)	*(0.012)*		
PA	< 1/2 mile			0.001	0.053
				(0.039)	*(0.045)*
PA	1/2 - 1 mile			-0.023	-0.018
				(0.027)	*(0.035)*
PA	1-2 miles			-0.015	0.008
				(0.011)	*(0.016)*
PA	> 3 miles			Omitted	Omitted
				n/a	*n/a*
PAPC	< 1/2 mile			-0.028	-0.065
				(0.049)	*(0.056)*
PAPC	1/2 - 1 mile			-0.038	-0.027
				(0.033)	*(0.036)*
PAPC	1-2 miles			-0.001	-0.034.
				(0.014)	*(0.017)*
PAPC	> 3 miles			-0.006	-0.033***
				(0.008)	*(0.009)*
PC	< 1/2 mile			-0.016	-0.036
				(0.041)	*(0.046)*
PC	1/2 - 1 mile			0.032	-0.016
				(0.031)	*(0.035)*
PC	1-2 miles			0.044***	-0.001
				(0.014)	*(0.018)*
PC	> 3 miles			-0.005	-0.031**
				(0.010)	*(0.012)*
lambda			0.247 ***		0.247 ***
			(0.008)		*(0.008)*
*Note: p-values: < 0.1 *, < 0.05 **, <0.01 ***.*					
n		51,276	38,407	51,276	38,407
adj R-sqr		0.67	0.64	0.67	0.64

5.1.3. Impact of Wind Turbines

As discussed above, there are important differences in property values between development periods for the reference group of homes (those located outside of 3 miles) that must be accounted for. Further, although they are not significant, differences between the reference category and those transactions inside of 1 mile in the PA period still must be accounted for if accurate measurements of PAPC or PC wind turbine effects are to be estimated. The DD specification accounts for both of these critical effects.

Table 10 shows the results of the DD tests across the four models, based on the results for the variables of interest presented in Table 9.[35] For example, to determine the net difference for homes that sold inside of a half mile (drawing from the *half-mile* OLS model) in the PAPC period, we use the following formula: PAPC half-mile coefficient (-0.028) less the PAPC 3-mile coefficient (-0.006) less the PA half-mile coefficient (0.001), which equals -0.024 (without rounding), which equates to 2.3% difference,[36] and is not statistically significant.

None of the DD effects in either the OLS or SEM specifications are statistically significant in the PAPC or PC periods, indicating that we do not observe a statistically significant impact of wind turbines on property values. Some small differences are apparent in the calculated coefficients, with those for PAPC being generally more negative/less positive than their PC counterparts, perhaps suggestive of a small announcement effect that declines once a facility is constructed. Further, the inside-a-half-mile coefficients are more negative/less positive than their between-a-half-and-1-mile counterparts, perhaps suggestive of a small property value impact very close to turbines.[37] However, in all cases, the sizes of these differences are smaller than the margins of error in the model (i.e., 90% confidence interval) and thus are not statistically significant. Therefore, based on these results, we do not find evidence supporting either of our two core hypotheses (*research questions 2 and 3*). In other words, there is no statistical evidence that homes in either the PAPC or PC periods that sold near turbines (i.e., within a mile or even a half

[35] All DD estimates for the OLS models were calculated using the post-estimation "lincom" test in Stata, which uses the stored results' variance/covariance matrix to test if a linear combination of coefficients is different from 0. For the SEM models, a similar test was performed in R.

[36] All differences in coefficients are converted to percentages in the table as follows: exp(coef)-1.

[37] Although not discussed in the text, this trend continues with homes between 1 and 2 miles being less negative/more positive than homes closer to the turbines (e.g., those within 1 mile).

mile) did so for less than similar homes that sold between 3 and 10 away miles in the same period.

Further, using the standard errors from the DD models we can estimate the maximum size an average effect would have to be in our sample for the model to detect it (*research question 4*). For an average effect in the PC period to be found for homes within 1 mile of the existing turbines (therefore using the *one-mile* model results), an effect greater than 4.9%, either positive or negative, would have to be present to be detected by the model.[38] In other words, it is highly unlikely that the true average effect for homes that sold in our sample area within 1 mile of an existing turbine is larger than +/-4.9%. Similarly, it is highly unlikely that the true average effect for homes that sold in our sample area within a half mile of an existing turbine is larger than +/-9.0%.[39] Regardless of these maximum effects, however, as well as the very weak suggestion of a possible small announcement effect and a possible small effect on homes that are very close to turbines, the core results of these models show effect sizes that are not statistically significant from zero, and are considerably smaller than these maximums.[40]

[38] Using the 90% confidence interval (i.e., 10% level of significance) and assuming more than 300 cases, the critical t-value is 1.65. Therefore, using the standard error of 0.030, the 90% confidence intervals for the test will be +/-0.049.

[39] Using the critical t-value of 1.66 for the 100 PC cases within a half mile in our sample and the standard error of 0.054.

[40] It is of note that these maximum effects are slightly larger than those we expected to find, as discussed earlier. This likely indicates that there was more variation in this sample, causing relatively higher standard errors for the same number of cases, than in the sample used for the 2009 study (Hoen et al., 2009, 2011).

Table 10: "Net" Difference-in-Difference Impacts of Turbines

		< 1 Mile	< 1 Mile	< 1/2 Mile	< 1/2 Mile
		OLS	SEM	OLS	SEM
fdp	tdis	b/se	b/se	b/se	b/se
PAPC	< 1 mile	-1.2% NS	-0.7% NS		
		(0.033)	*(0.037)*		
PC	< 1 mile	4.2% NS	0.7% NS		
		(0.030)	*(0.035)*		
PAPC	< 1/2 mile			-2.3% NS	-8.1% NS
				(0.060)	*(0.065)*
PAPC	1/2 - 1 mile			-0.8% NS	2.5% NS
				(0.039)	*(0.043)*
PC	< 1/2 mile			-1.2% NS	-5.6% NS
				(0.054)	*(0.057)*
PC	1/2 - 1 mile			6.3% NS	3.4% NS
				(0.036)	*(0.042)*

*Note: p-values: > 10% NS, < 10% *, < 5% **, <1 % ****

5.2. Robustness Tests

Table 11 summarizes the results from the robustness tests. For simplicity, only the DD coefficients are shown and only for the *half-mile* OLS models.[41] The first two columns show the base OLS and SEM *half-mile* DD results (also presented earlier, in Table 9), and the remaining columns show the results from the robustness models as follows: exclusion of outliers and influential cases from the dataset (*outlier*); using sale year/county interactions instead of sale year/state (*sycounty*); using only the most recent sales instead of the most recent and prior sales (*recent*); using homes between 5 and 10 miles as the reference category, instead of homes between 3 and 10 miles (*outside5*); and using transactions occurring more than 2 years before announcement as the reference category instead of using transactions simply *before* announcement (*prior*).

[41] Results were also estimated for the *one-mile* OLS models for each of the robustness tests and are available upon request: the results do not substantively differ from what is presented here for the *half-mile* models. Because of the similarities in the results between the OLS and SEM "base" models, robustness tests on the SEM models were not prepared as we assumed that differences between the two models for the robustness tests would be minimal as well.

The robustness results have patterns similar to the base model results: none of the coefficients are statistically different from zero; all coefficients (albeit non-significant) are lower in the PAPC period than the PC period; and, all coefficients (albeit non-significant) are lower (i.e., less negative/more positive) within a half mile than outside a half mile.[42] In sum, regardless of dataset or specification, there is no change in the basic conclusions drawn from the base model results: there is no evidence that homes near operating or announced wind turbines are impacted in a statistically significant fashion. Therefore, if effects do exist, either the average impacts are relatively small (within the margin of error in the models) and/or sporadic (impacting only a small subset of homes). Moreover, these results seem to corroborate what might be predicted given the other, potentially analogous disamenity literature that was reviewed earlier, which might be read to suggest that any property value effect of wind turbines might coalesce at a maximum of 3%–4%, on average. Of course, we cannot offer that corroboration directly because, although the size of the coefficients in the models presented here are reasonably consistent with effects of that magnitude, none of our models offer results that are statistically different from zero.

[42] This trend also continues outside of 1 mile, with those coefficients being less negative/more positive than those within 1 mile.

Table 11: Robustness Half-Mile Model Results

				Robustness OLS Models				
		Base OLS	Base SEM	outlier	sycounty	recent	outside5	prior
fdp	tdis	β (se)	β (se)	β (se)	β (se)	β (se)	β (se)	β (se)
PAPC	< 1/2 mile	-2.3% NS	-8.1% NS	-4.7% NS	-4.2% NS	-5.6% NS	-1.7% NS	0.1% NS
		(0.060)	*(0.065)*	*(0.056)*	*(0.060)*	*(0.066)*	*(0.060)*	*(0.062)*
PAPC	1/2 - 1 mile	-0.8% NS	2.5% NS	-1.7% NS	-2.5% NS	2.3% NS	-0.2% NS	0.4% NS
		(0.039)	*(0.043)*	*(0.036)*	*(0.039)*	*(0.043)*	*(0.039)*	*(0.044)*
PC	< 1/2 mile	-1.2% NS	-5.6% NS	-0.5% NS	-1.8% NS	-4.3% NS	-0.3% NS	1.3% NS
		(0.054)	*(0.057)*	*(0.047)*	*(0.054)*	*(0.056)*	*(0.054)*	*(0.056)*
PC	1/2 - 1 mile	6.3% NS	3.4% NS	6.2% NS	3.8% NS	4.1% NS	7.1% NS	7.5% NS
		(0.036)	*(0.041)*	*(0.033)*	*(0.036)*	*(0.042)*	*(0.036)*	*(0.041)*
*Note: p-values: > 0.1 NS, < 0.1 *, <0.5 **, <0.01 ****								
	n	51,276	38,407	50,106	51,276	38,407	51,276	51,276
	adj R-sqr	0.67	0.64	0.66	0.67	0.66	0.67	0.67

6. Conclusion

Wind energy facilities are expected to continue to be developed in the United States. Some of this growth is expected to occur in more-populated regions, raising concerns about the effects of wind development on home values in surrounding communities.

Previous published and academic research on this topic has tended to indicate that wind facilities, after they have been constructed, produce little or no effect on home values. At the same time, some evidence has emerged indicating potential home-value effects occurring after a wind facility has been announced but before construction. These previous studies, however, have been limited by their relatively small sample sizes, particularly in relation to the important population of homes located very close to wind turbines, and have sometimes treated the variable for distance to wind turbines in a problematic fashion. Analogous studies of other disamenities—including high-voltage transmission lines, landfills, and noisy roads—suggest that if reductions in property values near turbines were to occur, they would likely be no more than 3%–4%, on average, but to discover such small effects near turbines, much larger amounts of data are needed than have been used in previous studies. Moreover, previous studies have not accounted adequately for potentially confounding home-value factors, such as those affecting home values before wind facilities were announced, nor have they adequately controlled for spatial dependence in the data, i.e., how the values and characteristics of homes located near one another influence the value of those homes (independent of the presence of wind turbines).

This study helps fill those gaps by collecting a very large data sample and analyzing it with methods that account for confounding factors and spatial dependence. We collected data from more than 50,000 home sales among 27 counties in nine states. These homes were within 10 miles of 67 different then-current or existing wind facilities, with 1,198 sales that were within 1 mile of a turbine (331 of which were within a half mile)—many more than were collected by previous research efforts. The data span the periods well before announcement of the wind facilities to well after their construction. We use OLS and spatial-process difference-in-difference hedonic models to estimate the home-value impacts of the wind facilities; these models control for value factors existing prior to the wind facilities' announcements, the spatial dependence of home values, and value changes over time. We also employ a series of robustness models, which provide greater confidence in our results by testing the effects of data outliers and influential cases, heterogeneous inflation/deflation across regions, older sales data for multi-sale homes, the distance from turbines for homes in our reference case, and the amount of time before wind-facility announcement for homes in our reference case.

Across all model specifications, we find no statistical evidence that home prices near wind turbines were affected in either the post-construction or post-announcement/pre-construction periods. Therefore, if effects do exist, either the average impacts are relatively small (within the margin of error in the models) and/or sporadic (impacting only a small subset of homes). Related, our sample size and analytical methods enabled us to bracket the size of effects that would be detected, if those effects were present at all. Based on our results, we find that it is *highly unlikely* that the actual average effect for homes that sold in our sample area within 1 mile of an existing turbine is larger than +/-4.9%. In other words, the average value of these homes could be as much as 4.9% higher than it would have been without the presence of wind turbines, as much as 4.9% lower, the same (i.e., zero effect), or anywhere in between. Similarly, it is highly unlikely that the average actual effect for homes that sold in our sample area within a half mile of an existing turbine is larger than +/-9.0%. In other words, the average value of these homes could be as much as 9% higher than it would have been without the presence of wind turbines, as much as 9% lower, the same (i.e., zero effect), or anywhere in between.

Regardless of these potential maximum effects, the core results of our analysis consistently show no sizable statistically significant impact of wind turbines on nearby property values. The maximum impact suggested by potentially analogous disamenities (high-voltage transmission lines, landfills, roads etc.) of 3%-4% is at the far end of what the models presented in this study would have been able to discern, potentially helping to explain why no statistically significant effect was found. If effects of this size are to be discovered in future research, even larger samples of data may be required. For those interested in estimating such effects on a more micro (or local) scale, such as appraisers, these possible data requirements may be especially daunting, though it is also true that the inclusion of additional market, neighborhood, and individual property characteristics in these more-local assessments may sometimes improve model fidelity.

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8. Appendix – Full Results

	OneMile OLS		HalfMile OLS		OneMile SEM		HalfMile SEM	
Variables	**coef**	**se**	**coef**	**se**	**coef**	**se**	**coef**	**se**
Intercept	11.332***	(0.058)	11.330***	(0.058)	11.292***	(0.090)	11.292***	(0.090)
fdp3tdis3_11	-0.017	(0.024)			0.002	(0.031)		
fdp3tdis3_12	-0.015	(0.011)			0.008	(0.016)		
fdp3tdis3_21	-0.035	(0.029)			-0.038	(0.033)		
fdp3tdis3_22	-0.001	(0.014)			-0.033*	(0.017)		
fdp3tdis3_23	-0.006	(0.008)			-0.033***	(0.009)		
fdp3tdis3_31	0.019	(0.026)			-0.022	(0.031)		
fdp3tdis3_32	0.044***	(0.014)			-0.001	(0.018)		
fdp3tdis3_33	-0.005	(0.010)			-0.031***	(0.012)		
fdp3tdis4_10			0.001	(0.039)			0.053	(0.045)
fdp3tdis4_11			-0.023	(0.027)			-0.018	(0.035)
fdp3tdis4_12			-0.015	(0.011)			0.008	(0.016)
fdp3tdis4_20			-0.028	(0.049)			-0.065	(0.056)
fdp3tdis4_21			-0.038	(0.033)			-0.027	(0.036)
fdp3tdis4_22			-0.001	(0.014)			-0.034*	(0.017)
fdp3tdis4_23			-0.006	(0.008)			-0.033***	(0.009)
fdp3tdis4_30			-0.016	(0.041)			-0.036	(0.046)
fdp3tdis4_31			0.032	(0.031)			-0.016	(0.035)
fdp3tdis4_32			0.044***	(0.014)			-0.001	(0.018)
fdp3tdis4_33			-0.005	(0.010)			-0.031***	(0.012)
lsfla1000_ia_car	0.750***	(0.042)	0.749***	(0.042)	0.723***	(0.045)	0.722***	(0.045)
lsfla1000_ia_flo	0.899***	(0.054)	0.900***	(0.054)	0.879***	(0.060)	0.88***	(0.060)
lsfla1000_ia_fra	0.980***	(0.077)	0.980***	(0.077)	0.932***	(0.083)	0.934***	(0.083)
lsfla1000_ia_sac	0.683***	(0.061)	0.683***	(0.061)	0.633***	(0.065)	0.633***	(0.064)
lsfla1000_il_dek	0.442***	(0.037)	0.441***	(0.037)	0.382***	(0.040)	0.38***	(0.040)
lsfla1000_il_liv	0.641***	(0.030)	0.641***	(0.030)	0.643***	(0.046)	0.643***	(0.046)
lsfla1000_il_mcl	0.512***	(0.019)	0.512***	(0.019)	0.428***	(0.029)	0.428***	(0.029)
lsfla1000_mn_cot	0.800***	(0.052)	0.800***	(0.052)	0.787***	(0.077)	0.787***	(0.077)
lsfla1000_mn_fre	0.594***	(0.028)	0.595***	(0.028)	0.539***	(0.031)	0.539***	(0.031)
lsfla1000_mn_jac	0.587***	(0.101)	0.587***	(0.101)	0.551***	(0.102)	0.55***	(0.102)
lsfla1000_mn_mar	0.643***	(0.025)	0.643***	(0.025)	0.603***	(0.029)	0.603***	(0.029)
lsfla1000_nj_atl	0.421***	(0.012)	0.421***	(0.012)	0.389***	(0.014)	0.389***	(0.014)
lsfla1000_ny_cli	0.635***	(0.044)	0.635***	(0.044)	0.606***	(0.045)	0.606***	(0.045)
lsfla1000_ny_fra	0.373***	(0.092)	0.375***	(0.092)	0.433***	(0.094)	0.436***	(0.094)
lsfla1000_ny_her	0.520***	(0.034)	0.520***	(0.034)	0.559***	(0.035)	0.559***	(0.035)
lsfla1000_ny_lew	0.556***	(0.054)	0.556***	(0.054)	0.518***	(0.057)	0.518***	(0.057)
lsfla1000_ny_mad	0.503***	(0.025)	0.503***	(0.025)	0.502***	(0.025)	0.502***	(0.025)
lsfla1000_ny_ste	0.564***	(0.032)	0.564***	(0.032)	0.534***	(0.034)	0.534***	(0.034)
lsfla1000_ny_wyo	0.589***	(0.034)	0.589***	(0.034)	0.566***	(0.034)	0.566***	(0.034)
lsfla1000_oh_pau	0.625***	(0.080)	0.624***	(0.080)	0.567***	(0.090)	0.565***	(0.090)
lsfla1000_oh_woo	0.529***	(0.030)	0.529***	(0.030)	0.487***	(0.035)	0.487***	(0.035)
lsfla1000_ok_cus	0.838***	(0.037)	0.838***	(0.037)	0.794***	(0.046)	0.793***	(0.046)
lsfla1000_ok_gra	0.750***	(0.063)	0.750***	(0.063)	0.706***	(0.072)	0.706***	(0.072)
lsfla1000_pa_fay	0.332***	(0.111)	0.332***	(0.111)	0.335***	(0.118)	0.334***	(0.118)
lsfla1000_pa_som	0.564***	(0.025)	0.564***	(0.025)	0.548***	(0.031)	0.548***	(0.031)
lsfla1000_pa_way	0.486***	(0.056)	0.486***	(0.056)	0.44***	(0.063)	0.44***	(0.063)
lsfla1000_wa_kit	0.540***	(0.073)	0.540***	(0.073)	0.494***	(0.078)	0.494***	(0.078)

	OneMile OLS		HalfMile OLS		OneMile SEM		HalfMile SEM	
Variables	**coef**	**se**	**coef**	**se**	**coef**	**se**	**coef**	**se**
acres_ia_car	0.033	(0.030)	0.033	(0.030)	0.013	(0.032)	0.013	(0.032)
acres_ia_flo	0.050***	(0.014)	0.050***	(0.014)	0.044***	(0.014)	0.044***	(0.014)
acres_ia_fra	-0.008	(0.022)	-0.008	(0.022)	-0.009	(0.022)	-0.009	(0.022)
acres_ia_sac	0.064***	(0.014)	0.064***	(0.014)	0.054***	(0.015)	0.054***	(0.015)
acres_il_dek	0.068**	(0.027)	0.064**	(0.027)	0.055*	(0.029)	0.048*	(0.029)
acres_il_liv	0.023	(0.014)	0.023	(0.014)	0.014	(0.018)	0.014	(0.018)
acres_il_mcl	0.091***	(0.010)	0.091***	(0.010)	0.092***	(0.011)	0.092***	(0.011)
acres_mn_cot	-0.030***	(0.011)	-0.030***	(0.011)	-0.024*	(0.013)	-0.024*	(0.013)
acres_mn_fre	-0.002	(0.007)	-0.002	(0.007)	0.002	(0.008)	0.002	(0.008)
acres_mn_jac	0.019	(0.016)	0.020	(0.016)	0.03*	(0.016)	0.03*	(0.016)
acres_mn_mar	0.020**	(0.008)	0.020**	(0.008)	0.017*	(0.009)	0.017*	(0.009)
acres_nj_atl	-0.041	(0.031)	-0.041	(0.031)	-0.013	(0.026)	-0.013	(0.026)
acres_ny_cli	0.019***	(0.007)	0.019***	(0.007)	0.022***	(0.007)	0.022***	(0.007)
acres_ny_fra	0.009	(0.010)	0.009	(0.010)	0.014	(0.011)	0.014	(0.011)
acres_ny_her	-0.004	(0.008)	-0.004	(0.008)	0.012	(0.008)	0.012	(0.008)
acres_ny_lew	0.014*	(0.008)	0.014*	(0.008)	0.014	(0.009)	0.014	(0.009)
acres_ny_mad	0.021***	(0.003)	0.021***	(0.003)	0.021***	(0.004)	0.021***	(0.004)
acres_ny_ste	0.009*	(0.005)	0.009*	(0.005)	0.007	(0.005)	0.007	(0.005)
acres_ny_wyo	0.016***	(0.004)	0.016***	(0.004)	0.019***	(0.004)	0.019***	(0.004)
acres_oh_pau	-0.010	(0.020)	-0.010	(0.020)	0.01	(0.024)	0.009	(0.024)
acres_oh_woo	-0.007	(0.010)	-0.007	(0.010)	0.002	(0.010)	0.002	(0.010)
acres_ok_cus	-0.037*	(0.019)	-0.037*	(0.019)	-0.034	(0.022)	-0.034	(0.022)
acres_ok_gra	0.014	(0.010)	0.014	(0.010)	0.019*	(0.011)	0.019*	(0.011)
acres_pa_fay	-0.006	(0.023)	-0.006	(0.023)	0.01	(0.023)	0.01	(0.023)
acres_pa_som	0.003	(0.009)	0.004	(0.009)	0.009	(0.010)	0.009	(0.010)
acres_pa_way	0.017**	(0.007)	0.017**	(0.007)	0.024***	(0.007)	0.024***	(0.007)
acres_wa_kit	0.009	(0.010)	0.009	(0.010)	0.014	(0.011)	0.014	(0.011)
acreslt1_ia_car	0.446***	(0.136)	0.448***	(0.136)	0.559***	(0.144)	0.56***	(0.143)
acreslt1_ia_flo	0.436***	(0.112)	0.435***	(0.112)	0.384***	(0.118)	0.383***	(0.118)
acreslt1_ia_fra	0.670***	(0.124)	0.668***	(0.124)	0.684***	(0.139)	0.68***	(0.139)
acreslt1_ia_sac	0.159	(0.115)	0.160	(0.115)	0.222*	(0.123)	0.221*	(0.123)
acreslt1_il_dek	0.278***	(0.066)	0.285***	(0.066)	0.282***	(0.073)	0.294***	(0.073)
acreslt1_il_liv	0.278***	(0.063)	0.276***	(0.063)	0.383***	(0.088)	0.38***	(0.088)
acreslt1_il_mcl	-0.069***	(0.021)	-0.070***	(0.021)	-0.007	(0.032)	-0.007	(0.032)
acreslt1_mn_cot	0.529***	(0.093)	0.529***	(0.093)	0.466***	(0.120)	0.465***	(0.120)
acreslt1_mn_fre	0.314***	(0.053)	0.314***	(0.053)	0.294***	(0.061)	0.293***	(0.061)
acreslt1_mn_jac	0.250*	(0.144)	0.247*	(0.145)	0.169	(0.146)	0.162	(0.146)
acreslt1_mn_mar	0.452***	(0.062)	0.452***	(0.062)	0.461***	(0.069)	0.462***	(0.069)
acreslt1_nj_atl	0.135***	(0.048)	0.135***	(0.048)	0.044	(0.047)	0.043	(0.047)
acreslt1_ny_cli	0.115***	(0.044)	0.115***	(0.044)	0.108**	(0.047)	0.108**	(0.047)
acreslt1_ny_fra	0.118	(0.100)	0.118	(0.100)	0.113	(0.115)	0.113	(0.115)
acreslt1_ny_her	0.364***	(0.047)	0.364***	(0.047)	0.331***	(0.050)	0.332***	(0.050)
acreslt1_ny_lew	0.119*	(0.061)	0.120**	(0.061)	0.117*	(0.067)	0.117*	(0.067)

	OneMile OLS		HalfMile OLS		OneMile SEM		HalfMile SEM	
Variables	**coef**	**se**	**coef**	**se**	**coef**	**se**	**coef**	**se**
acreslt1_ny_mad	0.017	(0.031)	0.018	(0.031)	0.043	(0.032)	0.043	(0.032)
acreslt1_ny_ste	0.100**	(0.042)	0.100**	(0.042)	0.18***	(0.047)	0.18***	(0.047)
acreslt1_ny_wyo	0.144***	(0.035)	0.144***	(0.035)	0.137***	(0.039)	0.137***	(0.039)
acreslt1_oh_pau	0.426***	(0.087)	0.425***	(0.087)	0.507***	(0.120)	0.507***	(0.120)
acreslt1_oh_woo	0.124***	(0.034)	0.124***	(0.034)	0.114***	(0.041)	0.114***	(0.041)
acreslt1_ok_cus	0.103	(0.070)	0.104	(0.070)	0.091	(0.092)	0.093	(0.092)
acreslt1_ok_gra	-0.038	(0.054)	-0.038	(0.054)	-0.065	(0.066)	-0.065	(0.066)
acreslt1_pa_fay	0.403***	(0.153)	0.403***	(0.153)	0.42**	(0.165)	0.42**	(0.164)
acreslt1_pa_som	0.243***	(0.039)	0.243***	(0.039)	0.223***	(0.047)	0.223***	(0.047)
acreslt1_pa_way	0.138**	(0.062)	0.138**	(0.062)	0.108	(0.077)	0.109	(0.077)
acreslt1_wa_kit	0.335**	(0.134)	0.335**	(0.134)	0.342**	(0.164)	0.342**	(0.164)
age_ia_car	-0.013***	(0.001)	-0.013***	(0.001)	-0.011***	(0.001)	-0.011***	(0.001)
age_ia_flo	-0.013***	(0.002)	-0.013***	(0.002)	-0.013***	(0.002)	-0.013***	(0.002)
age_ia_fra	-0.012***	(0.003)	-0.012***	(0.003)	-0.011***	(0.003)	-0.011***	(0.003)
age_ia_sac	-0.013***	(0.003)	-0.013***	(0.003)	-0.011***	(0.003)	-0.011***	(0.003)
age_il_dek	-0.004***	(0.001)	-0.004***	(0.001)	-0.004***	(0.001)	-0.004***	(0.001)
age_il_liv	-0.001	(0.001)	-0.002	(0.001)	-0.003	(0.002)	-0.003	(0.002)
age_il_mcl	-0.004***	(0.001)	-0.004***	(0.001)	-0.006***	(0.001)	-0.006***	(0.001)
age_mn_cot	-0.021***	(0.003)	-0.021***	(0.003)	-0.013***	(0.005)	-0.013***	(0.005)
age_mn_fre	-0.013***	(0.001)	-0.013***	(0.001)	-0.012***	(0.002)	-0.012***	(0.002)
age_mn_jac	-0.018***	(0.005)	-0.018***	(0.005)	-0.018***	(0.005)	-0.018***	(0.005)
age_mn_mar	-0.010***	(0.001)	-0.010***	(0.001)	-0.009***	(0.002)	-0.009***	(0.002)
age_nj_atl	-0.004***	(0.000)	-0.004***	(0.000)	-0.003***	(0.001)	-0.003***	(0.001)
age_ny_cli	-0.005***	(0.001)	-0.005***	(0.001)	-0.005***	(0.001)	-0.005***	(0.001)
age_ny_fra	-0.004	(0.003)	-0.005	(0.003)	-0.005*	(0.003)	-0.005*	(0.003)
age_ny_her	-0.008***	(0.001)	-0.008***	(0.001)	-0.008***	(0.001)	-0.008***	(0.001)
age_ny_lew	-0.008***	(0.001)	-0.008***	(0.001)	-0.009***	(0.001)	-0.009***	(0.001)
age_ny_mad	-0.006***	(0.001)	-0.006***	(0.001)	-0.006***	(0.001)	-0.006***	(0.001)
age_ny_ste	-0.006***	(0.001)	-0.006***	(0.001)	-0.007***	(0.001)	-0.007***	(0.001)
age_ny_wyo	-0.006***	(0.001)	-0.006***	(0.001)	-0.006***	(0.001)	-0.006***	(0.001)
age_oh_pau	0.003	(0.003)	0.003	(0.003)	0.003	(0.004)	0.003	(0.004)
age_oh_woo	0.008***	(0.001)	0.008***	(0.001)	0.01***	(0.001)	0.01***	(0.001)
age_ok_cus	-0.000	(0.002)	-0.000	(0.002)	0.002	(0.003)	0.002	(0.003)
age_ok_gra	-0.000	(0.002)	-0.000	(0.002)	0.001	(0.002)	0.001	(0.002)
age_pa_fay	0.010**	(0.004)	0.010**	(0.004)	0.01**	(0.005)	0.01**	(0.005)
age_pa_som	-0.006***	(0.001)	-0.006***	(0.001)	-0.008***	(0.001)	-0.008***	(0.001)
age_pa_way	0.006***	(0.002)	0.006***	(0.002)	0.007***	(0.002)	0.007***	(0.002)
age_wa_kit	0.010***	(0.003)	0.010***	(0.003)	0.014***	(0.003)	0.014***	(0.003)
agesq_ia_car	0.034***	(0.011)	0.034***	(0.000)	0.022*	(0.012)	0.022*	(0.012)
agesq_ia_flo	0.040***	(0.016)	0.040**	(0.016)	0.044***	(0.016)	0.044***	(0.016)
agesq_ia_fra	0.025	(0.022)	0.025	(0.022)	0.02	(0.023)	0.021	(0.023)
agesq_ia_sac	0.032	(0.022)	0.032	(0.022)	0.025	(0.023)	0.025	(0.023)
agesq_il_dek	0.008	(0.010)	0.008	(0.010)	0.013	(0.012)	0.013	(0.011)
agesq_il_liv	-0.023**	(0.009)	-0.023**	(0.009)	-0.011	(0.014)	-0.011	(0.014)
agesq_il_mcl	0.005	(0.007)	0.005	(0.007)	0.021*	(0.011)	0.021*	(0.011)
agesq_mn_cot	0.109**	(0.043)	0.109**	(0.043)	0.032	(0.069)	0.033	(0.069)
agesq_mn_fre	0.046***	(0.010)	0.045***	(0.010)	0.044***	(0.012)	0.044***	(0.012)
agesq_mn_jac	0.103***	(0.035)	0.104***	(0.035)	0.1***	(0.034)	0.101***	(0.034)
agesq_mn_mar	0.012	(0.012)	0.012	(0.012)	0.006	(0.014)	0.006	(0.014)

	OneMile OLS		HalfMile OLS		OneMile SEM		HalfMile SEM	
Variables	**coef**	**se**	**coef**	**se**	**coef**	**se**	**coef**	**se**
agesq_nj_atl	0.010***	(0.003)	0.010***	(0.003)	0.003	(0.005)	0.003	(0.005)
agesq_ny_cli	0.011*	(0.006)	0.011*	(0.006)	0.011*	(0.006)	0.011*	(0.006)
agesq_ny_fra	-0.011	(0.022)	-0.011	(0.022)	-0.002	(0.020)	-0.002	(0.020)
agesq_ny_her	0.022***	(0.005)	0.022***	(0.005)	0.022***	(0.006)	0.022***	(0.006)
agesq_ny_lew	0.031***	(0.006)	0.031***	(0.006)	0.032***	(0.007)	0.032***	(0.007)
agesq_ny_mad	0.017***	(0.003)	0.017***	(0.003)	0.023***	(0.003)	0.023***	(0.003)
agesq_ny_ste	0.013**	(0.005)	0.013**	(0.005)	0.018***	(0.005)	0.018***	(0.005)
agesq_ny_wyo	0.016***	(0.005)	0.016***	(0.005)	0.017***	(0.005)	0.017***	(0.005)
agesq_oh_pau	-0.044**	(0.022)	-0.045**	(0.022)	-0.043	(0.028)	-0.043	(0.028)
agesq_oh_woo	-0.074***	(0.007)	-0.074***	(0.007)	-0.091***	(0.009)	-0.091***	(0.009)
agesq_ok_cus	-0.091***	(0.019)	-0.091***	(0.019)	-0.113***	(0.026)	-0.113***	(0.026)
agesq_ok_gra	-0.081***	(0.023)	-0.081***	(0.023)	-0.097***	(0.029)	-0.097***	(0.029)
agesq_pa_fay	-0.112***	(0.032)	-0.112***	(0.032)	-0.105***	(0.034)	-0.106***	(0.034)
agesq_pa_som	0.000	(0.008)	0.002	(0.008)	0.016*	(0.009)	0.016*	(0.009)
agesq_pa_way	-0.000***	(0.012)	-0.052***	(0.012)	-0.053***	(0.014)	-0.053***	(0.014)
agesq_wa_kit	-0.000***	(0.027)	-0.097***	(0.027)	-0.132***	(0.031)	-0.132***	(0.031)
bathsim_ia_sac	-0.050	(0.073)	-0.050	(0.073)	-0.082	(0.077)	-0.081	(0.077)
bathsim_il_dek	-0.005	(0.015)	-0.005	(0.015)	0.001	(0.018)	0.001	(0.018)
bathsim_ny_cli	0.090***	(0.025)	0.090***	(0.025)	0.087***	(0.024)	0.087***	(0.024)
bathsim_ny_fra	0.246***	(0.062)	0.245***	(0.062)	0.213***	(0.064)	0.212***	(0.064)
bathsim_ny_her	0.099***	(0.022)	0.099***	(0.022)	0.079***	(0.022)	0.079***	(0.022)
bathsim_ny_lew	0.168***	(0.030)	0.167***	(0.030)	0.142***	(0.031)	0.142***	(0.031)
bathsim_ny_mad	0.180***	(0.014)	0.180***	(0.014)	0.157***	(0.013)	0.157***	(0.013)
bathsim_ny_ste	0.189***	(0.019)	0.189***	(0.019)	0.166***	(0.020)	0.166***	(0.020)
bathsim_ny_wyo	0.107***	(0.021)	0.107***	(0.021)	0.1***	(0.021)	0.1***	(0.021)
bathsim_oh_pau	0.095*	(0.051)	0.095*	(0.051)	0.149***	(0.057)	0.149***	(0.057)
bathsim_oh_woo	0.094***	(0.017)	0.094***	(0.017)	0.092***	(0.019)	0.092***	(0.019)
bathsim_pa_fay	0.367***	(0.077)	0.367***	(0.077)	0.301***	(0.082)	0.302***	(0.082)
bathsim_pa_way	0.082**	(0.036)	0.082**	(0.036)	0.081**	(0.041)	0.081**	(0.041)
pctvacant_ia_car	-2.515*	(1.467)	-2.521*	(1.468)	-2.011	(1.936)	-2.019	(1.937)
pctvacant_ia_flo	0.903	(1.152)	0.921	(1.152)	1.358	(1.409)	1.339	(1.410)
pctvacant_ia_fra	8.887**	(3.521)	8.928**	(3.518)	-2.596	(1.703)	-2.6	(1.703)
pctvacant_ia_sac	0.672	(0.527)	0.673	(0.527)	1.267***	(0.377)	1.266***	(0.377)
pctvacant_il_dek	0.052	(0.639)	0.062	(0.638)	0.037	(0.964)	0.069	(0.961)
pctvacant_il_liv	-0.475	(0.474)	-0.476	(0.474)	-0.699	(0.872)	-0.701	(0.872)
pctvacant_il_mcl	-0.365	(0.397)	-0.366	(0.397)	0.445	(0.670)	0.442	(0.670)
pctvacant_mn_cot	1.072*	(0.592)	1.072*	(0.592)	0.272	(1.039)	0.273	(1.039)
pctvacant_mn_fre	-1.782**	(0.703)	-1.787**	(0.703)	-1.372	(0.965)	-1.384	(0.965)
pctvacant_mn_jac	-1.345	(0.883)	-1.318	(0.884)	-1.285	(1.084)	-1.313	(1.084)
pctvacant_mn_mar	2.178***	(0.502)	2.175***	(0.502)	1.53**	(0.622)	1.528**	(0.622)
pctvacant_nj_atl	-0.054	(0.062)	-0.054	(0.062)	0.096	(0.085)	0.095	(0.085)
pctvacant_ny_cli	0.709***	(0.224)	0.709***	(0.224)	0.842***	(0.251)	0.841***	(0.251)
pctvacant_ny_fra	6.173***	(2.110)	6.104***	(2.113)	0.519	(0.710)	0.499	(0.709)
pctvacant_ny_her	-1.226***	(0.247)	-1.226***	(0.247)	-1.347***	(0.288)	-1.347***	(0.288)
pctvacant_ny_lew	-0.125	(0.127)	-0.125	(0.127)	-0.266*	(0.159)	-0.266*	(0.159)
pctvacant_ny_mad	0.750***	(0.196)	0.752***	(0.196)	0.767***	(0.246)	0.765***	(0.246)
pctvacant_ny_ste	0.280	(0.190)	0.281	(0.190)	0.039	(0.242)	0.04	(0.242)
pctvacant_ny_wyo	0.179*	(0.101)	0.178*	(0.101)	0.225*	(0.119)	0.224*	(0.119)
pctvacant_oh_pau	-1.473	(1.498)	-1.473	(1.499)	-1.341	(1.951)	-1.256	(1.952)

	OneMile OLS		HalfMile OLS		OneMile SEM		HalfMile SEM	
Variables	**coef**	**se**	**coef**	**se**	**coef**	**se**	**coef**	**se**
pctvacant_oh_woo	-0.565	(0.400)	-0.565	(0.400)	-0.304	(0.563)	-0.306	(0.563)
pctvacant_ok_cus	-0.127	(0.358)	-0.140	(0.359)	-0.167	(0.521)	-0.189	(0.521)
pctvacant_ok_gra	1.413*	(0.777)	1.414*	(0.777)	0.537	(1.045)	0.536	(1.045)
pctvacant_pa_fay	0.227	(0.596)	0.229	(0.596)	0.232	(0.807)	0.235	(0.807)
pctvacant_pa_som	0.517***	(0.098)	0.516***	(0.098)	0.562***	(0.138)	0.562***	(0.138)
pctvacant_pa_way	0.445***	(0.156)	0.444***	(0.156)	0.446**	(0.175)	0.446**	(0.175)
pctvacant_wa_kit	-0.076	(0.546)	-0.075	(0.546)	-0.377	(0.282)	-0.377	(0.281)
pctowner_ia_car	-0.225	(0.244)	-0.225	(0.244)	-0.156	(0.324)	-0.156	(0.324)
pctowner_ia_flo	0.579**	(0.238)	0.578**	(0.238)	0.75***	(0.290)	0.75***	(0.290)
pctowner_ia_fra	0.207	(0.310)	0.206	(0.310)	0.172	(0.393)	0.169	(0.393)
pctowner_ia_sac	0.274	(0.585)	0.261	(0.586)	-0.34	(0.545)	-0.345	(0.545)
pctowner_il_dek	0.075	(0.088)	0.073	(0.087)	0.032	(0.123)	0.028	(0.123)
pctowner_il_liv	0.176	(0.140)	0.176	(0.140)	0.265	(0.200)	0.264	(0.200)
pctowner_il_mcl	0.389***	(0.051)	0.388***	(0.051)	0.331***	(0.101)	0.331***	(0.101)
pctowner_mn_cot	0.375***	(0.138)	0.375***	(0.138)	0.609**	(0.254)	0.609**	(0.254)
pctowner_mn_fre	-0.119	(0.090)	-0.120	(0.090)	-0.072	(0.124)	-0.073	(0.124)
pctowner_mn_jac	-0.206	(0.474)	-0.205	(0.474)	-0.175	(0.569)	-0.185	(0.570)
pctowner_mn_mar	0.262***	(0.076)	0.262***	(0.076)	0.151	(0.103)	0.151	(0.103)
pctowner_nj_atl	-0.087**	(0.037)	-0.087**	(0.037)	-0.036	(0.052)	-0.037	(0.052)
pctowner_ny_cli	-0.229	(0.171)	-0.229	(0.171)	-0.305	(0.199)	-0.303	(0.199)
pctowner_ny_fra	2.743*	(1.500)	2.693*	(1.505)	-0.315	(1.447)	-0.398	(1.442)
pctowner_ny_her	0.246***	(0.095)	0.246***	(0.095)	0.213*	(0.109)	0.213*	(0.109)
pctowner_ny_lew	-0.034	(0.185)	-0.034	(0.185)	-0.126	(0.219)	-0.126	(0.219)
pctowner_ny_mad	0.750***	(0.075)	0.750***	(0.075)	0.723***	(0.084)	0.723***	(0.084)
pctowner_ny_ste	0.192	(0.128)	0.191	(0.128)	-0.083	(0.162)	-0.084	(0.162)
pctowner_ny_wyo	-0.089	(0.111)	-0.089	(0.111)	-0.109	(0.138)	-0.108	(0.138)
pctowner_oh_pau	-0.187	(0.347)	-0.185	(0.348)	-1.245***	(0.473)	-1.249***	(0.474)
pctowner_oh_woo	0.263***	(0.092)	0.264***	(0.092)	0.274**	(0.136)	0.274**	(0.136)
pctowner_ok_cus	0.068	(0.104)	0.068	(0.104)	-0.041	(0.146)	-0.043	(0.146)
pctowner_ok_gra	0.271*	(0.159)	0.271*	(0.159)	0.253	(0.217)	0.253	(0.217)
pctowner_pa_fay	-0.413	(1.736)	-0.420	(1.736)	-0.15	(2.037)	-0.165	(2.037)
pctowner_pa_som	0.171	(0.114)	0.170	(0.114)	0.098	(0.173)	0.098	(0.173)
pctowner_pa_way	-0.351	(0.441)	-0.348	(0.441)	-0.251	(0.345)	-0.252	(0.345)
pctowner_wa_kit	0.257	(2.139)	0.259	(2.139)	-0.358	(1.889)	-0.361	(1.890)
med_age_ia_car	0.002	(0.002)	0.002	(0.002)	0.003	(0.003)	0.003	(0.003)
med_age_ia_flo	0.003	(0.002)	0.003	(0.002)	0.004	(0.003)	0.004	(0.003)
med_age_ia_fra	0.066***	(0.015)	0.066***	(0.015)	0.014**	(0.006)	0.014**	(0.006)
med_age_ia_sac	0.028**	(0.014)	0.028**	(0.014)	0.012	(0.010)	0.012	(0.010)
med_age_il_dek	-0.001	(0.002)	-0.001	(0.002)	-0.001	(0.003)	-0.001	(0.003)
med_age_il_liv	-0.004	(0.004)	-0.004	(0.004)	-0.005	(0.005)	-0.005	(0.005)
med_age_il_mcl	-0.006***	(0.002)	-0.006***	(0.002)	-0.006**	(0.003)	-0.006**	(0.003)
med_age_mn_cot	0.017***	(0.005)	0.017***	(0.005)	0.018**	(0.008)	0.018**	(0.008)
med_age_mn_fre	0.012***	(0.002)	0.012***	(0.002)	0.013***	(0.002)	0.013***	(0.002)
med_age_mn_jac	0.013	(0.008)	0.013	(0.008)	0.012	(0.010)	0.012	(0.010)
med_age_mn_mar	0.013***	(0.003)	0.013***	(0.003)	0.012***	(0.003)	0.012***	(0.003)
med_age_nj_atl	0.010***	(0.001)	0.010***	(0.001)	0.016***	(0.002)	0.016***	(0.002)
med_age_ny_cli	0.020***	(0.004)	0.020***	(0.004)	0.02***	(0.004)	0.02***	(0.004)
med_age_ny_fra	-0.517***	(0.198)	-0.511***	(0.198)	0.008	(0.040)	0.01	(0.039)
med_age_ny_her	0.007*	(0.003)	0.007*	(0.003)	0.005	(0.003)	0.005	(0.003)

	OneMile OLS		HalfMile OLS		OneMile SEM		HalfMile SEM	
Variables	**coef**	**se**	**coef**	**se**	**coef**	**se**	**coef**	**se**
med_age_ny_lew	0.013***	(0.005)	0.013***	(0.005)	0.008	(0.005)	0.008	(0.005)
med_age_ny_mad	0.004**	(0.002)	0.004**	(0.002)	0.004*	(0.002)	0.004*	(0.002)
med_age_ny_ste	0.012***	(0.003)	0.012***	(0.003)	0.001	(0.004)	0.001	(0.004)
med_age_ny_wyo	0.008	(0.005)	0.007	(0.005)	0.008	(0.006)	0.008	(0.006)
med_age_oh_pau	0.034***	(0.013)	0.034***	(0.013)	0.019	(0.012)	0.019	(0.012)
med_age_oh_woo	-0.004	(0.003)	-0.004	(0.003)	-0.004	(0.004)	-0.004	(0.004)
med_age_ok_cus	0.004	(0.002)	0.004	(0.002)	0.008**	(0.004)	0.008**	(0.004)
med_age_ok_gra	0.011	(0.009)	0.011	(0.009)	0	(0.006)	0	(0.006)
med_age_pa_fay	0.049	(0.073)	0.049	(0.073)	0.052	(0.095)	0.052	(0.095)
med_age_pa_som	0.008***	(0.002)	0.008***	(0.002)	0.012***	(0.004)	0.012***	(0.004)
med_age_pa_way	-0.005	(0.012)	-0.005	(0.012)	0.002	(0.007)	0.002	(0.007)
med_age_wa_kit	-0.015	(0.095)	-0.015	(0.095)	0.025	(0.034)	0.025	(0.034)
swinter_ia	-0.034**	(0.015)	-0.034**	(0.015)	-0.039***	(0.015)	-0.039***	(0.015)
swinter_il	-0.020**	(0.008)	-0.020**	(0.008)	-0.013	(0.012)	-0.013	(0.012)
swinter_mn	-0.053***	(0.009)	-0.053***	(0.009)	-0.057***	(0.011)	-0.057***	(0.011)
swinter_nj	-0.007	(0.006)	-0.007	(0.006)	-0.008	(0.007)	-0.008	(0.007)
swinter_ny	-0.030***	(0.007)	-0.030***	(0.007)	-0.026***	(0.007)	-0.026***	(0.007)
swinter_oh	-0.048***	(0.012)	-0.048***	(0.012)	-0.055***	(0.014)	-0.055***	(0.014)
swinter_ok	-0.039**	(0.015)	-0.039**	(0.015)	-0.024	(0.018)	-0.024	(0.018)
swinter_pa	-0.025*	(0.015)	-0.025*	(0.015)	-0.02	(0.017)	-0.02	(0.017)
swinter_wa	-0.004	(0.046)	-0.004	(0.046)	0.014	(0.051)	0.013	(0.051)
sy_1996_ia	-0.436***	(0.137)	-0.433***	(0.137)	-0.493***	(0.157)	-0.489***	(0.157)
sy_1996_il	-0.267***	(0.037)	-0.267***	(0.037)	-0.344***	(0.061)	-0.344***	(0.061)
sy_1996_mn	-0.521***	(0.058)	-0.521***	(0.059)	-0.585***	(0.065)	-0.585***	(0.065)
sy_1996_nj	-0.820***	(0.022)	-0.820***	(0.022)	-0.717***	(0.038)	-0.717***	(0.038)
sy_1996_oh	-0.298***	(0.042)	-0.298***	(0.042)	-0.43***	(0.053)	-0.43***	(0.053)
sy_1996_ok	-0.444***	(0.073)	-0.444***	(0.073)	-0.846***	(0.079)	-0.846***	(0.079)
sy_1996_pa	-0.584***	(0.060)	-0.584***	(0.060)	-0.604***	(0.067)	-0.604***	(0.067)
sy_1997_il	-0.242***	(0.036)	-0.242***	(0.036)	-0.234***	(0.052)	-0.232***	(0.052)
sy_1997_mn	-0.445***	(0.055)	-0.445***	(0.055)	-0.535***	(0.060)	-0.535***	(0.060)
sy_1997_nj	-0.791***	(0.021)	-0.791***	(0.021)	-0.686***	(0.038)	-0.686***	(0.038)
sy_1997_oh	-0.302***	(0.043)	-0.302***	(0.043)	-0.39***	(0.053)	-0.39***	(0.053)
sy_1997_pa	-0.458***	(0.057)	-0.458***	(0.057)	-0.51***	(0.066)	-0.51***	(0.066)
sy_1998_ia	-0.442***	(0.078)	-0.441***	(0.078)	-0.633***	(0.099)	-0.634***	(0.099)
sy_1998_il	-0.156***	(0.031)	-0.156***	(0.031)	-0.175***	(0.048)	-0.175***	(0.048)
sy_1998_mn	-0.391***	(0.054)	-0.391***	(0.054)	-0.484***	(0.059)	-0.484***	(0.059)
sy_1998_nj	-0.723***	(0.020)	-0.723***	(0.021)	-0.633***	(0.037)	-0.633***	(0.037)
sy_1998_oh	-0.217***	(0.040)	-0.217***	(0.040)	-0.302***	(0.047)	-0.302***	(0.047)
sy_1998_ok	-0.394***	(0.048)	-0.395***	(0.048)	-0.816***	(0.059)	-0.818***	(0.059)
sy_1998_pa	-0.481***	(0.059)	-0.480***	(0.059)	-0.554***	(0.068)	-0.552***	(0.067)
sy_1998_wa	-0.433***	(0.115)	-0.433***	(0.115)	-0.356**	(0.161)	-0.356**	(0.161)
sy_1999_ia	-0.347***	(0.085)	-0.345***	(0.086)	-0.568***	(0.117)	-0.565***	(0.117)
sy_1999_il	-0.155***	(0.031)	-0.156***	(0.031)	-0.215***	(0.046)	-0.214***	(0.046)
sy_1999_mn	-0.302***	(0.055)	-0.303***	(0.055)	-0.367***	(0.059)	-0.368***	(0.059)
sy_1999_nj	-0.679***	(0.020)	-0.679***	(0.020)	-0.583***	(0.036)	-0.583***	(0.036)
sy_1999_oh	-0.161***	(0.040)	-0.161***	(0.040)	-0.243***	(0.047)	-0.243***	(0.047)
sy_1999_ok	-0.347***	(0.044)	-0.348***	(0.044)	-0.743***	(0.050)	-0.743***	(0.050)
sy_1999_pa	-0.452***	(0.058)	-0.452***	(0.058)	-0.515***	(0.066)	-0.515***	(0.066)
sy_1999_wa	-0.432***	(0.114)	-0.432***	(0.114)	-0.454***	(0.166)	-0.453***	(0.165)

	OneMile OLS		HalfMile OLS		OneMile SEM		HalfMile SEM	
Variables	coef	se	coef	se	coef	se	coef	se
sy_2000_ia	-0.165	(0.145)	-0.164	(0.146)	-0.246	(0.183)	-0.246	(0.183)
sy_2000_il	-0.088***	(0.031)	-0.088***	(0.031)	-0.172***	(0.045)	-0.171***	(0.045)
sy_2000_mn	-0.148***	(0.051)	-0.149***	(0.051)	-0.224***	(0.053)	-0.224***	(0.053)
sy_2000_nj	-0.565***	(0.020)	-0.565***	(0.020)	-0.461***	(0.036)	-0.462***	(0.036)
sy_2000_oh	-0.098**	(0.041)	-0.098**	(0.041)	-0.161***	(0.047)	-0.16***	(0.047)
sy_2000_ok	-0.330***	(0.050)	-0.331***	(0.050)	-0.748***	(0.059)	-0.749***	(0.059)
sy_2000_pa	-0.394***	(0.057)	-0.395***	(0.057)	-0.478***	(0.067)	-0.478***	(0.067)
sy_2000_wa	-0.463***	(0.115)	-0.463***	(0.115)	-0.403**	(0.160)	-0.402**	(0.160)
sy_2001_ia	-0.334***	(0.065)	-0.332***	(0.065)	-0.435***	(0.066)	-0.433***	(0.066)
sy_2001_il	-0.080**	(0.031)	-0.080***	(0.031)	-0.101**	(0.048)	-0.101**	(0.048)
sy_2001_mn	-0.119**	(0.050)	-0.119**	(0.050)	-0.204***	(0.051)	-0.204***	(0.052)
sy_2001_nj	-0.438***	(0.018)	-0.438***	(0.018)	-0.333***	(0.034)	-0.333***	(0.034)
sy_2001_oh	-0.033	(0.036)	-0.033	(0.036)	-0.078**	(0.040)	-0.078**	(0.040)
sy_2001_ok	-0.250***	(0.041)	-0.251***	(0.041)	-0.648***	(0.044)	-0.648***	(0.044)
sy_2001_pa	-0.402***	(0.055)	-0.402***	(0.055)	-0.446***	(0.063)	-0.447***	(0.063)
sy_2001_wa	-0.378***	(0.122)	-0.378***	(0.122)	-0.275*	(0.163)	-0.275*	(0.163)
sy_2002_ia	-0.130**	(0.059)	-0.128**	(0.059)	-0.264***	(0.064)	-0.261***	(0.064)
sy_2002_il	0.008	(0.030)	0.007	(0.030)	-0.013	(0.043)	-0.013	(0.043)
sy_2002_mn	-0.072	(0.050)	-0.072	(0.050)	-0.138***	(0.051)	-0.139***	(0.051)
sy_2002_nj	-0.330***	(0.019)	-0.330***	(0.019)	-0.195***	(0.035)	-0.195***	(0.035)
sy_2002_ny	-0.307***	(0.020)	-0.307***	(0.020)	-0.342***	(0.020)	-0.342***	(0.020)
sy_2002_oh	-0.022	(0.038)	-0.022	(0.038)	-0.053	(0.042)	-0.053	(0.042)
sy_2002_ok	-0.249***	(0.045)	-0.249***	(0.045)	-0.649***	(0.052)	-0.649***	(0.052)
sy_2002_pa	-0.313***	(0.053)	-0.313***	(0.053)	-0.355***	(0.059)	-0.354***	(0.059)
sy_2002_wa	-0.241**	(0.123)	-0.241**	(0.123)	-0.216	(0.166)	-0.216	(0.166)
sy_2003_ia	-0.195**	(0.081)	-0.194**	(0.081)	-0.311***	(0.085)	-0.314***	(0.084)
sy_2003_il	0.034	(0.030)	0.034	(0.030)	0.021	(0.040)	0.021	(0.040)
sy_2003_mn	0.034	(0.049)	0.034	(0.049)	-0.026	(0.049)	-0.026	(0.049)
sy_2003_nj	-0.119***	(0.017)	-0.119***	(0.017)	0.023	(0.033)	0.023	(0.033)
sy_2003_ny	-0.247***	(0.020)	-0.247***	(0.020)	-0.276***	(0.020)	-0.276***	(0.020)
sy_2003_oh	0.005	(0.036)	0.005	(0.036)	-0.019	(0.039)	-0.019	(0.039)
sy_2003_ok	-0.229***	(0.046)	-0.229***	(0.046)	-0.632***	(0.053)	-0.632***	(0.053)
sy_2003_pa	-0.191***	(0.052)	-0.191***	(0.052)	-0.213***	(0.054)	-0.213***	(0.054)
sy_2003_wa	-0.326***	(0.114)	-0.326***	(0.114)	-0.335**	(0.159)	-0.337**	(0.159)
sy_2004_ia	-0.209***	(0.076)	-0.208***	(0.076)	-0.307***	(0.087)	-0.308***	(0.087)
sy_2004_il	0.087***	(0.029)	0.087***	(0.029)	0.105***	(0.034)	0.105***	(0.034)
sy_2004_mn	0.082*	(0.049)	0.081*	(0.049)	0.036	(0.049)	0.036	(0.049)
sy_2004_ny	-0.179***	(0.019)	-0.179***	(0.019)	-0.2***	(0.020)	-0.2***	(0.020)
sy_2004_oh	0.059	(0.037)	0.059	(0.037)	0.067*	(0.039)	0.067*	(0.039)
sy_2004_ok	-0.143***	(0.041)	-0.143***	(0.041)	-0.511***	(0.044)	-0.511***	(0.044)
sy_2004_pa	-0.146***	(0.052)	-0.146***	(0.052)	-0.145***	(0.053)	-0.145***	(0.053)
sy_2004_wa	-0.144	(0.113)	-0.144	(0.113)	-0.082	(0.152)	-0.081	(0.152)
sy_2005_ia	-0.074**	(0.037)	-0.075**	(0.037)	-0.151***	(0.040)	-0.151***	(0.040)
sy_2005_il	0.125***	(0.027)	0.125***	(0.027)	0.139***	(0.032)	0.138***	(0.032)
sy_2005_mn	0.163***	(0.048)	0.162***	(0.048)	0.12**	(0.048)	0.119**	(0.048)
sy_2005_nj	0.278***	(0.018)	0.278***	(0.018)	0.453***	(0.034)	0.453***	(0.034)
sy_2005_ny	-0.110***	(0.019)	-0.111***	(0.019)	-0.122***	(0.019)	-0.122***	(0.019)
sy_2005_oh	0.112***	(0.036)	0.112***	(0.036)	0.099***	(0.037)	0.098***	(0.037)
sy_2005_ok	-0.018	(0.038)	-0.018	(0.038)	-0.354***	(0.038)	-0.354***	(0.038)

	OneMile OLS		HalfMile OLS		OneMile SEM		HalfMile SEM	
Variables	**coef**	**se**	**coef**	**se**	**coef**	**se**	**coef**	**se**
sy_2005_pa	-0.060	(0.051)	-0.060	(0.051)	-0.058	(0.053)	-0.058	(0.053)
sy_2005_wa	-0.070	(0.111)	-0.070	(0.111)	0.025	(0.153)	0.025	(0.153)
sy_2006_ia	-0.050*	(0.028)	-0.051*	(0.028)	-0.106***	(0.028)	-0.106***	(0.028)
sy_2006_il	0.192***	(0.026)	0.192***	(0.026)	0.215***	(0.030)	0.215***	(0.030)
sy_2006_mn	0.206***	(0.049)	0.206***	(0.049)	0.164***	(0.049)	0.164***	(0.049)
sy_2006_nj	0.340***	(0.017)	0.340***	(0.017)	0.514***	(0.032)	0.514***	(0.032)
sy_2006_ny	-0.066***	(0.019)	-0.066***	(0.019)	-0.073***	(0.019)	-0.073***	(0.019)
sy_2006_oh	0.147***	(0.034)	0.147***	(0.034)	0.144***	(0.035)	0.144***	(0.035)
sy_2006_ok	0.025	(0.039)	0.026	(0.039)	-0.3***	(0.037)	-0.3***	(0.037)
sy_2006_pa	0.008	(0.051)	0.008	(0.051)	-0.001	(0.052)	-0.001	(0.052)
sy_2006_wa	-0.066	(0.131)	-0.066	(0.131)	0.02	(0.160)	0.021	(0.160)
sy_2007_ia	0.013	(0.028)	0.012	(0.028)	-0.019	(0.028)	-0.019	(0.028)
sy_2007_il	0.218***	(0.025)	0.218***	(0.025)	0.251***	(0.028)	0.251***	(0.028)
sy_2007_mn	0.177***	(0.049)	0.177***	(0.049)	0.145***	(0.048)	0.144***	(0.048)
sy_2007_nj	0.297***	(0.017)	0.297***	(0.017)	0.459***	(0.031)	0.459***	(0.031)
sy_2007_ny	-0.020	(0.019)	-0.020	(0.019)	-0.022	(0.019)	-0.022	(0.019)
sy_2007_oh	0.144***	(0.035)	0.143***	(0.035)	0.138***	(0.036)	0.138***	(0.036)
sy_2007_ok	0.149***	(0.037)	0.150***	(0.037)	-0.154***	(0.034)	-0.154***	(0.034)
sy_2007_pa	0.030	(0.051)	0.030	(0.051)	0.067	(0.052)	0.067	(0.052)
sy_2007_wa	0.189*	(0.110)	0.189*	(0.110)	0.209	(0.147)	0.209	(0.147)
sy_2008_ia	0.011	(0.029)	0.010	(0.029)	-0.029	(0.029)	-0.029	(0.029)
sy_2008_il	0.219***	(0.026)	0.218***	(0.026)	0.217***	(0.029)	0.217***	(0.029)
sy_2008_mn	0.149***	(0.050)	0.149***	(0.050)	0.108**	(0.049)	0.108**	(0.049)
sy_2008_nj	0.195***	(0.018)	0.195***	(0.018)	0.35***	(0.032)	0.35***	(0.032)
sy_2008_ny	-0.000	(0.019)	-0.000	(0.019)	-0.008	(0.019)	-0.008	(0.019)
sy_2008_oh	0.084**	(0.036)	0.084**	(0.036)	0.061*	(0.037)	0.061*	(0.037)
sy_2008_ok	0.154***	(0.039)	0.153***	(0.039)	-0.145***	(0.035)	-0.145***	(0.035)
sy_2008_pa	0.044	(0.053)	0.044	(0.053)	0.055	(0.053)	0.056	(0.053)
sy_2008_wa	0.178	(0.117)	0.179	(0.117)	0.326**	(0.148)	0.325**	(0.148)
sy_2009_ia	-0.056	(0.036)	-0.057	(0.036)	-0.102***	(0.036)	-0.102***	(0.036)
sy_2009_il	0.158***	(0.026)	0.158***	(0.026)	0.176***	(0.028)	0.176***	(0.028)
sy_2009_mn	0.104**	(0.051)	0.104**	(0.051)	0.089*	(0.050)	0.089*	(0.050)
sy_2009_nj	0.071***	(0.019)	0.071***	(0.019)	0.238***	(0.032)	0.238***	(0.032)
sy_2009_ny	-0.005	(0.019)	-0.005	(0.019)	-0.013	(0.019)	-0.013	(0.019)
sy_2009_oh	0.036	(0.035)	0.036	(0.035)	0.028	(0.036)	0.028	(0.036)
sy_2009_ok	0.219***	(0.038)	0.219***	(0.038)	-0.102***	(0.034)	-0.101***	(0.034)
sy_2009_pa	0.009	(0.053)	0.010	(0.053)	0.0003	(0.054)	0.0004	(0.054)
sy_2010_ia	0.018	(0.029)	0.017	(0.029)	-0.004	(0.028)	-0.004	(0.028)
sy_2010_il	0.105***	(0.028)	0.105***	(0.028)	0.104***	(0.029)	0.104***	(0.029)
sy_2010_mn	0.181***	(0.050)	0.180***	(0.050)	0.137***	(0.049)	0.137***	(0.049)
sy_2010_nj	0.010	(0.019)	0.010	(0.019)	0.177***	(0.032)	0.178***	(0.032)
sy_2010_ny	0.003	(0.021)	0.003	(0.021)	-0.006	(0.020)	-0.006	(0.020)
sy_2010_oh	-0.017	(0.036)	-0.017	(0.036)	-0.024	(0.036)	-0.024	(0.036)
sy_2010_ok	0.231***	(0.038)	0.231***	(0.038)	-0.074**	(0.033)	-0.074**	(0.033)
sy_2010_pa	0.013	(0.057)	0.013	(0.057)	0.013	(0.057)	0.013	(0.057)
sy_2010_wa	0.207	(0.127)	0.207	(0.127)	0.305*	(0.165)	0.305*	(0.165)
note: *** p<0.01, ** p<0.05, * p<0.1								
N	51,276		51,276		38,407		38,407	
Adjusted R^2	0.66		0.66		0.64		0.64	

BEFORE THE PUBLIC UTILITIES COMMISSION
OF THE STATE OF SOUTH DAKOTA

IN THE MATTER OF THE APPLICATION OF
CROWNED RIDGE, LLC FOR A FACILITIES PERMIT TO
CONSTRUCTION 300 MEGAWATT WIND FACILITY

Docket No. EL19-003

REBUTTAL TESTIMONY AND EXHIBITS
OF DR. ROBERT MCCUNNEY

May 24, 2019

INTRODUCTION

Q. PLEASE STATE YOUR NAME AND BUSINESS ADDRESS.

A. My name is Dr. Robert McCunney. My business address is PO Box 29077, Charlestown MA 02129.

Q. **BY WHOM ARE YOU EMPLOYED AND IN WHAT CAPACITY?**

A. Brigham and Women's Hospital, Boston, MA; Staff physician in Pulmonary, Center for Chest Diseases; Role: I perform clinical evaluations and recommend treatment of occupational and environmental illnesses and serve in an educational capacity as part of Harvard Medical School faculty position. My curriculum vitae is attached as Exhibit RM-R-1.

Q. **WHAT ARE YOUR RESPONSIBILITIES?**

A. I was hired by Crowned Ridge Wind, LLC ("CRW") to submit rebuttal testimony and testify in this proceeding on the health and welfare issues and concerns raised in the testimony of Staff and proposed conditions of the Intervenors.

Q. **PLEASE DESCRIBE YOUR BACKGROUND AND QUALIFICATIONS.**

A. In summary, I am a licensed practicing physician. I completed training as a specialist in internal medicine and am also board certified in occupational and environmental medicine. My background in noise and health includes post graduate residency training in occupational medicine at Harvard, as an author of peer reviewed publications, such as three book chapters on occupational noise exposure; clinical experience in reviewing audiometric tests of workers exposed to noise and experience related to occupational hearing conservation programs. With respect to wind turbines and health, I am the lead author of a critical review of the scientific literature on wind turbines and health sponsored by the Massachusetts Institute of Technology and published in the Journal of Occupational and Environmental Medicine in 2014; a co-author of a document entitled "Wind Turbines and Health"; (Colby et al, 2009) and lead author of a mathematical analysis of a proposed case definition related to health and living proximity to wind turbines. (Full citations are set forth in Exhibit RM-R-1). In addition, I have lectured to scientific, professional and lay audiences in numerous settings in the USA and Canada on wind turbines and health. I have also been admitted as an expert to testify in wind turbine hearings in numerous jurisdictions in the USA and Canada.

Q. HAS THIS TESTIMONY BEEN PREPARED BY YOU OR UNDER YOUR DIRECT SUPERVISION?

A. Yes.

Q. HAVE YOU PREVIOUSLY TESTIFIED BEFORE THE SOUTH DAKOTA PUBLIC UTILITIES COMMISSION?

A. No.

Q. PLEASE DESCRIBE THE PURPOSE OF YOUR REBUTTAL TESTIMONY.

A. The purpose of my testimony is to respond to Intervenors' proposed conditions as set forth in Staff witness Darren Kearney's Direct Testimony, Exhibit DK-8.

Sound Study

Intervenors' Proposed Conditions

Q. THE INTERVENORS' PROPOSED CONDITION 1 (KEARNEY EXHIBIT DK-8) WOULD REQUIRE THE FOLLOWING : THAT THERE BE A 2 MILE SETBACK FROM ALL NON-PARTICIPATING LANDOWNERS, BASED ON THE ASSUMPTION THAT THEY SHOULD NOT BE EXPOSED TO THE EFFECTS OF THE PROJECT. IS SUCH A CONDITION NEEDED TO ADDRESS A HEALTH OR WELFARE CONCERN FOR NON-PARTICIPANTS?

A. A two mile setback is not necessary for non-participating landowners. Moreover, the most appropriate scientific measure of potential health impacts from a noise generating source, including wind turbines, is to model or measure the noise levels outside of the home. One can then assess these noise levels in the context of scientific studies and regulations. I am unaware of any scientific peer reviewed study in the world's literature that indicates the necessity of a two mile setback. In fact, to the contrary, results of the largest epidemiology study that evaluated health issues associated with living in proximity to wind turbines noted no adverse health effects, including sleep and stress, among others, at noise levels up to 46 dB. (Michaud et al, 2016 -- Exhibit CO-11). As far as I am aware, no scientific studies indicate that wind turbine operations can generate sound to 46 dB or higher two miles from the source.

Q. THE INTERVENORS' PROPOSED CONDITION 2 (KEARNEY EXHIBIT DK-8) WOULD REQUIRE THAT THERE BE A 2 MILE SETBACK FROM THE WAVERLY SCHOOL TO PROTECT CHILDREN FROM DISTURBANCES

FROM THE PROJECT WHILE IN THEIR LEARNING ENVIRONMENT. IS SUCH A CONDITION NEEDED TO ADDRESS A HEALTH OR WELFARE CONCERN FOR THE STUDENTS AT WAVERLY?

A. No, it is not. As part of my work on this rebuttal, I reviewed the distances and noise levels from the nearest turbines to the school. The modeled sound level at Waverly School was 39 dBA and the closest turbine is 6,207 feet away. In light of these noise levels and the absence of any scientific support that such noise levels would interfere with the children's learning and behavior as well as health, this setback is safe for the school children.

Q. THE INTERVENORS' PROPOSE A NUMBER OF CONDITIONS (KEARNEY EXHIBIT DK-8) RELATED TO MEASUREMENT AND MONITORING OF INFRASOUND. ARE THESE CONDITIONS NEEDED TO ADDRESS A HEALTH OR WELFARE CONCERN?

A. Such conditions are not necessary. It is not necessary to differentiate low frequency sound or infrasound from broad noise level measurements conducted in the A scale. (See, Berger et al, 2015, which is Exhibit CO-6). Further, recent reviews conclude that there is no scientific evidence to support the hypothesis that wind turbine infrasound and low-frequency sound have unique adverse health effects that other sources of noise do not have. (McCunney et al, 2014 – Exhibit CO-8)

In summary, although wind turbines can generate infrasound and low-frequency sound, detectable levels of infrasound and low-frequency sound at residences are not at harmful levels based on studies near wind farms in the United States, the United Kingdom, the Netherlands, Denmark, and Australia. No studies demonstrate harmful effects to humans as a result of exposure to infrasound or low-frequency sound at the noise levels measured in the vicinity of wind turbines or in experimental studies involving noise levels several orders of magnitude higher than those noted in the vicinity of wind turbines.

Q. THE INTERVENORS' PROPOSED CONDITIONS 19, 20, AND 21 (KEARNEY EXHIBIT DK-8) WOULD LIMIT SOUND AT 40 DBA AT THE PROPERTY LINE OF A NON-PARTICIPATING PROPERTY OWNER. IS SUCH A CONDITION NEEDED TO ADDRESS A HEALTH OR WELFARE CONCERN?

A 40 dBA limit outside of a non-participant's home is not necessary to prevent adverse health effects from noise. The Health Canada study, the largest epidemiology study in the world, found no adverse health effects, including sleep, stress, and blood pressure, among others, at noise levels up to 46dB. (Michaud et al, 2016 – Exhibit CO-3).

Q. A NUMBER OF THE INTERVENORS' CONDITIONS (KEARNEY EXHIBIT DK-8) ARE PREMISED ON PEOPLE COMPLAINING ABOUT PHYSICAL CONDITIONS OR HEALTH ISSUES THEY BELIEVE ARE BROUGHT ON BY THE CRW WIND PROJECT. DO YOU HAVE AN OPINION ON WHETHER CONDITIONS SHOULD BE IMPOSED BECAUSE PEOPLE MAY ATTRIBUTE A PHYSICAL OR HEALTH ISSUE TO THE CRW WIND PROJECT?

A. I disagree that such a condition would be appropriate. There is no direct link between wind projects and adverse impact on health. To understand why, it is important to distinguish the process involved in diagnosing symptoms in contrast to determining the cause of symptoms. Below, I outline a well-accepted method to evaluate whether symptoms may be due to exposure to an occupational or environmental hazard and use sleep disturbances as an example.

In determining the cause of a disease or symptoms, the essential first step in the process is forming a diagnosis. It is necessary to establish a diagnosis based on accepted medical criteria. For example, the National Heart Lung and Blood Institute of the USA have proposed objective criteria for the diagnosis of asthma since the disorder is widely recognized to be "over diagnosed". (NHLBI, 2007 – Exhibit RM-R-2). In population surveys, the prevalence of self-reported asthma may be as high as 10%, whereas asthma diagnosed according to widely accepted criteria is about 5%. The point of this example is that any causality assessment needs to begin with an accurate diagnosis of the symptoms, based on well-accepted criteria. Once a diagnosis is made, one can then assess its potential cause. It is critical in this process, however, to conduct a routine procedure performed by physicians known as a differential diagnosis. In short, most symptoms have numerous causes. Headaches, for example, can occur due to a major illness like a brain tumour, as well as stress, and alcohol abuse, among others. A differential diagnosis is the process by which a physician considers these various explanations as the cause of a patient's symptoms through a medical history and appropriate diagnostic studies.

In my experience, patients' own self-assessments of causes of symptoms, although potentially helpful in the evaluation, can often be incorrect. For instance, if sleep disturbance is misattributed to wind turbines, serious treatable illnesses could be overlooked. In fact, recall bias, a well-recognized factor in epidemiological studies, can distort the accuracy of a person's recall. This phenomenon of recall bias has been confirmed in studies of breast cancer, Parkinson's disease and coronary artery disease (Rugbjerg et al, 2011 Zota et al, 2010 and Metcalfe et al, 2008, attached as Exhibit RM-R-3). In fact, Zota et al noted that their "results highlight the difficulty of distinguishing in retrospective self-report studies between valid associations and the influence of recall bias." Further, Metcalfe et al concluded, "Recall is likely to be influenced by present outcome" (Metcalfe et al, 2008). The point of this commentary is to demonstrate the limited utility of recall when evaluating self-reported symptoms. These comments are not intended to discredit or ignore a person's own assessment of causality but in contrast, to place in perspective the shortcomings and uncertainty in relying on recall to document events and timing thereof in the past.

What follows is a summary of the steps involved in forming a causality assessment. A critical component in assessing potential environmental illness is an evaluation of the exposure, which in this case is noise and its components, such as low frequency sound and infra sound, associated with wind turbine operations. A causality assessment where noise exposure may be a factor should also consist of a thorough review of noise measurements conducted in the vicinity of the individual's home along with a comparison of the symptoms, diagnosis and noise levels in light of what has been published in the peer reviewed scientific literature.

In addition, it is equally important to understand that in contrast to a placebo response in which favorable expectations can influence favorable outcomes in clinical practice and pharmaceutical research, a nocebo response refers to new or worsening symptoms produced by negative expectations that being treated with, or exposed to, an external stimuli will cause adverse health effects (Colloca et al, 2012; Hauser et al. 2012; Webster et al, 2016; Dodd et al; 2017 and Chavaria et al, 2017, attached as Exhibit RM-R-4)). A nocebo response is a well-recognized phenomenon in medical practice and can affect the integrity of pharmaceutical research and patient compliance with treatment, among others. For example, in clinical trials, expectations can influence the reporting of symptoms, such as side effects of a medication or a medical procedure involving informed consent (Ruan et al, 2016 – Exhibit RM-R-5), and adherence to treatment, (Tobert et al, 2016 – Exhibit RM-R-6) among others. This matter can have serious clinical and therapeutic impacts if symptoms that are misattributed to the medication lead to poor therapeutic responses, as a result of poor compliance-not taking the medications.

Thus, in trying to understand why some people are more apt to report annoyance in the context of wind turbines, it is important to consider how nocebo effects may contribute to self-reported symptoms. In a nocebo reaction, people expect untoward reactions and develop symptoms in ***anticipation*** of an event, in this case, wind turbine operations. (Dodd et al, 2017 – Exhibit RM-R-4). Indeed, a study analyzed Canadian newspaper coverage of wind turbines and found that media coverage might contribute to nocebo responses. (Deignan et al, 2013 – Exhibit RM-R-7)

Chapman, (et al, 2013 – Exhibit RM-R-8) also explored patterns of formal complaints (health and noise) made in relation to 51 wind farms in Australia from 1993 to 2012.

Very few complaints were formally lodged; only 129 individuals in Australia formally or publicly complained during the time period studied; the majority of wind farms had no complaint made against them. Complaints increased around 2009 when "wind turbine syndrome" was introduced. The authors concluded that nocebo effects likely play an important role in wind farm health complaints. People living near large wind farms filed the most complainants (16 out of 18; r=0.32) Furthermore, the strongest predictor of a formal complaint was the presence of an opposition group in the area of the wind farm. Opposition groups were present in 15 of the 18 sites that filled complaints while only 1 opposition group was present in the 33 areas that did not file a complaint (r=0.82). Accordingly, these studies show that while there may be a perceived health impact from wind farms, the health complaints do not correlate to actual adverse health impacts.

Q. **A NUMBER OF THE INTERVENORS' CONDITIONS (KEARNEY EXHIBIT DK-8) ARE PREMISED ON PEOPLE BEING ANNOYED BY THE WIND PROJECT. DO YOU HAVE AN OPINION ON WHETHER CONDITIONS SHOULD BE IMPOSED BECAUSE PEOPLE COULD BE ANNOYED BY THE CRW WIND PROJECT?**

A. My opinion is that such conditions are inappropriate. Annoyance is one of the most common assessments made in environmental noise studies, including those related to wind turbines. However, many factors can contribute to a person reporting "annoyance" in the context of living near wind turbines, including attitudes towards the turbines, visual aspects of the turbines, and whether a person derives economic benefit and noise from the turbines. (Pedersen et al, 2010 – Exhibit RB-R-9)

Annoyance is an outcome measure that has been used in environmental noise studies, primarily self-completed questionnaires. Noise levels, however, account for only a modest portion of self-reported annoyance in the context of wind turbines. (Knopper & Ollson, 2011 (Exhibit CO-2), McCunney et al, 2014 (Exhibit CO-8) and Michaud et al, 2016 Exhibit CO-11). Further, in the Health Canada study (Exhibit CO-3), annoyance was related to several reported measures of health and well-being, although these associations were statistically weak ($R^2 < 0.09\%$), independent of wind turbine noise ("WTN") levels, and not retained as a significant predictive variable in multiple regression models. A correlation coefficient (R^2) of 0.09 is extremely weak and indicates that the wind turbine noise category alone was a weak predictor of whether or not an individual was highly annoyed by WTN or not. The Health Canada study confirmed earlier research in which noise from wind turbines was noted to play a minor-if any- role in people reporting annoyance, in contrast to more significant factors, such as attitudes towards wind turbines, the impact of visual factors on the landscape and finally whether a person derives economic benefit from the turbines, a group that is completely absent of reported annoyance, despite residing in areas with the highest WTN levels. Therefore, sound pressure levels appear to play a limited-role in the experience of annoyance associated with wind turbines, a conclusion similar to that reached by Knopper & Ollson (2011) – Exhibit CO-2.

Further, self-reported annoyance is not coded as a specific diagnosis in the International Classification of Diseases. (ICD, 10th edition) The ICD is used worldwide for diagnostic, insurance and research purposes. Accordingly, I do not view that annoyance is sufficiently supported as a reason to adopt the Intervenors conditions or require a reduction in the sound and shadow/flicker thresholds proposed by CRW – 30 hours of shadow/flicker a year and 50 dBA at a participant's residence, and 45 dBA at a non-participant's residence.

Q. GIVEN THE INTERVENORS CONDITIONS THAT ARE CRITICAL OF THE PROPOSED CRW SETBACKS FOR TURBINES FOR THE CRW PROJECT, ARE THE PROPOSED TURBINE PLACEMENT AND SETBACKS PROPOSED BY CRW SUFFICIENT TO NOT SUBSTANTIALLY IMPAIR THE HEALTH OR WELFARE OF NON-PARTICIPANTS?

A. Yes. The proposed turbine placement and setbacks proposed by CRW will not substantially impair the health or welfare of non-participants. I based the conclusion on a variety of factors, including the sound and shadow/flicker results developed by CRW witness Jay Haley; my professional experience as a physician addressing health risks from noise; and the scientific peer reviewed literature.

Q. DOES THIS CONCLUDE YOUR REBUTTAL TESTIMONY?

A. Yes, it does.

Harvard Medical School Curriculum Vitae

Date Prepared: March 22, 2019

Name: Robert J. McCunney, M.D., M.P.H., M.S.

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Work Phone: 617-732-6770; 617-251-5152

Work Email: mccunney@mit.edu; rmccunney@bwh.harvard.edu

Place of Birth: Philadelphia, PA

Education

1971	BS	Chemical Engineering	Drexel University, Philadelphia, PA
1972	MS	Environmental Health	University of Minnesota, Minneapolis, MN
1976	MD	Medicine	Thomas Jefferson University Medical School, Philadelphia, PA
1981	MPH	Occupational Medicine	Harvard School of Public Health, Boston, MA

Postdoctoral Training

7/76 – 6/77	Intern	Internal Medicine	Northwestern University Medical Center, Chicago, IL
7/77 – 6/78	Resident	Internal Medicine	Northwestern University Medical Center
1/79- 6/79	Resident	Internal Medicine	Faulkner Hospital, Boston
1/80 – 6/81	Fellow	Occupational Medicine	Peter Bent Brigham Hospital, Boston, MA

Faculty Academic Appointments

1981 – 1983	Instructor	Medicine	Brown University School of Medicine, Providence, RI
1983 – 1993	Adjunct Assistant Professor	Public Health	Boston University School of Medicine, Boston, MA
1989 – 1995	Clinical Assistant Professor	Preventive Medicine	Medical College of Wisconsin, Milwaukee, WI
1996 – present	Lecturer	Medicine	Harvard Medical School, Boston, MA

Appointments at Hospitals/Affiliated Institutions

1983 – 1994	Director	Medicine Occupational Health	Boston University School of Medicine

1996 – 2010	Physician	Medicine Pulmonary Unit	Massachusetts General Hospital
2012- present	Physician	Medicine Pulmonary Division	Brigham and Women's Hospital, Boston
2001 – present	Research Scientist	Biological Engineering	Massachusetts Institute of Technology
2014-2016	Consulting Staff	Dana Farber Cancer Institute	Dana Farber Cancer Institute

Major Administrative Leadership Positions

Local

1981 – 1983	Medical Director, Occupational Health	Sturdy Memorial Hospital, Attleboro, MA
1983 – 1989	Medical Director, Occupational Health	Goddard Memorial Hospital, Stoughton, MA
1989 – 1994	Medical Director, Occupational Health Residency Program	Boston University Medical Center, Boston, MA
1994 – 2000	Director, Environmental Medicine	Massachusetts Institute of Technology

Regional

1982 – 1986	Board Member	New College of Occupational and Environmental Medicine, Boston, MA
1983 – 1985	President	New College of Occupational and Environmental Medicine

Committee Service

Local

2005- present	Member of Residency Advisory Committee for the occupational and environmental medicine training program	Harvard School of Public Health
1994 – 2000	Radiation Protection Committee	Massachusetts Institute of Technology
1994 – 2000	Pharmacy and Therapeutics Committee	Massachusetts Institute of Technology

Professional Societies: Past President of the American College of Occupational and Environmental Medicine. (1999-2000)

1981 -	American College of Occupational and Environmental Medicine	Member
	1983 – 1989	Member, House of Delegates
	1984 – 1986	President, New England Chapter
	1986 – 1994	Member, Publications Committee
	1985 – 1988	Chair, Publications Committee
	1988 – 1993	Member, Residency Director Section
	1989	Chair, Scientific Sessions of Annual Meeting

	1989 – 1993	Member, Government Affairs
	1994	Member, Ethical Practice Committee
	1993 – 1995	Co-Chair, Occupational Medicine Self-Assessment Program
	1996 – 1999	President Elect, 1st VP, 2nd VP
	1999 – 2000	**President**
1981 -	New England College of Occupational and Environmental Medicine	Member
1986 -	Medichem	Member
	1989 – 1993	Secretary
	1995	Chair, Annual Congress
	1999	Honorary Life Membership
1981 – 1991	American Public Health Association	Member
1983 -	American College of Preventive Medicine	Member
	1983 -	Fellow
1983 – 2000	American Medical Association	Member
2008 -	American Thoracic Society	Member
2010 -	American College of Chest Physicians	Member

Grant Review Activities

1996 - 1997	Medical Research Committee	US Department of Energy Member

Editorial Activities (Ad hoc peer reviewer for the journals noted below)

Journal of Occupational and Environmental Medicine
Environmental Research
Journal of the Acoustical Society of America
Epidemiology
Chest
American Journal of Industrial Medicine
International Archives of Occupational and Environmental Medicine
Inhalation Toxicology

Other Editorial Roles

1995	Co-Editor	International Archives of Occupational and Environmental Medicine (special issue: 1996; 6: 349-530)
1996	Co-Editor	Inhalation Toxicology (special issue: 1996; 8 (suppl): 29-39)
2000	Guest Editor	Journal of Occupational and Environmental Medicine (special issue: 2001; 43: 1-55)
2006	Guest Editor	Journal of Occupational and Environmental Medicine (special issue: 2006; 48: 1217-1338)

Honors and Prizes

1971	Phi Beta Epsilon	National Honor Society

1972	Tau Beta Pi	National Engineering Honor Society
1995	Presidential Award	American College of Occupational and Environmental Medicine (ACOEM)
1996	Drexel 100	Drexel University
2000	National Leadership	Central States Occupational Medical Association
2001	Harriet Hardy Leadership Award	New England College of Occupational and Environmental Medicine
2004	Health Achievement Award	ACOEM
2006	Presidential Award	ACOEM

Report of Funded and Unfunded Projects

Funding Information

Past

2000 – 2009 Cabot Corporation foundation for unrestricted work in occupational and environmental medicine
PI
The goal of this gift was to publish and teach in occupational medicine.

Current

International Carbon Black Association
- Mortality study of USA carbon black workers
- Particle exposure and risk of heart disease: an international meta analysis of German, British and American cohorts

American Wind Energy Association
- Health effects of wind turbine operations: a critical review of literature

US Power Gen
- Cluster evaluation of apparent cancer elevation among employees: a preliminary assessment
- Parkinson's Disease and Environmental Risk Factors

Current Unfunded Projects

2007 - Occupational causes of kidney cancer
PI
The purpose of this project is to evaluate occupational causes of kidney cancer secondary to recognition of a "cluster" of kidney cancer at a manufacturing plant

2007 - Health implications of occupational and environmental mold exposure.
The purpose of this project is to develop a Continuing Medical Education (CME) course for physicians with other MGH colleagues.

Report of Local Teaching and Training

Teaching of Students in Courses

2000 -	Occupational Noise Exposure Graduate students	Harvard School of Public Health 1 hr/yr

2007 -	Public Health and Epidemiology Graduate students	Massachusetts Institute of Technology 4 hr/wk x 6 wks

Clinical Supervisory and Training Responsibilities

1994 – 1999	Preceptor, Occupational Medicine, Boston University Medical Center	6-8 hr/wk x 6 wks
1994 – 1999	Preceptor, Occupational Medicine, Harvard School of Public Health	6-8 hr/wk x 6 wks
2000 - 2010	Preceptor, Allergy and Immunology, Massachusetts General Hospital	

Formally Supervised Trainees

1991 – 1993	Cheryl Barbanel, M.D., M.P.H., M.B.A., Prof Occupational Medicine, University of Connecticut; Chair, Residency section, ACOEM I served as residency director. Trainee published a paper on chest film opacities in workers and noise exposure.
1992 – 1994	Joseph Chern, M.D., M.P.H., Director of Occupational Neurology at University of Taipei, Taiwan I served as residency director. Trainee published a book chapter on health effects of solvents.
1990 – 1992	Alain Couturier, M.D., M.P.H., Editor: "Occupational Infectious Disease" *deceased* I served as residency director. Trainee published a paper on medical surveillance.
1988 – 1990	Ross Myerson, M.D., M.P.H., Chair ACOEM Annual Meeting Consultant, 2004 I served as residency director. Trainee published a book chapter on Health effects of cleaning agents and sterilants
1988 – 1990	John Doyle, M.D., M.P.H., Director, Occupational Health, Taunton Hospital I served as residency director. Trainee published a paper on occupational illness in the arts.
1989 – 1991	Robert Godefroi, M.D., M.P.H., Director, Occupational Health Center, Manchester, NH I served as residency director. Trainee published a paper on drug screening practices in industry
1991 – 1993	Khalid Kabrum, M.D., M.P.H., Medical Director, Aluminum Company of Bahrain I served as residency director. Trainee published a book chapter on Health effects of cleaning agents and sterilants

Formal Teaching of Peers (e.g., CME and other continuing education courses)

1987	Managing Occupational Risks in the High Technology Industries Annual Meeting of American Occupational Medical Association	½ day postgraduate seminar Philadelphia, PA
1987	Introduction to Occupational Medicine Annual Meeting of American Occupational Medical Association	½ day postgraduate seminar Philadelphia, PA
1987	Indoor Air Quality and Health Annual Meeting of American Occupational Medical Association	½ day postgraduate seminar Philadelphia, PA
1988	Establishing Health Services for Small Businesses Annual Meeting of American Occupational Medical Association	4 hr postgraduate seminar New Orleans, LA

1988	Occupational Medicine: An Introduction American College of Occupational Medicine	1 presentation San Antonio, TX
1990	Introduction to Occupational Medicine American College of Occupational Medicine	4 hr seminar Pittsburgh, PA
1991	Introduction to Occupational Medicine American College of Occupational Medicine	1 presentation San Francisco, CA
1991	Ethical Issues in Occupational Medicine American College of Occupational Medicine	seminar San Francisco, CA
1991	Publishing in Occupational Medicine American College of Occupational Medicine	1 presentation San Francisco, CA
1994	Introduction to Occupational Medicine American College of Occupational Medicine	Seminar Dallas, TX

Local Invited Presentations

Sponsored Lectures are marked *

1984 Setting Policy for Reproductive Hazards/Invited Talk
Harvard School of Public Health, Boston, MA

1985 Medical Surveillance: Screening for Occupational Illness/ Invited Talk
Harvard School of Public Health and the New England Occupational Medical Association, Boston, MA

1986 Cholesterol and Heart Disease: A Role for Fitness Programs?/Invited Talk
Harvard School of Public Health, Boston, MA

1987 Indoor Pollution. A Look at an Active Problem/Invited Talk
Harvard School of Public Health, Boston, MA

1989 The American Government and Occupational Medicine: New Developments/Invited Talk
New England College of Occupational Medicine, Harvard School of Public Health, Boston, MA

1994 Setting Policy for Reproductive Hazards/Invited Talk
New England Occupational Medical Association and the Harvard School of Public Health, Boston, MA

1998 Occupational Health at a Major Research Institution/Grand Rounds
Harvard School of Public Health, Boston, MA

2001 Noise and Hearing Loss/Grand Rounds
Harvard School of Public Health, Boston, MA

2007 Screening for Lung Cancer/Grand Rounds
Harvard School of Public Health, Boston, MA

2007 Screening for Lung Cancer/Grand Rounds
Pulmonary Unit, Massachusetts General Hospital

2014 Wind Turbines and Health effects; New England College of Occ/Env Med regional meeting

2014 Pulmonary Grand Rounds at BWH: Lung cancer screening

2017 Update on Occupational Medicine: Invited presentation for BWH Pulmonary Medicine Update; Boston, MA

2018 Epidemiology studies of titanium dioxide workers; presented at annual meeting of TDMA; Boston, MA

2019 Pulmonary Grand Rounds at BWH: Pitfalls in interpreting PFTs in the Occupational Setting

2019 Pulmonary Grand Rounds at BWH Uranium Lung Presented to US Indian Health Service

Report of Regional, National and International Invited Teaching and Presentations

Invited Presentations and Courses

Sponsored Lectures are marked *

Regional

1981	A Clinical Approach to the Patient with Exposure to Asbestos/Invited Talk Medicine/Surgery Sturdy Memorial Hospital, Attleboro, MA
1982	The Health Hazards in the Jewelry Industry/Invited Talk 25th Annual Safety Institute of Rhode Island, University of Rhode Island, Providence, RI
1982	The Health Hazard Evaluation/Invited Talk Occupational Medicine, Brown University School of Medicine, Providence, RI
1982	Medical Concerns of the Jewelry Industry/Invited Talk Medicine/Surgery Sturdy Memorial Hospital, Attleboro, MA
1982	Stress and Its Ramifications/Invited Talk Medicine/Surgery Sturdy Memorial Hospital, Attleboro, MA
1982	The Role of an Occupational Health Service./Invited Talk Board of Trustees, Goddard Memorial Hospital, Brockton, MA
1983	A Clinical Approach to the Patient Exposed to Asbestos/Invited Talk Roger Williams Hospital, Brown University School of Medicine affiliate, Providence, RI
1983	Should Your Company Have an Employee Assistance Program?/Invited Talk Attleboro Chamber of Commerce Personnel Directors monthly meeting, Attleboro, MA
1983	Asbestosis: A Survey of the Health Effects/Medical Grand Rounds Department of Medicine, Pawtucket Memorial Hospital, Pawtucket, RI
1983	Occupational Medicine in the People's Republic of China/Invited Talk South Shore Community Hospital, Weymouth, MA
1983	Cost Containment Through Occupational Health/Invited Talk South Shore Community Hospital, Weymouth, MA
1984	Asbestos, Current Controversies/Invited Talk Massachusetts American Lung Association, Boston, MA
1984	Does Exercise Reduce the Risk of Heart Disease?/Invited Talk Goddard Memorial Hospital and Massasoit College, Brockton, MA
1984	Occupational Medicine Today/Invited Talk Boston University School of Public Health, Boston, MA
1984	Role of Occupational Medicine Today/Medical Grand Rounds Braintree Hospital, Braintree, MA
1985	Stress, How To Recognize and Control its Effects/Invited Talk S.E. Mass Chapter of American Society of Inventory Control Specialist, Stoughton, MA
1985	Indoor Air Pollution/Invited Talk Down East American Industrial Hygiene Association, Portland, ME
1986	Indoor Air Pollution: An Update/Invited Talk University of Massachusetts Medical Center, Worcester, MA
1986	Clinical Applications of Epidemiology/ 2 3hr Invited Talks Occupational Nursing Program, Boston, MA
1986	Drug Screening in Industry: An Overview/Invited Talk New England Occupational Medical Association, Boston, MA
1986	Staying Healthy in Retirement/Invited Talk

Billerica, MA
1986 Indoor Air Pollution: An Update/Invited Talk
University of Massachusetts Medical Center, Worcester, MA.
1986 Clinical Applications of Epidemiology/2 3 hr Invited Talks
Occupational Nursing Program, Simmons College, Boston, MA
1986 Drug Screening in Industry: An Overview/Invited Talk
New England Occupational Medical Association, Boston, MA
1986 AIDS: What are the Occupational Risks?/Invited Talk
Goddard Memorial Hospital, Stoughton, MA
1986 Silicosis: A Disease of the Past or Current Concern/Invited Talk
Goddard Memorial Hospital, Stoughton, MA
1987 Controlling the Health Risks of Asbestos/Invited Talk
Asbestos Information Center of Tufts University Medical Center, Boston, MA
1987 Health Care Hazardous Waste Sites/Invited Talk
Environmental Protection Agency, Boston, MA
1987 Recognition and Treatment of Occupational Skin disease/Invited Talk
Associated Industries of Massachusetts, Boston, MA
1987 Drug Screening. Scientific and Ethical Issues/Invited Talk
New England Chapter of the American Industrial Hygiene Association, Boston, MA
1988 Occupational Medicine: An Introduction/Invited Talk
American College of Occupational Medicine,
1989 When to Suspect the Building as a Cause of Your Patient's Symptoms/Grand Rounds
University Hospital, Boston, MA
1989 Preventing Back Injuries at Work/Invited Talk
Massachusetts Safety Council, Boston, MA
1990 Occupational Health in Cost Containment/Invited Talk
Health Care Financial Management Association, Boston, MA
1990 Emergency Triage Systems for Work Related Injuries/Invited Talk
American College of Rehabilitation Medicine, Boston, MA
1990 Occupational Health and Cost Containment/Invited Talk
Health Care Financial Management Association, Boston, MA
1990 Recognizing Hand Disorders Due to Vibrating Tools/Invited Talk
New England College of Occupational Medicine, Boston, MA
1991 Occupational Health Challenges in Primary Care/Grand Rounds
Carney Hospital, Boston, MA
1991 Occupational Cancer in the 1990s/Invited Talk
National Workers Compensation and Occupational Medicine Seminar, Hyannis, MA
1993 Indoor Air pollution: A Recurring Problem in Occupational Medicine Practice; the Case Report: Recognition of Occupational Disease/Invited Talk
Workers Compensation and Occupational Medicine, Hyannis, MA
1998 Genetics in the Courtroom/Invited Talk
Einstein Institute for Science, Health and the Courts, Orleans, MA
2000 Work Implications of Sedating Antihistamines/Invited to Testify
Boston City Council, Boston, MA
2001 Risk Assessment: Current Issues/Invited Talk
MIT, Cambridge, MA
2006 Future of Occupational and Environmental Medicine/Invited Talk
Cape Cod Conference SEAK, Hyannis, MA
2010 Health Implications of Wind Turbines/Invited Talk
Rutland Medical Center, Rutland, VT

National

1981	The Need for a National Commission in Boxing/Scientific Panel American Medical Association, Chicago, IL
1982	Health Hazards in the Garment Industry/Invited Talk International Ladies Garment Workers Union. New York, New York.
1983	A Hospital Develops an Occupational Health Service/Invited Talk American Occupational Medical Association, Washington, DC
1983	The Role of Fitness in Preventing Heart Disease/Invited Talk Amateur Athletic Union Annual Meeting, Washington, DC
1983	Diverse Manifestations of Trichloroethylene/Invited Invited Talk American Academy of Occupational Medicine Annual Meeting, New Orleans, LA
1985	The Effect of Fitness on High Density Lipoproteins and Heart Disease/Panel Moderator American Occupational Medical Association, Kansas City, MO.
1985	Indoor Air Quality: A Review With Recommended Protocol to Evaluate Complaints/Invited Invited Talk New York State Medical Society, New York, New York
1986	Staying Healthy in Retirement/Invited Talk Cabot Corp, Champagne, IL, Indianapolis, MO, Atlanta, GA, Ville Platte, LA, Amarillo and Midland, TX
1986	Environmental Medicine: Setting Policy at Hazardous Waste Sites/Invited Talk New York State Medical Society, New York, New York
1987	Managing Workers Compensation Costs Through Fitness Programs/Invited Talk Food Marketing Institute, New Orleans, LA
1988	Pulmonary Alveolar Proteinosis and Cement Dust: A Case Report/Invited Talk The 7th International conference on Pneumoconiosis, Pittsburgh, PA
1988	Occupational Medicine: An Introduction/Invited Talk American College of Occupational Medicine, San Antonio, TX
1989	Establishing Health Services for Small Businesses/Seminar Leader New York Academy of Sciences, Boston, MA
1989	Hand-Arm Vibration Syndrome: Means of Control/Invited Talk National Safety Council annual meeting, Chicago, IL
1989	Providing High Quality Occupational Medical Services/Invited Invited Talk Annual Symposium on Delivery of Occupational Health Services, Washington, DC
1990	Current Developments in Occupational Medicine/Invited Invited Talk Centers for Disease Control, Atlanta, GA
1990	Ethical Issues in Occupational Medicine/Invited Talk American College of Occupational Medicine, Houston, TX
1992	A Hospital Based Occupational Medicine Residency Program/Moderator and Presenter American College of Occupational and Environmental Medicine, Washington, DC
1992	The Academic Industry Interface in Occupational Medicine/Invited Talk American College of Occupational and Environmental Medicine State of the Art Conference, New York City, New York
1993	Advanced Occupational Medicine/Invited Talk American College of Preventive Medicine, Chicago, IL
1994	The Use of Biomarkers in Clinical Practice/Invited Talk US Department of Energy, Santa Fe, NM
1995	Health effects of ionizing radiation exposure/Invited Talk US Department of Energy, Tampa, FL
1995	Preserving Confidentiality in Occupational Medical Practice; The Physician's Role in Emergency Response; The Occupational Medical Self Assessment Program/3 Invited

	Talks American College of Occupational and Environmental Medicine Annual Meeting, Las Vegas, NV
1996	New Directions in Occupational Medical Practice/Invited Talk American College of Occupational and Environmental Medicine, San Antonio, TX
1996	The International Agency for Research on Cancer (IARC) decision on Evaluating the Carcinogenicity of Carbon Black/Invited Talk Annual Joint Labor/Management Health and Safety Conference on United Rubber and Steel Workers, Cleveland, Ohio.
1997	The New EPA Standard on Ambient Particulates and Ozone: Implications for the Occupational Physician American College of Occupational and Environmental Medicine (ACOEM), Nashville, TN
1998	Health and Productivity: A Role for Occupational Health? /Invited Talk 4th Annual Employers Summit, Chicago, IL
1998	The Legacy of the Cold War; Challenges to the Occupational Health Professional/Invited Talk Annual Department of Energy meeting in Occupational Medicine, Washington, DC
1998	The Flu, A new Medication and Occupational Health; A Look At The Links/Seminar Leader Naples, Florida (Glaxo Wellcome)
1998	The Future of Occupational and Environmental Medicine/Invited Talk Annual meeting of the Maryland, Virginia, and Pennsylvania components of the American College of Occupational and Environmental Medicine (ACOEM), Williamsburg, VA.
2000	Health and Productivity/Invited Talk Annual meeting of American Journal of Health Promotion on Health and Productivity, Colorado Springs, CO
2000	Occupational Health and Productivity/Invited Talk Central States Occupational Medical Association annual meeting, Chicago, IL
2000	On behalf of ACOEM, gave oral testimony to OSHA on the proposed ergonomics standard/Invited to Testify (April and May) Washington, DC
2000	Latex Allergy/Invited Talk Annual meeting of the Michigan College of Occupational Medicine, Ann Arbor, MI
2000	Clinical application of recent research in occupational medicine/Invited Talk State of the art meeting, American College of Occupational and Environmental Medicine, Nashville, TN
2001	Health and Productivity: A Role for Occupational Health/Invited Talk Annual meeting of the Health Enhancement Research Organization, (HERO),Washington, DC
2001	The Human Genome Project: Implications on Occupational Medical Practice/Invited Talk Annual meeting at the American College of Occupational and Environmental Medicine, San Francisco, CA
2001	Health and Productivity Research/Invited Talk Annual meeting of the Institute of Productivity Management, Orlando, FL
2003	Future of Occupational Medicine/Invited Talk MIT and the American College of Occupational and Environmental Medicine, San Juan, Puerto Rico
2006	Should we screen for occupational lung cancer with low dose CT?/Invited Talk Annual meeting of the American College of Occupational and Environmental Medicine,

	Atlanta Georgia
2009	Are there health effects of wind turbine operations?/Invited Talk Annual meeting of American Wind Energy Association Orlando, FL
2010 thru 2015	Harvard School of Public Health; Graduate students in Public Health; "Health effects of occupational and environmental noise exposure
2012 thru 2015	Evaluating Occupational Lung Disease Part 1; Harvard Medical School Pulmonary Fellows Conference
2013	Evaluating Occupational Lung Disease Part 2; Harvard Medical School Pulmonary Fellows Conference
2014	"Evaluating health effects from exposure to hazardous materials." and "How to critically interpret the scientific literature." State Supreme Court Justices' Conference, sponsored by a grant from the US Department of Justice. Chapel Hill, NC
2014	Grand Rounds: Pulmonary Division. "Radiation risks in lung cancer screening programs." Brigham and Women's Hospital, Boston
2015	Grand Rounds: Harvard School of Public Health. Hypersensitivity Pneumonitis, Boston Grand Rounds: Pulmonary Division; Brigham and Women's (BWH) Hospital, Boston.
2016	Hypersensitivity Pneumonitis Occupational Lung Disease: Lecture to Pulmonary Fellows of BWH
2017	Amorphous Silica; A review of a cross sectional study at German plants; Grand Rounds: Pulmonary Division; Brigham and Women's (BWH) Hospital, Boston. Lung Tumors in Lab Rats: Implications for humans. Grand Rounds: Pulmonary Division; Brigham and Women's (BWH) Hospital, Boston. ;
2018	Epidemiology studies of Titanium Dioxide workers. Annual meeting of titanium dioxide manufacturers. Boston, MA

International Presentations

1982	Sino-American study tour in occupational medicine to hospitals and factories/Invited Participant People's Republic of China (Peking, Shanghai, Hangzhou and Canton)
1985	Diverse Manifestations of Trichloroethylene/Invited Talk Kyoto University Hospital, Kyoto, Japan
1985	Fitness and Heart Disease/Seminar Leader Mahidol University Hospital, Bangkok, Thailand
1985	Indoor Air Pollution: A Summary of an Investigation in an Office Setting/Invited Talk Society of Occupational Setting, Society of Occupational Medicine, Hong Kong, United Kingdom
1986	Diverse Manifestations of Trichloroethylene/Invited Speaker Annual meeting of Medichem, Ludwigshafen, West Germany
1987	Annual Health/Safety Meeting of Cabot Corporation/Seminar Leader Toronto, Canada
1987	Annual Health/Safety Meeting of Cabot Corporation/Educational Leader Kenya, East Africa
1988	A Cross-cultural Epidemiology Study/Invited Talk 16th Annual Meeting of Medichem, Helsinki, Finland

1989	Occupational Health in the Chemical Industry/Invited Co-Chair International Commission on Occupational Health triennial meeting, Montreal, Canada
1994	Medical Response to Environmental Emergencies/Invited Talk Annual meeting of Medichem, Melbourne, Australia
1995	Health Effects of Carbon Black/Invited Talk Presented in German to the German Automobile Association, Frankfurt, Germany
1997	Biomarkers and the Human Genome: A look at the Clinical Issues/Invited Talk US Department of Energy International Meeting, Charleston, SC.
1997	Particles and Lung Disease: A Look at the Clinical Issues/Invited Talk Health and Safety Executive of the United Kingdom, University of Leicester, Leicester, England
1999	Occupational Health and Productivity/Invited Talk Annual Latin American Conference on Occupational Medicine, Dorado, Puerto Rico
1999	Occupational Health and Productivity/Invited Talk Annual meeting of Medichem, Vienna, Austria
2000	Chemical Sensitivity and Idiopathic Environmental Intolerance/Invited Talk Ottawa, Canada
2001	The Role of the Human Genome in Occupational Medical Practice/Invited Talk Pulmonary Division, University of Bochum, Bochum, Germany
2002	Review of Epidemiology Studies and the Exposure Limit for Carbon Black./Invited Talk Health and Safety Executive Meeting (UK), London, England
2008	Occupational Health Research in the Carbon Black Industry/Invited Talk Carbon Black World Conference, Guilin, China
2015	Health Effects of Carbon Black; Institute of Occupational Medicine; Edinburgh, Scotland
2015	Health Effects of living near wind turbines: An update; annual meeting of the Canadian Wind Energy Association (Toronto, Canada)
2016	Lung tumors in Lab Rats: Implications for Human Risk Assessment; Titanium Dioxide International Meeting; Paris France
2016	Setting Occupational Exposure Limits; German MAK Commission; Berlin, Germany
2017	Role of epidemiology in evaluating Health Risks; presentation to Risk Assessment Committee of European Chemical Agency; Helsinki, Finland

Report of Clinical Activities and Innovations

Current Licensure and Certification

1983	American Board of Preventive Medicine – Occupational and Environmental Medicine

Practice Activities

1996 – 2010	Ambulatory Practice	MGH	1-2 days per week
2010-current	Ambulatory Practice	Brigham and Women's Hospital, Boston	1-2 days per week

Clinical Innovations

Implemented three hospital-based occupational health programs at:

- Sturdy Memorial Hospital, Attleboro, MA
- Goddard Memorial Hospital, Stoughton, MA

- University Hospital of Boston University Medical Center, Boston, MA

Report of Scholarship

Publications

Peer reviewed publications in print or other media

Research Investigations

1. **McCunney RJ**. "Acute and Chronic Brain Injuries in Boxers; Causes and Prevention". Physician and Sports Medicine, 1984;12:52-64.
2. **McCunney RJ**. "A Hospital-Based Occupational Health Service". Journal of Occupational Medicine, 1984;26:375-80.
3. **McCunney RJ**. "Are Stress Management Programs Cost Effective?" Journal of Occupational Medicine, 1984;26:410.
4. **McCunney RJ**. "Confidentiality of Medical Records." Journal of Occupational Medicine. 1984;26:790-91.
5. **McCunney RJ**. "Are Exercise EKG's Needed Prior to a Fitness Program?" Occupational Health and Safety. 1984, 23-24.
6. **McCunney RJ**. "Corporate Medical Programs". (letter) Harvard Business Review, Nov/Dec, 1984; 16-18
7. **McCunney RJ**. "Video display Terminals: What are the Health Risks?" Boston Business Journal, December 24, 1984; 7-9
8. **McCunney RJ**. Acid Rain. (book review) Journal of the American Medical Association, 1985;253: 2291-92.
9. **McCunney RJ**. "The Role of Fitness in Preventing Health Disease". Cardiovascular Reviews and Reports 1985;6:776-78.
10. **McCunney RJ**. "Health Effects of Work at Wastewater Treatment Plants: A review of the literature with guidelines for medical surveillance". American Journal of Industrial Medicine 1986;9:271-79.
11. **McCunney RJ**. Indoor Air Quality. (book review) Journal of the American Medical Association 1986;255:1261-62**.**
12. **McCunney RJ**. "The Patient with Asbestos Exposure". Journal of Family Practice 1986;22:73-78.
13. **McCunney RJ**. "Distilling Questions on Drug Testing". Boston Business Journal, November 17, 1986.; 2-3
14. **McCunney RJ**. "Physical Activity and HDL Levels". Physician and Sports Medicine 1987;15:67-74.
15. **McCunney RJ**. "The Role of Building Construction and Ventilation in Indoor Air Pollution: A Review of a Recurring Problem". New York State Journal of Medicine 1987;87:203-09.
16. **McCunney RJ**. "Effective Drug Screening Programs Should Be Applied Judiciously". Occupational Health and Safety: News Digest, Feature Story, May 1987, 9-10.
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1. **McCunney RJ**, editor, A Practical Approach to Occupational and Environmental Medicine, Little Brown, Boston, 1994. *This 50-chapter book is based on revision of The Handbook of Occupational Medicine, with the addition of 25 new chapters. An official publication of the American College of Occupational and Environmental Medicine; peer reviewed by the Publications Committee. Royalties donated to the Bacon Research Fund.*
2. **McCunney RJ**, editor, A Practical Approach to Occupational and Environmental Medicine, third edition, Lippincott, Williams, Wilcox, Baltimore, 2003 *This 60-chapter text includes contributions from 90 authors. It has been peer reviewed by the American College of Occupational and Environmental Medicine (ACOEM). I have donated the royalties to the ACOEM*

Non-peer reviewed scientific or medical publications/materials in print or other media

Proceedings of Meetings or Other Non-Peer Reviewed Research Publications

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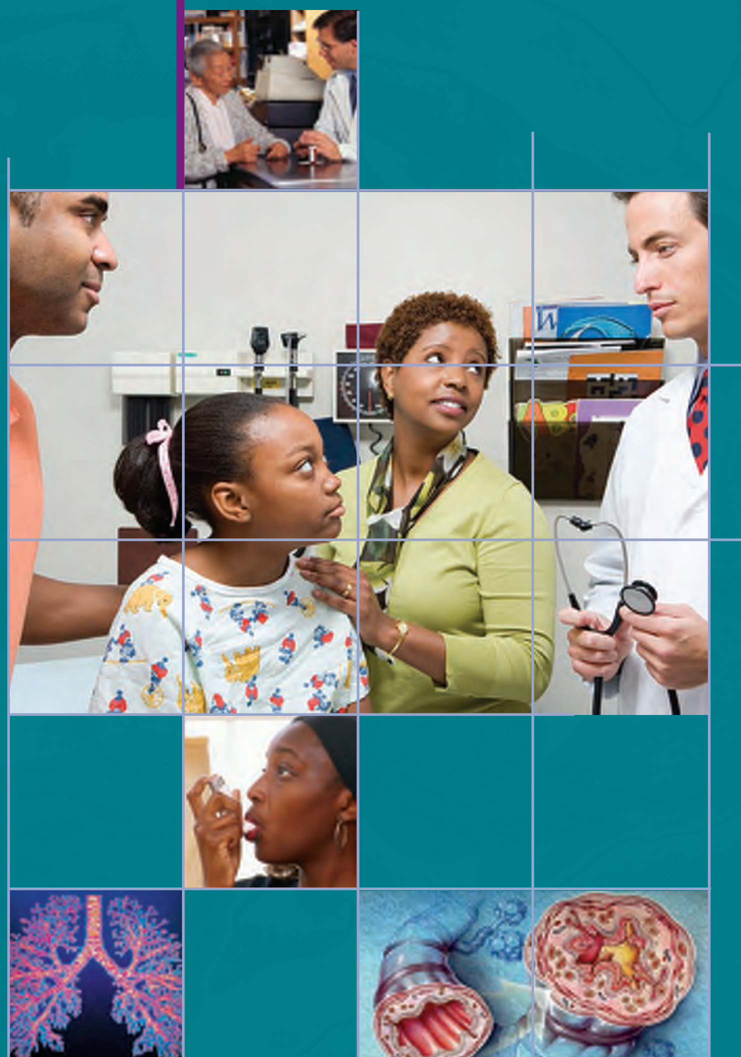
8. **McCunney RJ**, guest editor, Particles and Cancer, Special Issue of the *Journal of Occupational and Environmental Medicine,* December, 2006

SUMMARY REPORT 2007

Exhibit A40-2

National Asthma Education and Prevention Program
Expert Panel Report 3

Guidelines for the Diagnosis and Management of Asthma



U.S. Department of Health and Human Services
National Institutes of Health
National Heart, Lung, and Blood Institute

SUMMARY REPORT 2007

Exhibit A40-2

National Asthma Education and Prevention Program
Expert Panel Report 3

Guidelines for the Diagnosis and Management of Asthma

U.S. Department of Health and Human Services
National Institutes of Health

National Heart Lung and Blood Institute

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Contents

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Preface

The Expert Panel Report 3 (EPR—3) Summary Report 2007: Guidelines for the Diagnosis and Management of Asthma was developed by an expert panel commissioned by the National Asthma Education and Prevention Program (NAEPP) Coordinating Committee (CC), coordinated by the National Heart, Lung, and Blood Institute (NHLBI) of the National Institutes of Health.

Using the 1997 EPR—2 guidelines and the 2002 update on selected topics as the framework, the expert panel organized the literature review and updated recommendations for managing asthma long term and for managing exacerbations around four essential components of asthma care, namely: assessment and monitoring, patient education, control of factors contributing to asthma severity, and pharmacologic treatment. Subtopics were developed for each of these four broad categories.

The EPR—3 Full Report and the EPR—3 Summary Report 2007 have been developed under the excellent leadership of Dr. William Busse, Panel Chair. The NHLBI is grateful for the tremendous dedication of time and outstanding work of all the members of the expert panel, and for the advice from an expert consultant group in developing this report. Sincere appreciation is also extended to the NAEPP CC and the Guidelines Implementation Panel as well as other stakeholder groups (professional societies, voluntary health, government, consumer/patient advocacy organizations, and industry) for their invaluable comments during the public review period that helped to enhance the scientific credibility and practical utility of this document.

Ultimately, the broad change in clinical practice depends on the influence of local primary care physicians and other health professionals who not only provide state-of-the-art care to their patients, but also communicate to their peers the importance of doing the same. The NHLBI and its partners will forge new initiatives based on these guidelines to stimulate adoption of the recommendations at all levels, but particularly with primary care clinicians at the community level. We ask for the assistance of every reader in reaching our ultimate goal: improving asthma care and the quality of life for every asthma patient with asthma

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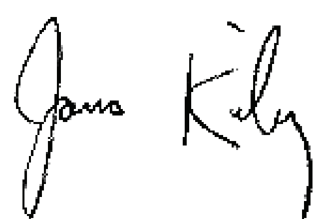

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Introduction

More than 22 million Americans have asthma, and it is one of the most common chronic diseases of childhood, affecting an estimated 6 million children. The burden of asthma affects the patients, their families, and society in terms of lost work and school, lessened quality of life, and avoidable emergency department (ED) visits, hospitalizations, and deaths. Improved scientific understanding of asthma has led to significant improvements in asthma care, and the National Asthma Education and Prevention Program (NAEPP) has been dedicated to translating these research findings into clinical practice through publication and dissemination of clinical practice guidelines. The first NAEPP guidelines were published in 1991, and updates were made in 1997, 2002, and now with the current report. Important gains have been made in reducing morbidity and mortality rates due to asthma; however, challenges remain. The NAEPP hopes that the “Expert Panel Report 3: Guidelines for the Diagnosis and Management of Asthma—Full Report 2007” (EPR—3: Full Report 2007) will support the efforts of those who already incorporate best practices and will help enlist even greater numbers of primary care clinicians, asthma specialists, health care systems and providers, and communities to join together in making quality asthma care available to all people who have asthma. The goal, simply stated, is to help people with asthma control their asthma so that they can be active all day and sleep well at night.

This EPR—3: Summary Report 2007 presents the key recommendations from the EPR—3: Full Report 2007 (See www.nhlbi.nih.gov/guidelines/asthma/asthgdln. htm). Detailed recommendations, the levels of scientific evidence upon which they are based, citations from the published scientific literature, discussion of the Expert Panel’s rationale for the recommendations, and description of methods used to develop the report are included in that resource document. Because EPR—3: Full Report 2007 is an update of previous NAEPP guidelines, highlights of major changes in the update are presented below, and figure 1 presents a summary of recommended key clinical activities.

HIGHLIGHTS OF MAJOR CHANGES IN EPR—3: FULL REPORT 2007

The following are highlights of major changes. Many recommendations were updated or expanded based on new evidence. See EPR—3: Full Report 2007 for key differences at the beginning of each section and for a full discussion.

New focus on monitoring asthma control as the goal for asthma therapy and distinguishing between classifying asthma severity and monitoring asthma control.

- Severity: the intrinsic intensity of the disease process. Assess asthma severity to initiate therapy.
- Control: the degree to which the manifestations of asthma are minimized by therapeutic interventions and the goals of therapy are met. Assess and monitor asthma control to adjust therapy.

New focus on impairment and risk as the two key domains of severity and control, and multiple measures for assessment. The domains represent different manifestations of asthma, they may not correlate with each other, and they may respond differentially to treatment.

- Impairment: frequency and intensity of symptoms and functional limitations the patient is experiencing currently or has recently experienced.
- Risk: the likelihood of either asthma exacerbations, progressive decline in lung function (or, for children, lung growth), or risk of adverse effects from medication.

Modifications in the stepwise approach to managing asthma long term.

- Treatment recommendations are presented for three age groups (0–4 years of age, 5–11 years of age, and youths ≥12 years of age and adults). The course of the disease may change over time; the relevance of different measures of impairment or risk and the potential short- and long-term impact of medications may be age related; and varied levels of scientific evidence are available for these three age groups.
- The stepwise approach expands to six steps to simplify the actions within each step. Previous guidelines had several progressive actions within different steps; these are now separated into different steps.
- Medications have been repositioned within the six steps of care.
  - — Inhaled corticosteroids (ICSs) continue as preferred long-term control therapy for all ages.
  - — Combination of long-acting beta$_2$-agonist (LABA) and ICS is presented as an equally preferred option, with increasing the dose of ICS in step 3 care, in patients 5 years of age or older. This approach balances the established beneficial effects of combination therapy in older children and adults with the increased risk for severe exacerbations, although uncommon, associated with daily use of LABA.
  - — Omalizumab is recommended for consideration for youths ≥12 years of age who have allergies or for adults who require step 5 or 6 care (severe asthma). Clinicians who administer omalizumab should be prepared and equipped to identify and treat anaphylaxis that may occur.

New emphasis on multifaceted approaches to patient education and to the control of environmental factors or comorbid conditions that affect asthma.

- Patient education for a partnership is encouraged in expanded settings.
  - — Patient education should occur at all points of care: clinic settings (offering separate self-management programs as well as integrating education into every patient visit), Emergency Departments (EDs) and hospitals, pharmacies, schools and other community settings, and patients' homes.
  - — Provider education should encourage clinician and health care systems support of the partnership (e.g., through interactive continuing medical education, communication skills training, clinical pathways, and information system supports for clinical decisionmaking.
- Environmental control includes several strategies:
  - — Multifaceted approaches to reduce exposures are necessary; single interventions are generally ineffective.
  - — Consideration of subcutaneous immunotherapy for patients who have allergies at steps 2–4 of care (mild or moderate persistent asthma) when there is a clear relationship between symptoms and exposure to an allergen to which the patient is sensitive. Clinicians should be prepared to treat anaphylaxis that may occur.
  - — Potential benefits to asthma control by treating comorbid conditions that affect asthma.

Modifications to treatment strategies for managing asthma exacerbations. These changes:

- Simplify the classification of severity of exacerbations. For the urgent or emergency care setting: <40 percent predicted forced expiratory volume in 1 second (FEV_1) or peak expiratory flow (PEF) indicates severe exacerbation and potential benefit from use of adjunctive therapies; ≥70 percent predicted FEV_1 or PEF is a goal for discharge from the emergency care setting.
- Encourage development of prehospital protocols for emergency medical services to allow administration of albuterol, oxygen, and, with medical oversight, anticholinergics and oral systemic corticosteroids.
- Modify recommendations on medications:
  - — Add levalbuterol.
  - — Add magnesium sulfate or heliox for severe exacerbations unresponsive to initial treatments.
  - — Emphasize use of oral corticosteroids. Doubling the dose of ICS for home management is not effective.
  - — Emphasize that anticholinergics are used in emergency care, not hospital care.
  - — Add consideration of initiating ICS at discharge.

Figure 1. SUMMARY OF RECOMMENDED KEY CLINICAL ACTIVITIES FOR THE DIAGNOSIS AND MANAGEMENT OF ASTHMA

Clinical Issue	Key Clinical Activities	Action Steps
DIAGNOSIS		
	Establish asthma diagnosis.	Use medical history and physical examination to determine that symptoms of recurrent episodes of airflow obstruction are present. Use spirometry in all patients ≥5 years of age to determine that airway obstruction is at least partially reversible. Consider alternative causes of airway obstruction.
MANAGING ASTHMA LONG TERM	**Goal of asthma therapy is asthma control:** ■ **Reduce impairment (prevent chronic symptoms, require infrequent use of short-acting $beta_2$-agonist (SABA), maintain (near) normal lung function and normal activity levels).** ■ **Reduce risk (prevent exacerbations, minimize need for emergency care or hospitalization, prevent loss of lung function, or for children, prevent reduced lung growth, have minimal or no adverse effects of therapy).**	
Four Components of Care		
Assessment and Monitoring	Assess asthma severity to initiate therapy.	Use severity classification chart, assessing both domains of impairment and risk, to determine initial treatment.
	Assess asthma control to monitor and adjust therapy.	Use asthma control chart, assessing both domains of impairment and risk, to determine if therapy should be maintained or adjusted (step up if necessary, step down if possible). Use multiple measures of impairment and risk: different measures assess different manifestations of asthma; they may not correlate with each other; and they may respond differently to therapy. Obtain lung function measures by spirometry at least every 1–2 years, more frequently for not-well-controlled asthma.
	Schedule followup care.	Asthma is highly variable over time, and periodic monitoring is essential. In general, consider scheduling patients at 2- to 6-week intervals while gaining control; at 1–6 month intervals, depending on step of care required or duration of control, to monitor if sufficient control is maintained; at 3-month intervals if a step down in therapy is anticipated. Assess asthma control, medication technique, written asthma action plan, patient adherence and concerns at every visit.
Education	Provide self-management education.	Teach and reinforce: ■ Self-monitoring to assess level of asthma control and signs of worsening asthma (either symptom or peak flow monitoring shows similar benefits for most patients). Peak flow monitoring may be particularly helpful for patients who have difficulty perceiving symptoms, a history of severe exacerbations, or moderate or severe asthma. ■ Using written asthma action plan (review differences between long-term control and quick-relief medication). ■ Taking medication correctly (inhaler technique and use of devices). ■ Avoiding environmental factors that worsen asthma. Tailor education to literacy level of patient. Appreciate the potential role of a patient's cultural beliefs and practices in asthma management.

Figure 1. SUMMARY OF RECOMMENDED KEY CLINICAL ACTIVITIES FOR THE DIAGNOSIS AND MANAGEMENT OF ASTHMA (continued)

Clinical Issue	Key Clinical Activities	Action Steps
Four Components of Care (continued)		
Education (continued	Develop a written asthma action plan in partnership with patient. Integrate education into all points of care where health professionals interact with patients.	Agree on treatment goals and address patient concerns. Provide instructions for (1) daily management (long-term control medication, if appropriate, and environmental control measures) and (2) managing worsening asthma (how to adjust medication, and know when to seek medical care). Involve all members of the health care team in providing/reinforcing education, including physicians, nurses, pharmacists, respiratory therapists, and asthma educators. Encourage education at all points of care: clinics (offering separate self-management education programs as well as incorporating education into every patient visit), Emergency Departments and hospitals, pharmacies, schools and other community settings, and patients' homes. Use a variety of educational strategies and methods.
Control Environmental Factors and Comorbid conditions	Recommend measures to control exposures to allergens and pollutants or irritants that make and asthma worse.	Determine exposures, history of symptoms in presence of exposures, and sensitivities (In patients who have persistent asthma, use skin or in vitro testing to assess sensitivity to perennial indoor allergens.). Advise patients on ways to reduce exposure to those allergens and pollutants, or irritants to which the patient is sensitive. Multifaceted approaches are beneficial; single steps alone are generally ineffective. Advise all patients and pregnant women to avoid exposure to tobacco smoke. Consider allergen immunotherapy, by specifically trained personnel, for patients who have persistent asthma and when there is clear evidence of a relationship between symptoms and exposure to an allergen to which the patient is sensitive.
	Treat comorbid conditions.	Consider especially: allergic bronchopulmonary aspergillosis; gastroesophageal reflux, obesity, obstructive sleep apnea, rhinitis and sinusitis, and stress or depression. Recognition and treatment of these conditions may improve asthma control. Consider inactivated influenza vaccine for all patients over 6 months of age.
Medications	Select medication and delivery devices to meet patient's needs and circumstances.	Use stepwise approach (See below.) to identify appropriate treatment options. Inhaled corticosteroids (ICSs) are the most effective long-term control therapy. When choosing among treatment options, consider domain of relevance to the patient (impairment, risk, or both), patient's history of response to the medication, and patient's willingness and ability to use the medication.

Figure 1. SUMMARY OF RECOMMENDED KEY CLINICAL ACTIVITIES FOR THE DIAGNOSIS AND MANAGEMENT OF ASTHMA (continued)

Clinical Issue	Key Clinical Activities	Action Steps
Stepwise Approach		
General Principles for All Age Groups	Incorporate four components of care.	Include medications, patient education, environmental control measures, and management of comorbidities at each step. Monitor asthma control regularly (See above, assessment and monitoring.).
	Initiate therapy based on asthma severity.	For patients not taking long-term control therapy, select treatment step based on severity (See figures on stepwise approach for different age groups.). Patients who have persistent asthma require daily long-term control medication.
	Adjust therapy based on asthma control.	Once therapy is initiated, monitor the level of asthma control and adjust therapy accordingly: step up if necessary and step down if possible to identify the minimum amount of medication required to maintain asthma control. Refer to an asthma specialist for consultation or comanagment if there are difficulties achieving or maintaining control; step 4 care or higher is required (step 3 care or higher for children 0–4 years of age); immunotherapy or omalizumab is considered; or additional testing is indicated; or if the patient required 2 bursts of oral systemic corticosticosteroids in the past year or a hospitalization.
Ages 0–4 Years	Consider daily long-term control therapy.	Young children may be at high risk for severe exacerbations, yet have low levels of impairment between exacerbations. Initiate daily long-term control therapy for: ■ Children who had ≥4 episodes of wheezing the past year that lasted >1 day and affected sleep AND who have a positive asthma risk profile, either (1) one of the following: parental history of asthma, physician diagnosis of atopic dermatitis, or evidence of sensitization to aeroallergens OR (2) two of the following: sensitization to foods, ≥4 percent blood eosinophilia, or wheezing apart from colds. Consider initiating daily long-term control therapy for: ■ Children who consistently require SABA treatment >2 days per week for >4 weeks. ■ Children who have two exacerbations requiring oral systemic corticosteroids within 6 months.
	Monitor response closely, and adjust treatment.	If no clear and positive response occurs within 4–6 weeks and the patient's/caregiver's medication technique and adherence are satisfactory, stop the treatment and consider alternative therapies or diagnoses. If clear benefit is sustained for at least 3 months, consider step down to evaluate the continued need for daily therapy. Children this age have high rates of spontaneous remission of symptoms.

Figure 1. SUMMARY OF RECOMMENDED KEY CLINICAL ACTIVITIES FOR THE DIAGNOSIS AND MANAGEMENT OF ASTHMA (continued)

Clinical Issue	Key Clinical Activities	Action Steps
Stepwise Approach (continued)		
Ages 5–11 Years	Involve child in developing a written asthma action plan.	Address child's concerns, preferences, and school schedule in selecting treatments. Encourage students to take a copy of written asthma action plan to school/afterschool activities.
	Promote physical activity.	Treat exercise-induced bronchospasm (EIB) (See below.) Step up daily therapy if the child has poor endurance or symptoms during normal play activities.
	Monitor for disease progression and loss of lung growth.	Treatment will not alter underlying progression of the disease, but a step up in therapy may be required to maintain asthma control.
Ages 12 and Older	Involve youths in developing written asthma action plan.	Address youth's concerns, preferences, and school schedule in selecting treatment. Encourage students to take a copy of written asthma action plan to school/afterschool activities.
	Promote physical activity.	Treat EIB. Step up daily therapy if the child has poor endurance or symptoms during normal daily activities.
	Assess possible benefit of treatment in older patients.	Establish reversibility with a short course of oral systemic corticosteroids.
	Adjust medications to address coexisting medical conditions common among older patients.	Consider, for example: calcium and vitamin D supplements for patients who take ICS and have risk factors for osteoporosis; increased sensitivity to side effects of bronchodilators with increasing age; increased drug interactions with theophylline; medications for arthritis (NSAIDs), hypertension, or glaucoma (beta blockers) may exacerbate asthma.
Exercise-Induced Bronchospasm (EIB)	Prevent EIB	Treatment strategies to prevent EIB include: ■ Long-term control therapy. ■ Pretreatment before exercise with SABA, leukotriene receptor antagonists (LTRAs), cromolyn or nedocromil; frequent or chronic use of long acting beta$_2$-agonist (LABA) for pretreatment is discouraged, as it may disguise poorly controlled persistent asthma. ■ Warmup period or a mask or scarf over the mouth for cold-induced EIB.
Pregnancy	Maintain asthma control through pregnancy.	Monitor asthma control during all prenatal visits; asthma worsens in one-third of women during pregnancy and improves in one-third; medications should be adjusted accordingly. It is safer to be treated with asthma medications than to have poorly controlled asthma. Maintaining lung function is important to ensure oxygen supply to the fetus. Albuterol is the preferred SABA. ICS is the preferred long-term control medication (Budesonide is preferred because more data are available on this medication during pregnancy.).
Surgery	Reduce risks for complications during and after surgery.	Assess asthma control prior to surgery. If lung function is not well controlled, provide medications to improve lung function. A short course of oral systemic corticosteroids may be necessary. For patients receiving oral systemic corticosteroids during 6 months prior to surgery, and for selected patients on high dose ICS, give 100 mg hydrocortisone every 8 hours intravenously during the surgical period, and reduce the dose rapidly within 24 hours after surgery.

Figure 1. SUMMARY OF RECOMMENDED KEY CLINICAL ACTIVITIES FOR THE DIAGNOSIS AND MANAGEMENT OF ASTHMA (continued)

Clinical Issue	Key Clinical Activities	Action Steps
Managing Exacerbations		
Home Management	Incorporate four components of care. Develop a written asthma action plan.	Include assessment and monitoring, patient education, environmental control, and medications. Instruct patients how to: ■ Recognize early signs, symptoms, peak expiratory flow (PEF) measures that indicate worsening asthma. ■ Adjust medications (increase SABA and, in some cases, add oral systemic corticosteroids) and remove or withdraw from environmental factors contributing to the exacerbation. ■ Monitor response and seek medical care if there is serious deterioration or lack of response to treatment.
Management in the Urgent or Emergency Care Setting	Assess severity. Treat to relieve hypoxemia and airflow obstruction; reduce airway inflammation. Monitor response. Discharge with medication and patient education	Treatment strategies include: ■ Assessing initial severity by lung function measures (for ages ≥5 years) and symptom and functional assessment ■ Supplemental oxygen ■ Repetitive or continuous SABA ■ Oral systemic corticosteroids ■ Monitoring response with serial assessment of lung function measures, pulse oximetry, and symptoms ■ Considering adjunctive treatments magnesium sulfate or heliox in severe exacerbations (e.g., forced expiratory volume in 1 second (FEV_1) or PEF <40 percent predicted) unresponsive to initial treatment ■ Providing at discharge: — Medications: SABA, oral systemic corticosteroids; consider initiating ICS — Referral to followup care — An emergency department asthma discharge plan — Review of inhaler technique and, whenever possible, environmental control measures

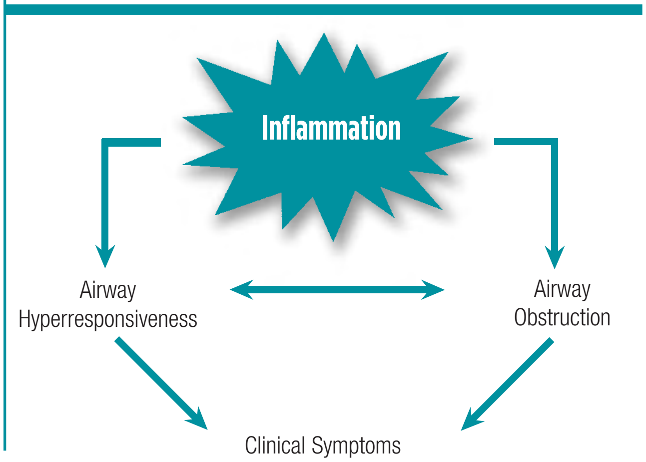
Asthma Definition and Implications for Treatment

Definition and Pathophysiology

Asthma is a complex disorder characterized by variable and recurring symptoms, airflow obstruction, bronchial hyperresponsiveness, and an underlying inflammation. The interaction of these features determines the clinical manifestations and severity of asthma (See figure 2, "The Interplay and Interaction Between Airway Inflammation and the Clinical Symptoms and Pathophysiology of Asthma.") and the response to treatment. The working definition of asthma is as follows:

Asthma is a chronic inflammatory disorder of the airways in which many cells and cellular elements play a role: in particular, mast cells, eosinophils, neutrophils (especially in sudden onset, fatal exacerbations, occupational asthma, and patients who smoke), T lymphocytes, macrophages, and epithelial cells. In susceptible individuals, this inflammation causes recurrent episodes of coughing (particularly at night or early in the morning), wheezing, breathlessness, and chest tightness. These episodes are usually associated with widespread but variable airflow obstruction that is often reversible either spontaneously or with treatment.

Figure 2. THE INTERPLAY AND INTERACTION BETWEEN AIRWAY INFLAMMATION AND THE CLINICAL SYMPTOMS AND PATHOPHYSIOLOGY OF ASTHMA



Airflow limitation is caused by a variety of changes in the airway, all in influenced by airway inflamation:

- Bronchoconstriction—bronchial smooth muscle contraction that quickly narrows the airways in response to exposure to a variety of stimuli, including allergens or irritants.
- Airway hyperresponsiveness—an exaggerated bronchoconstrictor response to stimuli.
- Airway edema—as the disease becomes more persistent and inflammation becomes more progressive, edema, mucus hypersecretion, and formation of inspissated mucus plugs further limit airflow.

Remodeling of airways may occur. Reversibility of airflow limitation may be incomplete in some patients. Persistent changes in airway structure occur, including sub-basement fibrosis, mucus hypersecretion, injury to epithelial cells, smooth muscle hypertrophy, and angiogenesis.

Recent studies provide insights on different phenotypes of asthma that exist. Different manifestations of asthma may have specific and varying patterns of inflammation (e.g., varying intensity, cellular mediator pattern, and therapeutic response). Further studies will determine if different treatment approaches benefit the different patterns of inflammation.

Causes of Asthma

The development of asthma appears to involve the interplay between host factors (particularly genetics) and environmental exposures that occur at a crucial time in the development of the immune system. A definitive cause of the inflammatory process leading to asthma has not yet been established.

- Innate immunity. Numerous factors may affect the balance between Th1-type and Th2- type cytokine responses in early life and increase the likelihood that the immune response will downregulate the Th1 immune response that fights infection and instead will be dominated by Th2 cells, leading to the expression of allergic diseases and asthma. This is known as the "hygiene hypothesis," which postulates that certain infections early in life, exposure to other children (e.g., presence of older siblings and early enrollment in childcare, which have greater likelihood of exposure to respiratory infection), less frequent use of antibiotics, and "country living" is associated with a Th1 response and lower incidence of asthma, whereas the absence of these factors is associated with a persistent Th2 response and higher rates of asthma. Interventions to prevent the onset of this process (e.g., with probiotics) are under study, but no recommendations can yet be made.
- Genetics. Asthma has an inheritable component, but the genetics involved remain complex. As the linkage of genetic factors to different asthma phenotypes becomes clearer, treatment approaches may become directed to specific patient phenotypes and genotypes.
- Environmental factors.
  - Two major factors are the most important in the development, persistence, and possibly the severity of asthma: airborne allergens (particularly sensitization and exposure to house-dust mite and Alternaria) and viral respiratory infections (including respiratory syncytial virus [RSV] and rhinovirus).
  - Other environmental factors are under study: tobacco smoke (exposure in utero is associated with an increased risk of wheezing, but it is not certain this is linked to subsequent development of asthma), air pollution (ozone and particular matter) and diet (obesity or low intake of antioxidants and omega-3 fatty acids). The association of these factors with the onset of asthma has not been clearly defined. A number of clinical trials have investigated dietary and environmental manipulations, but these trials have not been sufficiently long term or conclusive to permit recommendations.

Implications for Treatment

Knowledge of the importance of inflammation to the central features of asthma continues to expand and underscores inflammation as a primary target of treatment. Studies indicate that current therapeutic approaches are effective in controlling symptoms, reducing airflow limitation, and preventing exacerbations, but currently available treatments do not appear to prevent the progression of asthma in children. As various phenotypes of asthma are defined and inflammatory and genetic factors become more apparent, new therapeutic approaches may be developed that will allow even greater specificity to tailor treatment to the individual patient's needs and circumstances.

Diagnosis of Asthma

To establish a diagnosis of asthma, the clinician should determine that symptoms of recurrent episodes of airflow obstruction or airway hyperresponsiveness are present; airflow obstruction is at least partially reversible; and alternative diagnoses are excluded.

KEY SYMPTOM INDICATORS FOR CONSIDERING A DIAGNOSIS OF ASTHMA

The presence of multiple key indicators increases the probability of asthma, but spirometry is needed to establish a diagnosis.

- Wheezing—high-pitched whistling sounds when breathing out—especially in children. A lack of wheezing and a normal chest examination do not exclude asthma.
- History of any of the following:
  - — Cough (worse particularly at night)
  - — Recurrent wheeze
  - — Recurrent difficulty in breathing
  - — Recurrent chest tightness
- Symptoms occur or worsen in the presence of:
  - — Exercise
  - — Viral infection
  - — Inhalant allergens (e.g., animals with fur or hair, house-dust mites, mold, pollen)
  - — Irritants (tobacco or wood smoke, airborne chemicals)
  - — Changes in weather
  - — Strong emotional expression (laughing or crying hard)
  - — Stress
  - — Menstrual cycles
- Symptoms occur or worsen at night, awakening the patient.

- Episodic symptoms of airflow obstruction or airway hyperresponsiveness are present.
- Airflow obstruction is at least partially reversible, measured by spirometry. Reversibility is determined by an increase in FEV_1 of >200 mL and ≥12 percent from baseline measure after inhalation of short-acting $beta_2$-agonist (SABA). Some studies indicate that an increase of ≥10 percent of the predicted FEV_1 after inhalation of a SABA may have higher likelihood of separating patients who have asthma from those who have chronic obstructive pulmonary disease (COPD).
- Alternative diagnoses are excluded. See discussion below.

Recommended methods to establish the diagnosis are:

- **Detailed medical history.** See figure 3, "Suggested Items for Medical History," for questions to include.
- **Physical examination** may reveal findings that increase the probability of asthma, but the absence of these findings does not rule out asthma, because the disease is variable and signs may be absent between episodes. The examination focuses on:
  - — upper respiratory tract (increased nasal secretion, mucosal swelling, and/or nasal polyp;
  - — chest (sounds of wheezing during normal breathing or prolonged phase of forced exhalation, hyperexpansion of the thorax, use of accessory muscles, appearance of hunched shoulders, chest deformity); and
  - — skin (atopic dermatitis, eczema).
- **Spirometry** can demonstrate obstruction and assess reversibility in patients ≥5 years of age. Patients' perceptions of airflow obstruction are highly variable. Spirometry is an essential objective measure to establish the diagnosis of asthma,

DIFFERENTIAL DIAGNOSTIC POSSIBILITIES FOR ASTHMA

Infants and Children

Upper airway diseases

- Allergic rhinitis and sinusitis

Obstructions involving large airways

- Foreign body in trachea or bronchus
- Vocal cord dysfunction (VCD)
- Vascular rings or laryngeal webs
- Laryngotracheomalacia, tracheal stenosis, or bronchostenosis
- Enlarged lymph nodes or tumor

Obstructions involving small airways

- Viral bronchiolitis or obliterative bronchiolitis
- Cystic fibrosis
- Bronchopulmonary dysplasia
- Heart disease

Other causes

- Recurrent cough not due to asthma
- Aspiration from swallowing mechanism dysfunction or gastroesophageal reflux

Adults

- Chronic obstructive pulmonary disease (COPD) (e.g., chronic bronchitis or emphysema)
- Congestive heart failure
- Pulmonary embolism
- Mechanical obstruction of the airways (benign and malignant tumors)
- Pulmonary infiltration with eosinophilia
- Cough secondary to drugs (e.g., angiotensin-converting enzyme [ACE] inhibitors)
- Vocal cord dysfunction (VCD)

because the medical history and physical examination are not reliable means of excluding other diagnoses or of assessing lung status. Spirometry is generally recommended, rather than measurements by a peak flow meter, due to wide variability in peak flow meters and reference values. Peak flow meters are designed for monitoring, not as diagnostic tools.

A differential diagnosis of asthma should be considered. Recurrent episodes of cough and wheezing most often are due to asthma in both children and adults; however, other significant causes of airway obstruction leading to wheeze must be considered both in the initial diagnosis and if there is no clear response to initial therapy.

- **Additional studies are not routinely necessary but may be useful when considering alternative diagnoses.**
  - — **Additional pulmonary function studies** will help if there are questions about COPD (diffusing capacity), a restrictive defect (measures of lung volumes), or VCD (evaluation of inspiratory flow-volume loops).
  - — **Bronchoprovocation** with methacholine, histamine, cold air, or exercise challenge may be useful when asthma is suspected and spirometry is normal or near normal. For safety reasons, bronchoprovocation should be carried out only by a trained individual. A positive test is diagnostic for airway hyperre sponsiveness, which is a characteristic feature of asthma but can also be present in other conditions. Thus, a positive test is consistent with asthma, but a negative test may be more helpful to rule out asthma.
  - — **Chest x ray** may be needed to exclude other diagnoses.
  - — **Biomarkers of inflammation** are currently being evaluated for their usefulness in the diagnosis and assessment of asthma. Biomarkers include total and differential cell count and mediator assays in sputum, blood, urine, and exhaled air.
- **Common diagnostic challenges include the following:**
  - — **Cough variant asthma.** Cough can be the principal—or only—manifestation of asthma, especially in young children.

FIGURE 3. SUGGESTED ITEMS FOR MEDICAL HISTORY*

A detailed medical history of the new patient who is known or thought to have asthma should address the following items

1. Symptoms
- Cough
- Wheezing
- Shortness of breath
- Chest tightness
- Sputum production

2. Pattern of symptoms
- Perennial, seasonal, or both
- Continual, episodic, or both
- Onset, duration, frequency (number of days or nights, per week or month)
- Diurnal variations, especially nocturnal and on awakening in early morning

3. Precipitating and/or aggravating factors
- Viral respiratory infections
- Environmental allergens, indoor (e.g., mold, house-dust mite, cockroach, animal dander or secretory products) and outdoor (e.g., pollen)
- Characteristics of home including age, location, cooling and heating system, wood-burning stove, humidifier, carpeting over concrete, presence of molds or mildew, presense of pets with fur or hair, characteristics of rooms where patient spends time (e.g., bedroom and living room with attention to bedding, floor covering, stuffed furniture)
- Smoking (patient and others in home or daycare)
- Exercise
- Occupational chemicals or allergens
- Environmental change (e.g., moving to new home; going on vacation; and/or alterations in workplace, work processes, or materials used)
- Irritants (e.g., tobacco smoke, strong odors, air pollutants, occupational chemicals, dusts and particulates, vapors, gases, and aerosols)
- Emotions (e.g., fear, anger, frustration, hard crying or laughing)
- Stress (e.g., fear, anger, frustration)
- Drugs (e.g., aspirin; and other nonsteroidal anti-inflammatory drugs, beta-blockers including eye drops, others)
- Food, food additives, and preservatives (e.g., sulfites)
- Changes in weather, exposure to cold air
- Endocrine factors (e.g., menses, pregnancy, thyroid disease)
- Comorbid conditions (e.g. sinusitis, rhinitis, gastroesophageal reflux disease (GERD)

4. Development of disease and treatment
- Age of onset and diagnosis
- History of early-life injury to airways (e.g., bronchopulmonary dysplasia, pneumonia, parental smoking)
- Progression of disease (better or worse)
- Present management and response, including plans for managing exacerbations
- Frequency of using short-acting beta$_2$-agonist (SABA)
- Need for oral corticosteroids and frequency of use

5. Family history
- History of asthma, allergy, sinusitis, rhinitis, eczema, or nasal polyps in close relatives

6. Social history
- Daycare, workplace, and school characteristics that may interfere with adherence
- Social factors that interfere with adherence, such as substance abuse
- Social support/social networks
- Level of education completed
- Employment

7. History of exacerbations
- Usual prodromal signs and symptoms
- Rapidity of onset
- Duration
- Frequency
- Severity (need for urgent care, hospitalization, intensive care unit (ICU) admission.)
- Life-threatening exacerbations (e.g., intubation, intensive care unit admission)
- Number and severity of exacerbations in the past year.
- Usual patterns and management (what works?)

8. Impact of asthma on patient and family
- Episodes of unscheduled care (emergency department (ED), urgent care, hospitalization)
- Number of days missed from school/work
- Limitation of activity, especially sports and strenuous work
- History of nocturnal awakening
- Effect on growth, development, behavior, school or work performance, and lifestyle
- Impact on family routines, activities, or dynamics
- Economic impact

9. Assessment of patient's and family's perceptions of disease
- Patient's, parent's, and spouse's or partner's knowledge of asthma and belief in the chronicity of asthma and in the efficacy of treatment
- Patient's perception and beliefs regarding use and long-term effects of medications
- Ability of patient and parents, spouse, or partner to cope with disease
- Level of family support and patient's and parents', spouse's, or partner's capacity to recognize severity of an exacerbation
- Economic resources
- Sociocultural beliefs

* This list does not represent a standardized assessment or diagnostic instrument. The validity and reliability of this list have not been assessed.

Monitoring of PEF or bronchoprovocation may be helpful. Diagnosis is confirmed by a positive response to asthma medications.

— **VCD** can mimic asthma, but it is a distinct disorder. VCD may coexist with asthma. Asthma medications typically do little, if any thing, to relieve VCD symptoms. Variable flattening of the inspiratory flow loop on spirometry is strongly suggestive of VCD. Diagnosis of VCD is from indirect or direct vocal cord visualization during an episode, during which the abnormal adduction can be documented. VCD should be considered in difficult-to-treat, atypical asthma patients and in elite athletes who have exercise-related breathlessness unresponsive to asthma medication.

— **Gastroesophageal reflux disease (GERD), obstructive sleep apnea (OSA), and allergic bronchopulmonary aspergillosis (ABPA)** may coexist with asthma and complicate diagnosis. See the section on "Comorbid Conditions," for further discussion.

— **Children ages 0–4 years.** Diagnosis in infants and young children is challenging and is complicated by the difficulty in obtaining objective measurements of lung function in this age group. Caution is needed to avoid giving young children inappropriate prolonged asthma therapy. However, it is important to avoid underdiagnosing asthma, and thereby missing the opportunity to treat a child, by using such labels as "wheezy bronchitis," "recurrent pneumonia," or "reactive airway disease" (RAD). The chronic airway inflammatory response and structural changes that are characteristic of asthma can develop in the preschool years, and appropriate asthma treatment will reduce morbidity.

- **Consider referral to an asthma specialist if signs and symptoms are atypical, if there are problems with a differential diagnosis, or if additional testing is indicated.**

Managing Asthma Long Term

GOAL OF THERAPY: CONTROL OF ASTHMA

Reduce Impairment

- Prevent chronic and troublesome symptoms (e.g., coughing or breathlessness in the daytime, in the night, or after exertion).
- Require infrequent use (≤2 days a week) of inhaled SABA for quick relief of symptoms (not including prevention of exercise-induced bronchospasm [EIB]).
- Maintain (near) normal pulmonary function.
- Maintain normal activity levels (including exercise and other physical activity and attendance at school or work).
- Meet patients' and families' expectations of and satisfaction with asthma care.

Reduce Risk

- Prevent recurrent exacerbations of asthma and minimize the need for ED visits or hospitalizations.
- Prevent loss of lung function; for children, prevent reduced lung growth.
- Provide optimal pharmacotherapy with minimal or no adverse effects of therapy.

Achieving and maintaining asthma control requires four components of care: assessment and monitoring, education for a partnership in care, control of environmental factors and comorbid conditions that affect asthma, and medications. A stepwise approach to asthma management incorporates these four components, emphasizing that pharmacologic therapy is initiated based on asthma severity and adjusted (stepped up or down) based on the level of asthma control. Special considerations of therapeutic options within the stepwise approach may be necessary for situations such as exercise-induced bronchospasm (EIB), surgery, and pregnancy.

Four Components of Asthma Care

Component 1: Assessing and Monitoring Asthma Severity and Asthma Control

The functions of assessment and monitoring are closely linked to the concepts of severity, control, and responsiveness to treatment:

- **Severity:** the intrinsic intensity of the disease process. Severity is most easily and directly measured in a patient who is not receiving long-term control therapy. Severity can also be measured, once asthma control is achieved, by the step of care (i.e., the amount of medication) required to maintain control.
- **Control:** the degree to which the manifestations of asthma are minimized by therapeutic intervention and the goals of therapy are met.
- **Responsiveness:** the ease with which asthma control is achieved by therapy.

Asthma severity and asthma control include the domains of current impairment and future risk.

- **Impairment:** frequency and intensity of symptoms and functional limitations the patient is currently experiencing or has recently experienced.

- **Risk:** the likelihood of either asthma exacerbations, progressive decline in lung function (or, for children, reduced lung growth), or risk of adverse effects from medication.

This distinction emphasizes the multifaceted nature of asthma and the need to consider separately asthma's current, ongoing effects on the present quality of life and functional capacity and the future risk of adverse events. The two domains may respond differentially to treatment. For example, evidence demonstrates that some patients can have adequate control of symptoms and minimal day-to-day impairment, but still be at significant risk of exacerbations; these patients should be treated accordingly.

The specific measures used to assess severity and control are similar: symptoms, use of SABAs for quick relief of symptoms, limitations to normal activities due to asthma, pulmonary function, and exacerbations. Multiple measures are important, because different measures assess different manifestations of the disease and may not correlate with each other.

The concepts of severity and control are used as follows for managing asthma:

- **Assess severity to initiate therapy.** See section on "Stepwise Approach for Managing Asthma" for figures on classifying asthma severity and initiating therapy in different age groups. During a patient's initial presentation, if the patient is not currently taking long-term control medication, asthma severity is assessed to guide clinical decisions for initiating the appropriate medication and other therapeutic interventions.
- **Assess control to adjust therapy.** See section on "Stepwise Approach for Managing Asthma" for figures on assessing asthma control and adjusting therapy in different age groups. Once therapy is initiated, the emphasis for clinical management thereafter is changed to the assessment of asthma control. The level of asthma control will guide decisions either to maintain or to adjust therapy (i.e., step up if necessary, step down if possible).
- **For assessing a patient's overall asthma severity, once the most optimal asthma control is achieved and maintained,** or for population-based evaluations or clinical research, asthma severity can be inferred by correlating the level of severity with the lowest level of treatment required to maintain control.

Lowest level of treatment required to maintain control	Classification of Asthma Severity When Asthma Is Well Controlled			
		Persistent		
	Intermittent	Mild	Moderate	Severe
(See "Stepwise Approach for Managing Asthma" for treatment steps.)	Step 1	Step 2	Step 3 or Step 4	Step 5 or Step 6

However, the emphasis for clinical management is to assess asthma severity prior to initiating therapy and then to assess asthma control for monitoring and adjusting therapy.

For the initial assessment to characterize the patient's asthma and guide decisions for initiating therapy, use information from the diagnostic evaluation to:

- **Classify asthma severity.**
- **Identify precipitating factors** for episodic symptoms (e.g., exposure at home, work, daycare, or school to inhalant allergens or irritants).
- **Identify comorbid conditions** that may impede asthma management (e.g., sinusitis, rhinitis, GERD, OSA, obesity, stress, or depression).
- **Assess the patient's knowledge and skills** for self-management.

For periodic monitoring of asthma control to guide decisions for maintaining or adjusting therapy:

- **Instruct patients to monitor their asthma control in an ongoing manner. All patients should be taught how to recognize inadequate asthma control.**
  - Either symptom or peak flow monitoring is appropriate for most patients; evidence suggests the benefits are similar.
  - Consider daily peak-flow monitoring for patients who have moderate or severe persistent asthma, patients who have a history of severe exacerbations, and patients who poorly perceive airway obstruction or worsening asthma.
- **Monitor asthma control periodically in clinical visits,** because asthma is highly variable over time and therapy may need to be adjusted (stepped up if necessary, stepped down if possible). **The frequency of monitoring is a matter of clinical judgment. In general:**

FIGURE 4. SAMPLE PATIENT SELF-ASSESSMENT SHEET FOR FOLLOWUP VISITS*

Name:______________________________________ Date:__________________________

Your Asthma Control

How many days in the past week have you had chest tightness, cough, shortness of breath, or wheezing (whistling in your chest)?

_____ 0 _____ 1 _____ 2 _____ 3 _____ 4 _____ 5 _____ 6 _____ 7

How many nights in the past week have you had chest tightness, cough, shortness of breath, or wheezing (whistling in your chest)?

_____ 0 _____ 1 _____ 2 _____ 3 _____ 4 _____ 5 _____ 6 _____ 7

Do you perform peak flow readings at home? _______ yes _______ no

If yes, did you bring your peak flow chart? _______ yes _______ no

How many days in the past week has asthma restricted your physical activity?

_____ 0 _____ 1 _____ 2 _____ 3 _____ 4 _____ 5 _____ 6 _____ 7

Have you had any asthma attacks since your last visit? _______ yes _______ no

Have you had any unscheduled visits to a doctor, including to the emergency department, since your last visit? _______ yes _______ no

How well controlled is your asthma, in your opinion? _____ very well controlled

_____ somewhat controlled

_____ not well controlled

Average number of puffs per day of quick-relief medication (short acting beta$_2$-agonist) ______________________

Taking your medicine

What problems have you had taking your medicine or following your asthma action plan?

Please ask the doctor or nurse to review how you take your medicine.

Your questions

What questions or concerns would you like to discuss with the doctor?

How satisfied are you with your asthma care? _____ very satisfied

_____ somewhat satisfied

_____ not satisfied

* These questions are examples and do not represent a standardized assessment instrument. Other examples of asthma control questions: Asthma Control Questionnaire (Juniper); Asthma Therapy Assessment Questionnaire (Volmer); Asthma Control Test (Nathan); Asthma Control Score (Boulet)

— Schedule visits at 2- to 6-week intervals for patients who are just starting therapy or who require a step up in therapy to achieve or regain asthma control.

— Schedule visits at 1- to 6-month intervals, after asthma control is achieved, to monitor whether asthma control is maintained. The interval will depend on factors such as the duration of asthma control or the level of treatment required.

— Consider scheduling visits at 3-month intervals if a step down in therapy is anticipated.

- **Assess asthma control, medication technique, the written asthma action plan, adherence, and patient concerns at every patient visit.** See figure 4 for a sample patient self-assessment of overall asthma control and asthma care.

- Use spirometry to obtain objective measures of lung function.

  — Perform spirometry at the following times:

  - At the initial assessment.
  - After treatment is initiated and symptoms and PEF have stabilized.
  - During periods of progressive or prolonged loss of asthma control.
  - At least every 1–2 years; more frequently depending on response to therapy.

  — Low FEV_1 indicates current obstruction (impairment) and risk for future exacerbations (risk). For children, FEV_1/forced vital capacity (FVC) appears to be a more sensitive measure of severity and control in the impairment domain. FEV_1 is a useful measure of risk for exacerbations, although it is emphasized that even children who have normal lung function experience exacerbations.

- **Minimally invasive markers** (called biomarkers) such as fractionated exhaled nitric oxide (FeNO) and sputum eosinophils may be useful, but bio markers require further evaluation before they can be recommended as clinical tools for routine management.

Component 2: Education for a Partnership in Care

A partnership between the clinician and the person who has asthma (and the caregiver, for children) is required for effective asthma management. By working together, an appropriate treatment can be selected, and the patient can learn self-management skills necessary to control asthma. Self-management education improves patient outcomes (e.g., reduced urgent care visits, hospitalizations, and limitations on activities as well as improved health status, quality of life, and perceived control of asthma) and can be cost-effective. Self-management education is an integral component of effective asthma care and should be treated as such by health care providers as well as by health care policies and reimbursements.

KEY EDUCATIONAL MESSAGES: TEACH AND REINFORCE AT EVERY OPPORTUNITY

Basic Facts About Asthma

- The contrast between airways of a person who has and a person who does not have asthma; the role of inflammation.
- What happens to the airways during an asthma attack.

Role of Medications: Understanding the Difference Between:

- Long-term control medications: prevent symptoms, often by reducing inflammation. Must be taken daily. Do not expect them to give quick relief.
- Quick-relief medications: SABAs relax airway muscles to provide prompt relief of symptoms. Do not expect them to provide long-term asthma control. Using SABA >2 days a week indicates the need for starting or increasing long-term control medications.

Patient Skills

- Taking medications correctly
  — Inhaler technique (demonstrate to the patient and have the patient return the demonstration).
  — Use of devices, as prescribed (e.g., valved holding chamber (VHC) or spacer, nebulizer).
- Identifying and avoiding environmental exposures that worsen the patient's asthma; e.g., allergens, irritants, tobacco smoke.
- Self-monitoring
  — Assess level of asthma control.
  — Monitor symptoms and, if prescribed, PEF measures.
  — Recognize early signs and symptoms of worsening asthma.
- Using a written asthma action plan to know when and how to:
  — Take daily actions to control asthma.
  — Adjust medication in response to signs of worsening asthma.
- Seeking medical care as appropriate.

Develop an active partnership with the patient and family by:

- Establishing open communications that consider cultural and ethnic factors, as well as language and health care literacy needs, of each patient and family.
- Identifying and addressing patient and family concerns about asthma and asthma treatment.
- Developing treatment goals and selecting medications together with the patient and family, allowing full participation in treatment decision making.
- Encouraging self-monitoring and self-management by reviewing at each opportunity the patient's reports of asthma symptoms and response to treatment.

Provide to all patients a written asthma action plan that includes instructions for both daily management (long-term control medication, if appropriate, and environmental control measures) and actions to manage worsening asthma (what signs, symptoms, and PEF measurements (if used) indicate worsening asthma; what medications to take in response; what signs and symptoms indicate the need for immediate medical care). Written asthma action plans are particularly recommended for patients who have moderate or severe persistent asthma (i.e., requiring treatment at step 4, 5, or 6), a history of severe exacerbations, or poorly controlled asthma. See figures 5 and 6 for samples of written asthma action plans.

Integrate asthma self-management education into all aspects of asthma care. Asthma self management requires repetition and reinforcement. It should:

- Begin at the time of diagnosis and continue through followup care. See figure 7, "Delivery of Asthma Education by Clinicians During Patient Care Visits," for a sample of how to incorporate teaching into routine clinic visits.
- Involve all members of the health care team, including physicians, nurses, pharmacists, respiratory therapists, and asthma educators, as well as other health professionals who come in contact with asthma patients and their families.
- Occur at all points of care where health care professionals interact with patients who have asthma. The strongest evidence supports self-management education in the clinic setting. Evidence also supports education provided in patients' homes, pharmacies, targeted education in EDs and hospitals, and selected programs in schools and other community sites. Proven community programs should be considered because of their potential to reach large numbers of people who have asthma and encourage "asthma-friendly" support from their families and community environments.
- Use a variety of educational strategies to reach people who have varying levels of health literacy or learning styles. Individual instruction, group programs, written materials (at a 5th grade reading level or below), video- or audiotapes, and computer and Internet programs all provide effective educational opportunities. See figure 8, "Asthma Education Resources," for a sample of available resources.
- Incorporate individualized case/care management by trained health care professionals for patients who have poorly controlled asthma and have recurrent visits to the emergency department or hospital. This will provide tailored self-management education and skills training.

Encourage patients' adherence to the written asthma action plan by:

- Choosing treatment that achieves outcomes and addresses preferences that are important to the patient, and reminding patients that adherence will help them achieve the outcomes they want.
- Reviewing with the patient at each visit the success of the treatment plan to achieve asthma control and make adjustments as needed.
- Reviewing patients' concerns about their asthma or treatment at every visit. Inquire about any difficulties encountered in adhering to the written asthma action plan.
- Assessing the patient's and family's level of social support, and encouraging family involvement.
- Tailoring the self-management approach to the needs and literacy levels of the patient, and maintaining sensitivity to cultural beliefs and ethnocultural practices.

Encourage health care provider and health care system support of the therapeutic partnership by:

- Incorporating effective clinician education strategies,

FIGURE 5. SAMPLE ASTHMA ACTION PLAN—ADULT

ENGLISH

My Asthma Action Plan

Patient Name: ______

Medical Record #: ______

Physician's Name: ______ DOB: ______

Physician's Phone #: ______ Completed by: ______ Date: ______

Long-Term-Control Medicines	How Much To Take	How Often	Other Instructions
		______ times per day EVERY DAY!	
		______ times per day EVERY DAY!	
		______ times per day EVERY DAY!	
		______ times per day EVERY DAY!	

Quick-Relief Medicines	How Much To Take	How Often	Other Instructions
		Take ONLY as needed	NOTE: If this medicine is needed frequently, call physician to consider increasing long-term-control medications.

Special instructions when I feel *good,* *not good,* and *awful.*

GREEN ZONE

I feel *good.*

(My peak flow is in the GREEN zone.)

PREVENT asthma symptoms everyday:

- ☐ Take my long-term-control medicines (above) every day.
- ☐ Before exercise, take ______ puffs of ______
- ☐ Avoid things that make my asthma worse like: ______

YELLOW ZONE

I do *not* feel *good.*

(My peak flow is in the YELLOW zone.)

My symptoms may include one or more of the following:

- Wheeze
- Tight chest
- Cough
- Shortness of breath
- Waking up at night with asthma symptoms
- Decreased ability to do usual activities
- ______

CAUTION. I should continue taking my long-term-control asthma medicines every day AND:

- ☐ Take ______

If I still do not feel good, or my peak flow is not back in the *Green Zone* within 1 hour, then I should:

- ☐ Increase ______
- ☐ Add ______
- ☐ Call ______

RED ZONE

I feel *awful.*

(My peak flow is in the RED zone.)

Warning signs may include one or more of the following:

- It's getting harder and harder to breathe
- Unable to sleep or do usual activities because of trouble breathing

MEDICAL ALERT! Get help!

- ☐ Take ______ until I get help immediately.
- ☐ Take ______
- ☐ Call ______

Danger! Get help immediately! Call 9-1-1 if you have trouble walking or talking due to shortness of breath or lips or fingernails are gray or blue.

Adapted and reprinted with permission from the Regional Asthma Management and Prevention (RAMP) Initiative, a program of the Public Health Institute, to include terms used in the EPR—3: Full Report 2007.

Source: http://www.calasthma.org/uploads/resources/actionplanpdf.pdf; San Francisco Bay Area Regional Asthma Management Plan, http://www.rampasthma.org

FIGURE 6. SAMPLE ASTHMA ACTION PLAN—CHILD

ENGLISH

Child Asthma Action Plan

0–5 years of age

Patient Name: ______________________

Medical Record #: ______________________

Health Care Provider's Name: ______________________ DOB: ______________________

Health Care Provider's Phone #: ______________________ Completed by: ______________________ Date: ____________

Long-Term-Control Medicines (Use Every Day To Stay Healthy)	How Much To Take	How Often	Other Instructions (such as spacers/masks, nebulizers)
		______ times per day EVERY DAY!	
		______ times per day EVERY DAY!	
		______ times per day EVERY DAY!	
		______ times per day EVERY DAY!	

Quick-Relief Medicines	How Much To Take	How Often	Other Instructions
		Give ONLY as needed	NOTE: If this medicine is needed often (______ times per week), call physician.

GREEN ZONE

Child is ***well*** and has no asthma symptoms, even during active play.

PREVENT asthma symptoms every day:

- **Give the above long-term-control medicines every day.**
- Avoid things that make the child's asthma worse:

☑ Avoid tobacco smoke; ask people to smoke outside.

☐ ______________________

☐ ______________________

YELLOW ZONE

Child is ***not well*** and has asthma symptoms that may include:

- Coughing
- Wheezing
- Runny nose or other cold symptoms
- Breathing harder or faster
- Awakening due to coughing or difficulty breathing
- Playing less than usual
- ______________________
- ______________________

Other symptoms that could indicate that your child is having trouble breathing may include: difficulty feeding (grunting sounds, poor sucking), changes in sleep patterns, cranky and tired, decreased appetite.

CAUTION. Take action by continuing to give regular asthma medicines **every day** AND:

☐ Give ______________________
(include dose and frequency)

If the child is not in the ***Green Zone*** and still has symptoms after 1 hour, then:

☐ Give more ______________________
(include dose and frequency)

☐ ______________________
(include dose and frequency)

☐ Call ______________________

RED ZONE

Child ***feels awful!*** Warning signs may include:

- Child's wheeze, cough, or difficulty breathing continues or worsens, even after giving yellow zone medicines.
- Child's breathing is so hard that he/she is having trouble walking/talking/eating/playing.
- Child is drowsy or less alert than normal.

MEDICAL ALERT! Get help!

☐ Take the child to the hospital or call 9–1–1 immediately!

☐ Give more ______________________ until you get help.
(include dose and frequency)

☐ Give ______________________
(include dose and frequency)

Danger! Get help immediately!

Call 9–1–1 if:

- The child's skin is sucked in around neck and ribs, or
- Lips and/or fingernails are grey or blue, or
- Child doesn't respond to you.

Adapted and reprinted with permission from "The Asthma Action Plan" developed by a committee facilitated by the Regional Asthma Management and Prevention (RAMP) Initiative, a program of the Public Health Institute.

Source: http://www.calasthma.org/uploads/resources/actionplanpdf.pdf; San Francisco Bay Area Regional Asthma Management Plan, http://www.rampasthma.org

FIGURE 7. DELIVERY OF ASTHMA EDUCATION BY CLINICIANS DURING PATIENT CARE VISITS

Assessment Questions	Information	Skills
Recommendations for Initial Visit		
Focus on: ■ Expectations of visit ■ Asthma control ■ Patients' goals of treatment ■ Medications ■ Quality of life **Ask relevant questions** "What worries you most about your asthma?" "What do you want to accomplish at this visit?" "What do you want to be able to do that you can't do now because of your asthma?" "What do you expect from treatment?" "What medicines have you tried?" "What other questions do you have for me today?" "Are there things in your environment that make your asthma worse?"	**Teach in simple language:** ■ What is asthma? Asthma is a chronic lung disease. The airways are very sensitive. They become inflamed and narrow; breathing becomes difficult. ■ The definition of asthma control: few daytime symptoms, no nighttime awakenings due to asthma, able to engage in normal activities, normal lung function. ■ Asthma treatments: two types of medicines are needed: — Long-term control: medications that prevent symptoms, often by reducing inflammation. — Quick relief: short-acting bronchodilator relaxes muscles around airways. ■ Bring all medications to every appointment. ■ When to seek medical advice. Provide appropriate telephone number.	**Teach or review and demonstrate:** ■ Inhaler and spacer or valved holding chamber (VHC) use. Check performance. ■ Self-monitoring skills that are tied to a written asthma action plan: — Recognize intensity and frequency of asthma symptoms. — Review the signs of deterioration and the need to reevaluate therapy: • Waking at night or early morning with asthma • Increased medication use • Decreased activity tolerance ■ Use of a written asthma action plan (See figures 5 and 6.) that includes instructions for daily management and for recognizing and handling worsening asthma.
Recommendations for First Followup Visit (2 to 4 Weeks or Sooner as Needed)		
Focus on: ■ Expectations of visit ■ Asthma control ■ Patient's goals of treatment ■ Medications ■ Patient's treatment preferences ■ Quality of life **Ask relevant questions from previous visit and also ask:** "What medications are you taking?" "How and when are you taking them?" "What problems have you had using your medications?" "Please show me how you use your inhaled medications."	**Teach in simple language:** ■ Use of two types of medications. ■ Remind patient to bring all medications and the peak flow meter, if using, to every appointment for review. ■ Self/assessment of asthma control using symptoms and/or peak flow as a guide.	**Teach or review and demonstrate:** ■ Use of written asthma action plan. Review and adjust as needed. ■ Peak flow monitoring if indicated ■ Correct inhaler and spacer or VHC technique.
Recommendations for Second Followup Visit		
Focus on: ■ Expectations of visit ■ Asthma control ■ Patients' goals of treatment ■ Medications ■ Quality of life **Ask relevant questions from previous visits and also ask:** "Have you noticed anything in your home, work, or school that makes your asthma worse?" "Describe for me how you know when to call your doctor or go to the hospital for asthma care." "What questions do you have about the asthma action plan?" "Can we make it easier?" "Are your medications causing you any problems?" "Have you noticed anything in your environment that makes your asthma worse?" "Have you missed any of your medications?"	**Teach in simple language:** ■ Self-assessment of asthma control, using symptoms and/or peak flow as a guide. ■ Relevant environmental control/avoidance strategies: — How to identify home, work, or school exposures that can cause or worsen asthma — How to control house-dust mites, animal exposures if applicable — How to avoid cigarette smoke (active and passive) ■ Review all medications.	**Teach or review and demonstrate:** ■ Inhaler/spacer or VHC technique. ■ Peak flow monitoring technique. ■ Use of written asthma action plan. Review and adjust as needed. ■ Confirm that patient knows what to do if asthma gets worse

FIGURE 7. DELIVERY OF ASTHMA EDUCATION BY CLINICIANS DURING PATIENT CARE VISITS (continued)

Assessment Questions	Information	Skills
Recommendations for All Subsequent Visits		
Focus on: ■ Expectations of visit ■ Asthma control ■ Patients' goals of treatment ■ Medications ■ Quality of life **Ask relevant questions from previous visits and also ask:** "How have you tried to control things that make your asthma worse?" "Please show me how you use your inhaled medication."	**Teach in simple language:** ■ Review and reinforce all: — Educational messages — Environmental control strategies at home, work, or school — Medications — Self-assessment of asthma control, using symptoms and/or peak flow as a guide	**Teach or review and demonstrate:** ■ Inhaler/spacer or VHC technique. ■ Peak flow monitoring technique, if appropriate. ■ Use of written asthma action plan. Review and adjust as needed. ■ Confirm that patient knows what to do if asthma gets worse.

Sources: Adapted from Guevara et al. 2003; Janson et al. 2003; Powell and Gibson 2003; Wilson et al. 1993.

such as interactive formats, practice-based case studies, and multidimensional teaching approaches that reinforce guideline-based care.

- Providing communication skills training to clinicians to enhance competence in caring for all patients, especially multicultural populations.
- Using systems approaches, such as clinical pathways and clinical information system prompts, to improve the quality of asthma care and to support clinical care decisionmaking.

Component 3: Control of Environmental Factors and Comorbid Conditions That Affect Asthma

If patients who have asthma are exposed to irritants or inhalant allergens to which they are sensitive, their asthma symptoms may increase and precipitate an asthma exacerbation. Substantially reducing exposure to these factors may reduce inflammation, symptoms, and need for medication. Several comorbid conditions can impede asthma management. Recognition and treatment of these conditions may improve asthma control. See questions in figure 3, "Suggested Items for Medical History," above, for questions related to environmental exposures and comorbid conditions.

Allergens and Irritants

Evaluate the potential role of allergens (particularly inhalant allergens) and irritants.

- Identify allergen and pollutants or irritant exposures. The most important allergens for both children and adults appear to be those that are inhaled.
- For patients who have persistent asthma, use skin testing or in vitro testing to assess sensitivity to perennial indoor allergens. Assess the significance of positive tests in the context of the person's history of symptoms when exposed to the allergen.

Advise patients who have asthma to reduce exposure to allergens and pollutants or irritants to which they are sensitive.

- See figure 9, "How To Control Things That Make Your Asthma Worse," for a sample patient information sheet.
- Effective allergen avoidance requires a multifaceted, comprehensive approach; single steps alone are generally ineffective. Multifaceted allergen-control education programs provided in the home setting can help patients reduce exposures to cockroach, dust-mite, and rodent allergens and, consequently, improve asthma control.
- Advise patients who have severe persistent asthma, nasal polyps, or a history of sensitivity to aspirin or nonsteroidal anti-inflammatory drugs (NSAIDs) about their risk of severe and even fatal exacerbations from using these drugs.
- Indoor air-cleaning devices (high-efficiency particulate air [HEPA] and electrostatic precipitating filters), cannot substitute for more effective dust-mite and cockroach control measures because

FIGURE 8. ASTHMA EDUCATION RESOURCES

Allergy & Asthma Network Mothers of Asthmatics 2751 Prosperity Avenue, Suite 150 Fairfax, VA 22030 www.breatherville.org	1–800–878–4403 1–703–641–9595
American Academy of Allergy, Asthma and Immunology 555 East Wells Street, Suite 100 Milwaukee, WI 53202-3823 www.aaaai.org	1–414–272–6071
American Association For Respiratory Care 9125 North MacArthur Boulevard, Suite 100 Irving, TX 75063 www.aarc.org	1–972–243–2272
American College of Allergy, Asthma, and Immunology 85 West Algonquin Road Suite 550 Arlington Heights, IL 60005 www.Acaai.Org	1–800–842–7777 1–847–427–1200
American Lung Association 61 Broadway New York, NY 10006 www.lungusa.org	1–800–586–4872
Association of Asthma Educators 1215 Anthony Avenue Columbia, SC 29201 www.asthmaeducators.org	1–888–988–7747
Asthma and Allergy Foundation of America 1233 20th Street, NW., Suite 402 Washington, DC 20036 www.aafa.org	1–800–727–8462
Centers for Disease Control and Prevention 1600 Clifton Road Atlanta, GA 30333	1–800–311–3435
Food Allergy & Anaphylaxis Network 11781 Lee Jackson Highway, Suite 160 Fairfax, VA 22033 www.foodallergy.org	1–800–929–4040
National Heart, Lung, and Blood Institute Information Center P.O. Box 30105 Bethesda, MD 20824-0105 www.nhlbi.nih.gov	1–301–592–8573
National Jewish Medical and Research Center (Lung Line) 1400 Jackson Street Denver, CO 80206 www.njc.org	1–800–222–Lung
U.S. Environmental Protection Agency **National Center for Environmental Publications** P.O. Box 42419 Cincinnati, OH 45242-0419 www.airnow.gov	1–800–490–9198

these particles do not remain airborne. The devices can reduce airborne dog and cat allergens, mold spores, and particulate tobacco smoke; however, most studies do not show an effect on symptoms or lung function.

- Use of humidifiers or evaporative (swamp) coolers is not generally recommended in homes of patients who are sensitive to dust mites or mold.

Consider subcutaneous allergen immunotherapy for patients who have persistent asthma when there is clear evidence of a relationship between symptoms and exposure to an allergen to which the patient is sensitive. Evidence is strongest for use of subcutaneous immunotherapy for single allergens, particularly house dust mites, animal dander, and pollen. The role of allergy in asthma is greater in children than in adults. If use of allergen immunotherapy is elected, it should be administered only in a physician's office where facilities and trained personnel are available to treat any life-threatening reaction that can, but rarely does, occur.

Consider inactivated influenza vaccination for patients who have asthma. This vaccine is safe for administration to children over 6 months of age and adults, and the Advisory Committee on Immunization Practices of the Centers for Disease Control and Prevention (CDC) recommends vaccination for persons who have asthma because they are considered to be at risk for complications from influenza. However, the vaccine should not be given with the expectation that it will reduce either the frequency or severity of asthma exacerbations during the influenza season.

Dietary factors have an inconclusive role in asthma. Food allergenies are rarely an aggravating factor in asthma. An exception is that sulfites in foods (e.g., shrimp, dried fruit, processed potatoes, beer, and wine) can precipitate asthma symptoms in people who are sensitive to these food items. Furthermore, individuals who have both food allergy and asthma are at increased risk for fatal anaphlylactic reactions to the food to which they are sensitized.

Comorbid Conditions

Identify and treat comorbid conditions that may impede asthma management. If these conditions are treated appropriately, asthma control may improve.

- **Allergic Bronchopulmonary Aspergillosis (ABPA)** may be considered in patients who have asthma and a history of pulmonary infiltrates, immunoglobulin E (IgE) sensitization to Aspergillus, and/or are corticosteroid dependent. Diagnostic criteria include: positive immediate skin test and elevated serum IgE and/or IgG to Aspergillus, total serum IgE >417 IU (1,000 ng/mL), and central bronchiectasis. Treatment is prednisone, initially 0.5 mg per kilogram with gradual tapering. Azole antifungal agents as adjunctive therapy may also be helpful.

- **Gastroesophageal Reflux (GERD)** treatment may benefit patients who have asthma and complain of frequent heartburn or pyrosis, particularly those who have frequent nighttime asthma symptoms. Even in the absence of suggestive GERD symptoms, consider evaluation for GERD in patients who have poorly controlled asthma, especially with nighttime symptoms. Treatment includes: avoiding heavy meals, fried foods, caffeine, and alcohol; avoiding food and drink within 3 hours of retiring; elevating the head of the bed on 6- to 8-inch blocks; using proton pump inhibitor medication.

- **Obese or overweight patients** who have asthma may be advised that weight loss, in addition to improving overall health, might also improve asthma control.

- **Obstructive Sleep Apnea (OSA)** may be considered in patients who have not well controlled asthma, particularly those who are overweight or obese. Treatment for OSA is nasal continuous positive air way pressure (CPAP). However, this treatment may disrupt the sleep of asthma patients who do not also have OSA. Accurate diagnosis is important.

- **Rhinitis or sinusitis** symptoms or diagnosis should be evaluated in patients who have asthma, because the interrelationship of the upper and lower airway suggests that therapy for the upper airway will improve asthma control. Treatment of allergic rhinitis includes intranasal corticosteroids, antihistamine therapy, and the consideration of immunotherapy. Treatment of sinusitis includes intranasal corticosteroids and antibiotics. Evidence is inconclusive regarding the effect on asthma of sinus surgery in patients who have chronic rhinosinusitis.

- **Stress and depression** should be considered in patients who have asthma that is not well controlled. Additional education to improve self-management and coping skills may be helpful.

FIGURE 9. HOW TO CONTROL THINGS THAT MAKE YOUR ASTHMA WORSE

You can help prevent asthma episodes by staying away from things that make your asthma worse. This guide suggests many ways to help you do this.

You need to find out what makes your asthma worse. Some things that make asthma worse for some people are not a problem for others. You do not need to do all of the things listed in this guide.

Look at the things listed below. Put a check next to the ones that you know make your asthma worse, particularly if you are allergic to these things. Then, decide with your doctor what steps you will take. Start with the things in your bedroom that bother your asthma. Try something simple first.

Tobacco Smoke

- ☐ If you smoke, ask your doctor for ways to help you quit. Ask family members to quit smoking, too.
- ☐ Do not allow smoking in your home, car or around you.
- ☐ Be sure no one smokes at a child's daycare center or school.

Dust Mites

Many people who have asthma are allergic to dust mites. Dust mites are like tiny "bugs" you cannot see that live in cloth or carpet.

Things that will help the most:

- ☐ Encase your mattress in a special dust-mite proof cover.*
- ☐ Encase your pillow in a special dust-mite proof cover* or wash the pillow each week in hot water. Water must be hotter than 130 °F to kill the mites. Cooler water used with detergent and bleach can also be effective.
- ☐ Wash the sheets and blankets on your bed each week in hot water.

Other things that can help:

- ☐ Reduce indoor humidity to or below 60 percent, ideally 30–50 percent. Dehumidifiers or central air conditioners can do this.
- ☐ Try not to sleep or lie on cloth-covered cushions or furniture.
- ☐ Remove carpets from your bedroom and those laid on concrete, if you can.
- ☐ Keep stuffed toys out of the bed, or wash the toys weekly in hot water or in cooler water with detergent and bleach. Placing toys weekly in a dryer or freezer may help. Prolonged exposure to dry heat or freezing can kill mites but does not remove allergen.

***To find out where to get products mentioned in this guide, call:**

Asthma and Allergy Foundation of America (800–727–8462)

Allergy & Asthma Network Mothers of Asthmatics (800–878–4403)

American Academy of Allergy, Asthma, and Immunology (800–822–2762)

National Jewish Medical and Research Center (Lung Line) (800–222–5864)

American College of Allergy, Asthma, and Immunology (800–842–7777)

Animal Dander

Some people are allergic to the flakes of skin or dried saliva from animals.

The best thing to do:
- ☐ Keep pets with fur or hair out of your home.

If you can't keep the pet outdoors, then:
- ☐ Keep the pet out of your bedroom, and keep the bedroom door closed.
- ☐ Remove carpets and furniture covered with cloth from your home. If that is not possible, keep the pet out of the rooms where these are.

Cockroach

Many people with asthma are allergic to the dried droppings and remains of cockroaches.

- ☐ Keep all food out of your bedroom.
- ☐ Keep food and garbage in closed containers (Never leave food out).
- ☐ Use poison baits, powders, gels, or paste (for example, boric acid). You can also use traps.
- ☐ If a spray is used to kill roaches, stay out of the room until the odor goes away.

Vacuum Cleaning

- ☐ Try to get someone else to vacuum for you once or twice a week, if you can. Stay out of rooms while they are being vacuumed and for a short while afterward.
- ☐ If you vacuum, use a dust mask (from a hardware store), a central cleaner with the collecting bag outside the home, or a vacuum cleaner with a HEPA filter or a double-layered bag.*

Indoor Mold

- ☐ Fix leaking faucets, pipes, or other sources of water.
- ☐ Clean moldy surfaces.
- ☐ Dehumidify basements if possible.

Pollen and Outdoor Mold

During your allergy season (when pollen or mold spore counts are high):
- ☐ Try to keep your windows closed.
- ☐ If possible, stay indoors with windows closed during the midday and afternoon, if you can. Pollen and some mold spore counts are highest at that time.
- ☐ Ask your doctor whether you need to take or increase anti-inflammatory medicine before your allergy season starts.

Smoke, Strong Odors, and Sprays

- ☐ If possible, do not use a wood-burning stove, kerosene heater, fireplace, unvented gas stove, or heater.
- ☐ Try to stay away from strong odors and sprays, such as perfume, talcum powder, hair spray, paints, new carpet, or particle board.

Exercise or Sports

- ☐ You should be able to be active without symptoms. See your doctor if you have asthma symptoms when you are active—such as when you exercise, do sports, play, or work hard.
- ☐ Ask your doctor about taking medicine before you exercise to prevent symptoms.
- ☐ Warm up for a period before you exercise.
- ☐ Check the air quality index and try not to work or play hard outside when the air pollution or pollen levels (if you are allergic to the pollen) are high.

Other Things That Can Make Asthma Worse

- ☐ **Sulfites in foods:** Do not drink beer or wine or eat shrimp, dried fruit, or processed potatoes if they cause asthma symptoms.
- ☐ **Cold air:** Cover your nose and mouth with a scarf on cold or windy days.
- ☐ **Other medicines:** Tell your doctor about all the medicines you may take. Include cold medicines, aspirin, and even eye drops.

Key: HEPA, high-efficiency particulate air

Component 4: Medications

Medications for asthma are categorized into two general classes: long-term control medication and quick-relief medication. Selection of medications includes consideration of the general mechanisms and role of the medication in therapy, delivery devices, and safety.

General Mechanisms and Role in Therapy

Long-term control medications are used daily to achieve and maintain control of persistent asthma. The most effective are those that attenuate the underlying inflammation characteristic of asthma. Long-term control medications include the following (listed in alphabetical order):

- **Corticosteroids** are anti-inflammatory medications that reduce airway hyperresponsiveness, inhibit inflammatory cell migration and activation, and block late phase reaction to allergen. Inhaled Corticosteriods (ICSs) are the most consistently effective long-term control medication at all steps of care for persistent asthma, and ICSs improve asthma control more effectively in both children and adults than leukotriene receptor antagonists (LTRAs) or any other single, long-term control medication do. ICSs reduce impairment and risk of exacerbations, but ICSs do not appear to alter the progression or underlying severity of the disease in children. Short courses of oral systemic corticosteroids are often used to gain prompt control of asthma. Oral systemic corticosteroids are used long term to treat patients who require step 6 care (for severe persistent asthma).
- **Cromolyn sodium and nedocromil** stabilize mast cells and interfere with chloride channel function. They are used as alternative, but not preferred, medication for patients requiring step 2 care (for mild persistent asthma). They also can be used as preventive treatment before exercise or unavoidable exposure to known allergens.
- **Immunomodulators.** Omalizumab (anti-IgE) is a monoclonal antibody that prevents binding of IgE to the high-affinity receptors on basophils and mast cells. Omalizumab is used as adjunctive therapy for patients 12 years of age who have sensitivity to relevant allergens (e.g., dust mite, cockroach, cat, or dog) and who require step 5 or 6 care (for severe persistent asthma). Clinicians who administer omalizumab should be prepared and equipped to identify and treat anaphylaxis that may occur.
- **Leukotriene modifiers** interfere with the pathway of leukotriene mediators, which are released from mast cells, eosinophils, and basophils. These medications include LTRAs (montelukast and zafirlukast) and a 5-lipoxygenase inhibitor (zileuton). LTRAs are alternative, but not preferred, therapy for the treatment of patients who require step 2 care (for mild persistent asthma). LTRAs also can be used as adjunctive therapy with ICSs, but for youths 12 years of age and adults, they are not preferred adjunctive therapy compared to the addition of LABAs. LTRAs can attenuate EIB. Zileuton can be used as alternative, but not preferred, adjunctive therapy in adults; liver function monitoring is essential.
- **LABAs** (salmeterol and formoterol) are inhaled bronchodilators that have a duration of bronchodilation of at least 12 hours after a single dose.
  - — LABAs are not to be used as monotherapy for long-term control of asthma.
  - — LABAs are used in combination with ICSs for long-term control and prevention of symptoms in moderate or severe persistent asthma (Step 3 care or higher in children ≥5 years of age and adults and Step 4 care or higher in children 0–4 years of age, although few data are available for 0–4-year-olds.).
  - — Of the adjunctive therapies available, LABA is the preferred therapy to combine with ICS in youths ≥12 years of age and adults.
  - — A LABA may be used before exercise to prevent EIB, but duration of action does not exceed 5 hours with chronic, regular use. Frequent or chronic use before exercise is discouraged, because this may disguise poorly controlled persistent asthma. See also the section "Safety Issues for Inhaled Corticosteroids and Long-Acting Beta$_2$-Agonists."
- **Methylxanthines.** Sustained-release theophylline is a mild to moderate bronchodilator used as alternative, not preferred, therapy for step 2 care (for mild persistent asthma) or as adjunctive therapy with ICS in patients ≥5 years of age. Theophylline may have mild anti-inflammatory effects. Monitoring of serum theophylline concentration is essential.

Quick-relief medications are used to treat acute symptoms and exacerbations. They include the following (listed in alphabetical order):

- **Anticholinergics** inhibit muscarinic cholinergic receptors and reduce intrinsic vagal tone of the airway. Ipratropium bromide provides additive benefit to SABA in moderate or severe exacerbations in the emergency care setting, not the hospital setting. Ipratropium bromide may be used as an alternative bronchodilator for patients who do not tolerate SABA, although it has not been compared to SABAs.
- **SABAs**—albuterol, levalbuterol, and pirbuterol—are bronchodilators that relax smooth muscle. They are the treatment of choice for relief of acute symptoms and prevention of EIB. Increasing use of SABA treatment or the use of SABA >2 days a week for symptom relief (not prevention of EIB) generally indicates inadequate asthma control and the need for initiating or intensifying anti-inflammatory therapy. Regularly scheduled, daily, chronic use of SABA is not recommended.
- **Systemic corticosteroids.** Although not short-acting, oral systemic corticosteroids are used for moderate and severe exacerbations in addition to SABA to speed recovery and to prevent recurrence of exacerbations.

Complementary and alternative medications (CAMs) and interventions generally have insufficient evidence to permit recommendations. Because as much as one-third of the U.S. population uses complementary alternative healing methods, it is important to discuss their use with patients.

- **Ask patients about all the medications and interventions they are using.** Some cultural beliefs and practices may be of no harm and can be integrated into the recommended asthma management strategies, but it is important to advise patients that alternative healing methods are not substitutes for recommended therapeutic approaches. Clinical trials on safety and efficacy are limited, and their scientific basis has not been established.
- **Evidence is insufficient to recommend or not recommend most CAMs or treatments for asthma.** These include chiropractic therapy, homeopathy and herbal medicine, and breathing or relaxation techniques. Acupuncture is not recommended for the treatment of asthma.
- **Patients who use herbal treatments for asthma should be cautioned** about the potential for harmful ingredients and for interactions with recommended asthma medications.

Delivery Devices for Inhaled Medications

Patients should be instructed in the use of inhaled medications, and patients' technique should be reviewed at every patient visit. The major advantages of delivering drugs directly into the lungs via inhalation are that higher concentrations can be delivered more effectively to the airways and that systemic side effects are lessened. Inhaled medications, or aerosols, are available in a variety of devices that differ in the technique required. See figure 10, "Aerosol Delivery Devices," for a summary of issues to consider for different devices.

Safety Issues for Inhaled Corticosteroids and Long-Acting Beta$_2$-Agonists

Inhaled Corticosteroids

- ICSs are the preferred long-term control therapy in children of all ages and adults. In general, ICSs are well tolerated and safe at the recommended dosages.
- Most benefits of ICS for patients who have mild or moderate asthma occur at the low- to medium-dose ranges. Data suggest higher doses may further reduce the risk of exacerbations. Furthermore, higher doses are beneficial for patients who have more severe asthma. The risk of adverse effects increases with the dose.
- High doses of ICS administered for prolonged periods of time (e.g., >1 year) have significantly less potential than oral systemic corticosteroids for having adverse effects. High doses of ICS used for prolonged periods of time (e.g., >1 year), particularly in combination with frequent courses of oral corticosteroids, may be associated with risk of posterior subcapsular cataracts or reduced bone density. Slit-lamp eye exam and bone densitometry may be considered. For adult patients, consider supplements of calcium and vitamin D, particularly in perimenopausal women. For children, age-appropriate dietary intake of calcium and vitamin D should be reviewed with parents or caregivers.
- To reduce the potential for adverse effects, the following measures are recommended.
  - Advise patients to use spacers or VHCs with nonbreath-activated metered-dose inhalers

(MDIs) to reduce local side effects. There are no clinical data on use of spacers with ultrafine particle hydrofluoroalkane (HFA) MDIs.

— Advise patients to rinse the mouth (rinse and spit) after inhalation.

— Use the lowest dose of ICS that maintains asthma control. Evaluate the patient's inhaler technique and adherence, as well as environmental control measures, before increasing the dose.

— Consider adding a LABA, or alternative adjunctive therapy, to a low or medium dose of ICS rather than using a higher dose of ICS to maintain asthma control.

Inhaled Corticosteroids and Linear Growth in Children

- The potential risks of ICSs are well balanced by their benefits.
- Poorly controlled asthma may delay growth. Children who have asthma tend to have longer periods of reduced growth rates before puberty.
- Growth rates are highly variable in children. Short-term evaluation may not be predictive of final adult height attained.
- The potential for adverse effects on linear growth from ICS appear to be dose dependent. In treatment of children who have mild or moderate persistent asthma, low-to medium-dose ICS therapy may be associated with a possible, but not predictable, adverse effect on linear growth (approximately 1 cm). The effect on growth velocity appears to occur in the first several months of treatment and is generally small and not progressive. The clinical significance of this potential systemic effect has yet to be determined.
- In general, the efficacy of ICSs is sufficient to out weigh any concerns about growth or other systemic effects. However, ICSs should be titrated to as low a dose as needed to maintain good control of the child's asthma, and children receiving ICSs should be monitored for changes in growth by using a stadiometer.

Long-Acting Beta2-Agonists

- The addition of LABA (salmeterol or formoterol) to the treatment of patients who require more than low-dose ICS alone to control asthma improves lung function, decreases symptoms, reduces exacerbations and use of SABA for quick relief in most patients to a greater extent than doubling the dose of ICSs.
- A large clinical trial comparing daily treatment with salmeterol or placebo added to usual asthma therapy resulted in an increased risk of asthma-related deaths in patients treated with salmeterol (13 deaths among 13,176 patients treated for 28 weeks with salmeterol versus 3 deaths among 13,179 patients treated with placebo). In addition, increased numbers of severe asthma exacerbations were noted in the pivotal trials submitted to the U.S. Food and Drug Administration (FDA) for formoterol approval, particularly in the arms of the trials with higher dose formoterol. Thus, the FDA determined that a Black Box warning was warranted on all preparations containing a LABA.
- The established beneficial effects of LABA for the great majority of patients who require more therapy than low-dose ICS alone to control asthma (i.e., require step 3 care or higher) should be weighed against the increased risk for severe exacerbations, although uncommon, associated with the daily use of LABAs.
- Daily use of LABA generally should not exceed 100 mcg salmeterol or 24 mcg formoterol.
- It is not currently recommended that LABA be used for treatment of acute symptoms or exacerbations.
- LABAs are not to be used as monotherapy for long-term control. Patients should be instructed not to stop ICS therapy while taking LABA, even though their symptoms may significantly improve.

Stepwise Approach for Managing Asthma

Principles of The Stepwise Approach

A stepwise approach to managing asthma is recommended to gain and maintain control of asthma in both the impairment and risk domains. These domains may respond differentially to treatment.

For children, see:

Figure 11, "Classifying Asthma Severity and Initiating Therapy in Children"

FIGURE 10. AEROSOL DELIVERY DEVICES

Device/Drugs	Population	Optimal Technique*	Therapeutic Issues
Metered-dose inhaler (MDI) Beta$_2$-agonists Corticosteroids Cromolyn sodium Anticholinergics	≥5 years old (<5 with spacer or valved holding chamber (VHC) or mask)	Actuation during a slow (30 L/min or 3–5 seconds) deep inhalation, followed by 10-second breathhold. Under laboratory conditions, open-mouth technique (holding MDI 2 inches away from open mouth) enhances delivery to the lung. This technique, however, has not been shown to enhance clinical benefit consistently compared to closed-mouth technique (inserting MDI mouthpiece between lips and teeth).	Slow inhalation and coordination of actuation during inhalation may be difficult, particularly in young children and elderly. Patients may incorrectly stop inhalation at actuation. Deposition of 50–80 percent of actuated dose in oropharynx. Mouth washing and spitting is effective in reducing the amount of drug swallowed and absorbed systemically. Lung delivery under ideal conditions varies significantly between MDIs due to differences in formulation (suspension versus solution), propellant (chlorofluorocarbon [CFC] versus hydrofluoralkane [HFA]), and valve design. For example, inhaled corticosteroid (ICS) delivery varies from 5–50 percent.
Breath-actuated MDI Beta$_2$-agonist	≥5 years old	Tight seal around mouthpiece and slightly more rapid inhalation than standard MDI (see above) followed by 10-second breathhold.	May be particularly useful for patients unable to coordinate inhalation and actuation. May also be useful for elderly patients. Patients may incorrectly stop inhalation at actuation. Cannot be used with currently available spacer/valved holding chamber (VHC) devices.
Dry powder inhaler (DPI) Beta$_2$-agonists Corticosteroids Anticholinergics	≥4 years old	Rapid (60 L/min or 1–2 seconds), deep inhalation. Minimally effective inspiratory flow is device dependent. Most children <4 years of age may not generate sufficient inspiratory flow to activate the inhaler.	Dose is lost if patient exhales through device after actuating. Delivery may be greater or lesser than MDI, depending on device and technique. Delivery is more flow dependent in devices with highest internal resistance. Rapid inhalation promotes greater deposition in larger central airways. Mouth washing and spitting is effective in reducing amount of drug swallowed and absorbed.
Spacer or valved holding chamber (VHC)	≥4 years old <4 years old VHC with face mask	Slow (30 L/min or 3–5 seconds) deep inhalation, followed by 10-second breathhold immediately following actuation. Actuate only once into spacer/VHC per inhalation. If face mask is used, it should have a tight fit and allow 3–5 inhalations per actuation. Rinse plastic VHCs once a month with low concentration of liquid household dishwashing detergent (1:5,000 or 1–2 drops per cup of water) and let drip dry.	Indicated for patients who have difficulty performing adequate MDI technique. May be bulky. Simple tubes do not obviate coordinating actuation and inhalation. The VHCs are preferred. Face mask allows MDIs to be used with small children. However, use of a face mask reduces delivery to lungs by 50 percent. The VHC improves lung delivery and response in patients who have poor MDI technique. The effect of a spacer or VHC on output from an MDI depends on both the MDI and device type; thus data from one combination should not be extrapolated to all others. Spacers and/or VHCs decrease oropharyngeal deposition and thus decrease risk of topical side effects (e.g., thrush). Spacers will also reduce the potential systemic availability of ICSs with higher oral absorption. However, spacer/VHCs may increase systemic availability of ICSs that are poorly absorbed orally by enhancing delivery to lungs. No clinical data are available on use of spacers or VHCs with ultrafine-particle-generated HFA MDIs. Use anti-static VHCs or rinse plastic non-anti-static VHCs with dilute household detergents to enhance delivery to lungs and efficacy. This effect is less pronounced for albuterol MDIs with HFA propellant than for albuterol MDIs with CFC propellant. As effective as nebulizer for delivering SABAs and anticholinergics in mild- to moderate-exacerbations; data in severe exacerbations are limited.

FIGURE 10. AEROSOL DELIVERY DEVICES (continued)

Device/Drugs	Population	Optimal Technique*	Therapeutic Issues
Nebulizer Beta$_2$-agonists Corticosteroids Cromolyn sodium Anticholinergics	Patients of any age who cannot use MDI with VHC and face mask.	Slow tidal breathing with occasional deep breaths. Tightly fitting face mask for those unable to use mouthpiece. Using the "blow by" technique (i.e., holding the mask or open tube near the infant's nose and mouth) is not appropriate.	Less dependent on patient's coordination and cooperation. Delivery method of choice for cromolyn sodium in young children. May be expensive; time consuming; bulky; output is dependent on device and operating parameters (fill volume, driving gas flow); internebulizer and intranebulizer output variances are significant. Use of a face mask reduces delivery to lungs by 50 percent. Nebulizers are as effective as MDIs plus VHCs for delivering bronchodilators in the ED for mild to moderate exacerbations; data in severe exacerbations are limited. Choice of delivery system is dependent on resources, availability, and clinical judgment of the clinician caring for the patient. Potential for bacterial infections if not cleaned properly.

Key: ED, emergency department; SABAs, inhaled short-acting beta$_2$-agonists

*See figures in component 2—Education for a Partnership in Asthma Care for description of MDI and DPI techniques.

Figure 12, "Assessing Asthma Control and Adjusting Therapy in Children"

Figure 13, "Stepwise Approach for Managing Asthma Long Term in Children, 0–4 Years of Age and 5–11 Years of Age"

For adults, see:

Figure 14, "Classifying Asthma Severity and Initiating Treatment in Youths 12 Years of Age and Adults"

Figure 15, "Assessing Asthma Control and Adjusting Therapy in Youths ≥ 12 Years of Age and Adults"

Figure 16, "Stepwise Approach for Managing Asthma in Youths ≥12 Years of Age and Adults"

For medication dosages, see:

Figure 17, "Usual Dosages for Long-Term Control Medications"

Figure 18, "Estimated Comparative Daily Dosages for Inhaled Corticosteroids"

Figure 19, "Usual Dosages for Quick-Relief Medications"

- The stepwise approach incorporates all four components of care: assessment of severity to initiate therapy or assessment of control to monitor and adjust therapy; patient education; environmental control measures, and management of comorbid conditions at every step; and selection of medication.
- The type, amount, and scheduling of medication is determined by the level of asthma severity or asthma control.
  - Therapy is increased (stepped up) as necessary and decreased (stepped down) when possible.
  - Because asthma is a chronic inflammatory disorder, persistent asthma is most effectively controlled with daily long-term control medication directed toward suppressing inflammation. ICSs are the most consistently effective anti-inflammatory therapy for all age groups, at all steps of care for persistent asthma.
  - Selection among alternative treatment options is based on consideration of treatment effectiveness for the domain of particular relevance to the patient (impairment, risk, or both), the individual patient's history of previous response to therapies (sensitivity and responsiveness to different asthma medications can vary among patients), and the willingness and ability of the patient and family to use the medication.
- Once asthma control is achieved, monitoring and followup are essential, because asthma often varies over time. A step up in therapy may be needed, or a step down may be possible, to identify the minimum medication necessary to maintain control.

The stepwise approach and recommended treatments are meant to assist, not replace, the clinical decisionmaking necessary to determine the most appropriate treatment to meet the individual patient's needs and circumstances.

Referral to an asthma specialist for consultation or comanagement is recommended if there are difficulties achieving or maintaining control of asthma, if the patient required >2 bursts of oral systemic corticosteriods in 1 year or has an exacerbation requiring hospitalization, if step 4 care or higher is required (step 3 care or higher for children 0–4 years of age), if immunotherapy or omalizumab is considered, or if additional testing is indicated.

To achieve control of asthma, the following sequence of activities is recommended:

- For patients who are not already taking long-term control medications, assess asthma severity and initiate therapy according to the level of severity.
- For patients who are already taking long-term control medications, assess asthma control and step up therapy if the patient's asthma is not well controlled on current therapy. Before stepping up, review the patient's adherence to medications, inhaler technique, and environmental control measures.
- Evaluate asthma control in 2–6 weeks (depending on level of initial severity or control).
  - — In general, classify the level of asthma control by the most severe indicator of impairment or risk.
  - — The risk domain is usually more strongly associated with morbidity in young children than the impairment domain because young children are often symptom free between exacerbations.
  - — If office spirometry suggests worse control than other measures of impairment, consider fixed obstruction and reassess the other measures. If fixed obstruction does not explain the lack of control, step up therapy, because low FEV_1 is a predictor of exacerbations.
  - — If the history of exacerbations suggests poorer control than does assessment of impairment, reassess impairment measures, and consider a step up in therapy. Review plans for handling exacerbations and include the use of oral systemic corticosteroids, especially for patients who have a history of severe exacerbations.
- If asthma control is not achieved with the above actions:
  - — Review the patient's adherence to medications, inhaler technique, environmental control measures (or whether there are new exposures), and management of comorbid conditions.
  - — If adherence and environment control measures are adequate, then step up one step (if not well controlled) or two steps (if very poorly controlled).
  - — If an alternative treatment was used initially, discontinue its use and use the preferred treatment option before stepping up therapy.
  - — A short course of oral systemic corticosteroids may be considered to gain more rapid control for patients whose asthma frequently interrupts sleep or normal daily activities or who are experiencing an exacerbation at the time of assessment.
  - — If lack of control persists, consider alternative diagnoses before stepping up further.
  - — If the patient experiences side effects, consider different treatment options.

To maintain control of asthma, regular followup contact is essential because asthma often varies over time.

- Schedule patient contact at 1- to 6-month intervals; the interval will depend on such factors as the level or duration of asthma control and the level of treatment required.
- Consider a step down in therapy once asthma is well controlled for at least 3 months. A step down is necessary to identify the minimum therapy required to maintain good control. A reduction in therapy should be gradual and must be closely monitored. Studies are limited in guiding therapy reduction. In general, the dose of ICS may be reduced 25 percent to 50 percent every 3 months to the lowest possible dose.
- Consider seasonal periods of daily long-term control therapy for patients who have asthma

symptoms only in relation to certain seasons (e.g., seasonal pollens, allergens, or viral respiratory infections) and who have intermittent asthma the rest of the year. This approach has not been rigorously evaluated; close monitoring for 2–6 weeks after therapy is discontinued is essential to assure sustained asthma control.

Stepwise Treatment Recommendations for Different Ages

Recommendations for treatments in the different steps are presented in three different age groups (0–4 years, 5–11 years, and 12 years and older) because the course of the disease may change over time, the relevance of measures of impairment or risk and the potential short- and long-term impact of medications may be age related, and varied levels of scientific evidence are available for the different ages.

Steps for Children 0–4 Years of Age

See figure 13, for recommended treatments in the different steps and figures 17–19 for recommended medication dosages. In addition to the general principles of the stepwise approach, special considerations for this age group include initiating therapy, selecting among treatment options, and monitoring response to therapy.

The initiation of daily long-term control therapy in children ages 0–4 years is recommended as follows:

- It is recommended for reducing impairment and risk of exacerbations in infants and young children who had four or more episodes of wheezing in the past year that lasted more than 1 day and affected sleep AND who have a positive asthma predictive index (either (1) one of the following: a parental history of asthma, a physician's diagnosis of atopic dermatitis, or evidence of sensitization to aeroallergens; OR (2) two of the following: evidence of sensitization to foods, >4 percent peripheral blood eosinophilia, or wheezing apart from colds).
- It should be considered for reducing impairment in infants and young children who consistently require symptomatic treatment >2 days per week for a period of more than 4 weeks.
- It should be considered for reducing risk in infants and young children who have two exacerbations requiring systemic corticosteroids within 6 months.
- It may be considered for use only during periods, or seasons, of previously documented risk (e.g., during seasons of viral respiratory infections).

The decision about when to start long-term daily therapy is difficult. The chronic airway inflammatory response in asthma can develop in the preschool years; for example, between 50–80 percent of children who have asthma developed symptoms before their fifth birthday. Adequate treatment will reduce the burden of illness, and underdiagnosis and undertreatment are key problems in this age group. Not all wheeze and cough are caused by asthma, however, and caution is needed to avoid giving inappropriate, prolonged therapy.

Initiating long-term control therapy will depend on consideration of issues regarding diagnosis and prognosis.

— Viral respiratory infections are the most common cause of asthma symptoms in this age group, and many children who wheeze with respiratory infections respond well to asthma therapy even though the diagnosis of asthma is not clearly established. For children who have exacerbations with viral infections, exacerbations are often severe (requiring emergency care or hospitalization), yet the child has no significant symptoms in between these exacerbations. These children have a low level of impairment but a high level of risk.

— Most young children who wheeze with viral respiratory infection experience a remission of symptoms by 6 years of age, perhaps due to growing airway size.

— However, two-thirds of children who have frequent wheezing AND also have a positive asthma predictive index (see above) are likely to have asthma throughout childhood. Early identification of these children allows appropriate treatment with environmental control measures and medication to reduce morbidity.

Select medications with the following considerations for young children:

- Asthma treatment for young children, especially infants, has not been studied adequately. Most recommendations are based on limited data and extrapolations from studies in older children and adults. Preferred treatment options are based on individual drug efficacy studies in this age group; comparator trials are not available.

- The following long-term control medications are FDA approved for the following ages in young children: ICS budesonide nebulizer solution (1–8 years of age); ICS fluticasone dry power inhaler (DPI) (>4 years of age); LABA salmeterol DPI, alone or in combination with ICS (>4 years of age); LTRA montelukast (chewable tablets, 2–6 years of age; granules, down to 1 year old).
- Several delivery devices are available, and the doses received may vary considerably among devices and age groups. In general, children <4 years of age will have less difficulty with a face mask and either (1) a nebulizer or (2) an MDI with a VHC. (See figure 10 above.)
- ICSs are the preferred long-term control medication for initiating therapy. The benefits of ICSs out weigh any concerns about potential risks of a small, nonprogressive reduction in growth velocity or other possible adverse effects. ICSs, as with all medications, should be titrated to as low a dose as needed to maintain control.
- For children whose asthma is not well controlled on low-dose ICS, few studies are available on stepup therapy in this age group, and the studies have mixed findings. Some data on children ≤4 years old and younger show dose-dependent improvements in the domains of impairment and risk of exacerbation from taking ICS. Data from studies on LABA combined with ICS have only small numbers of 4-year-old children, and these data show improvement in the impairment but not risk domain. Adding a noncorticosteroid long-term control medication to medium-dose ICS may be considered before increasing the dose of ICS to high dose to avoid potential risk of side effects with high doses of medication.

Monitor response to therapy closely, because treatment of young children is often in the form of a therapeutic trial.

- **If a clear and beneficial response is not obvious within 4–6 weeks and the patient's/family's medication technique and adherence are satisfactory, treatment should be stopped. Alternative therapies or alternative diagnoses should be considered.**
- **If a clear and beneficial response is sustained for at least 3 months, consider a step down to evaluate the need for continued daily long-term control therapy.** Children in this age group have high rates of spontaneous remission of symptoms.

Steps for Children 5–11 Years of Age

See figure 13, "Stepwise Approach for Managing Asthma Long Term in Children, 0–4 Years of Age and 5–11 Years of Age," for recommended treatments in different steps and figures 17, 18, and 19 for recommended medication dosages. Special considerations for this age group include the following:

Promote active participation in physical activities, exercise, and sports because physical activity is an essential part of a child's life. Treatment immediately before vigorous activity usually prevents EIB (see section on "Exercise-Induced Bronchospasm"). However, if the child has poor endurance or has symptoms during usual play activities, a step up in therapy is warranted.

Directly involve children ≥10 years of age (and younger children as appropriate) in developing their written asthma action plans and reviewing their adherence. This involvement may help address developmental issues of emerging independence by building the children's confidence, increasing personal responsibility, and gaining problem-solving skills.

Encourage parents to take a copy of the written asthma action plan to the student's school, or childcare or extended care setting, or camp.

Consider the following when selecting treatment options:

- ICSs are the preferred long-term control therapy. The benefits of ICSs outweigh any concerns about potential risks of a small, nonprogressive reduction in growth velocity or other possible adverse effects. ICSs, as with all medications, should be titrated to as low a dose as needed to maintain control. High-quality evidence demonstrates the effectiveness of ICS in children 5–11 years of age, and comparator studies demonstrate improved control with ICS on a range of asthma outcomes compared to other long-term control medications.
- Step up treatment options for children whose asthma is not well controlled on low-dose ICS have not been adequately studied or compared in this age group. The selection will depend on the domain

SAMPLE RECORD FOR MONITORING THE RISK DOMAIN IN CHILDREN: RISK OF ASTHMA PROGRESSION (INCREASED EXACERBATIONS OR NEED FOR DAILY MEDICATION, OR LOSS OF LUNG FUNCTION), AND POTENTIAL ADVERSE EFFECTS OF CORTICOSTEROID THERAPY

Patient name: Date							
Long-term control medication							
ICS daily dose*							
LTRA							
LABA							
Theophylline							
Other							
Significant exacerbations							
Exacerbations (number/month)							
Oral systemic corticosteroids (number/year)*							
Hospitalization (number/year)							
Long-term control medication							
Prebronchodilator FEV_1/FVC							
Prebronchodilator FEV_1 percent predicted							
Postbronchodilator FEV_1 percent predicted							
Percent bronchodilator reversibility							
Potential risk of adverse corticosteroid effects (as indicated by corticosteroid dose and duration of treatment)							
Height, cm							
Percentile Plots of growth velocity							

FEV_1, forced expiratory volume in 1 second; FVC, forced vital capacity; ICS, inhaled corticosteroid; LABA, long-acting $beta_2$ agonist; LTRA, leukotriene receptor antagonist

*Consider ophthalmologic exam and bone density measurement in children using high doses of ICS or multiple courses of oral corticosteroids.

of particular relevance (impairment, risk, or both) and clinician–patient preference.

— For the impairment domain:

- Children who have low lung function and >2 days per week impairment may be better served by adding a LABA to a low dose of ICS (based on studies in older children and adults).
- Increasing the dose of ICS to medium dose can improve symptoms and lung function in those children who have greater levels of impairment (based on studies in children).
- One study in children suggests some benefit in the impairment domain with adding LTRA.

— For the risk domain:

- Studies have not demonstrated that adding LABA or LTRA reduces exacerbations in children. Adding LABA has the potential risk of rare life-threatening or fatal exacerbations.
- Studies in older children and adults show that increasing the dose of ICS can reduce the risk of exacerbations, but this may require up to a four-fold increase in the dose. This dose may increase the potential risk of systemic effects, although the risk is small within the medium-dose range.

■ The need for step 4 care usually involves children who have a low level of lung function contributing to their impairment. The combination of ICS and LABA is preferred, on the basis of studies in older children and adults.

■ Before maintenance dose of oral corticosteroids is initiated in step 6, consider a 2-week course of oral corticosteroids to confirm clinical reversibility, measured by spirometry, and the possibility of an effective response to therapy. If the response is poor, a careful review for other pulmonary conditions or comorbid conditions should be conducted to ensure that the primary diagnosis is severe asthma.

Monitor asthma progression. Declines in lung function or repeated periods of worsening asthma impairment may indicate a progressive worsening of the underlying severity of asthma. Although there is no indication that treatment alters the progression of the underlying disease in children, adjustments in treatment may be necessary to maintain asthma control.

Steps for Youths 12 Years of Age and Adults

See figure 16, "Stepwise Approach for Managing Asthma in Youths 12 Years of Age and Adults," for recommended treatment options in different steps and figures 18 and 19, for recommended medication dosages for youths 12 years of age and adults.

Special considerations for this age group include the following:

For youths:

■ Involve adolescents in the development of their written asthma action plans and reviewing their adherence.

■ Encourage students to take a copy of their plan to school, after school programs, and camps.

■ Encourage adolescents to be physically active.

For older adults:

■ Consider a short course of oral systemic corticosteroids to establish reversibility and the extent of possible benefit from asthma treatment. Chronic bronchitis and emphysema may coexist with asthma.

■ Adjust medications as necessary to address coexisting medical conditions. For example, consider calcium and vitamin D supplements for patients who take ICS and have risk factors for osteoporosis. Consider increased sensitivity to side effects of bronchodilators, especially tremor and tachycardia with increasing age, and increased possibilities for drug interactions with theophylline. Consider also that NSAIDs prescribed for arthritis and the beta-blockers prescribed for hypertension or glaucoma may exacerbate asthma.

■ Review the patient's technique and adherence in using medications, and make necessary adjustments. Physical or cognitive impairments may make proper technique difficult.

Consider the following when selecting treatment options:

■ Recommended treatment for step 3 weighs the high-quality evidence demonstrating the benefits of adding LABA to low-dose ICS against the potential risk of rare life-threatening or fatal exacerbations with the use of LABA. The selection will depend on the domain of particular relevance (impairment, risk, or both) and clinician–patient preference.

— Adding LABA more consistently results in improvements in the impairment domain compared to increasing the dose of ICS.

— If the risk domain is of particular concern, then a balance of potential risks needs to be considered.

• Adding LABA to low-dose ICS reduces the frequency of exacerbations to a greater extent than doubling the dose of ICS, but adding LABA has the potential risk of rare life-threatening or fatal exacerbations.

• Increasing the dose of ICS can significantly reduce the risk of exacerbations, but this benefit may require up to a fourfold increase in the ICS dose. This dose may increase the potential risk of systemic effects, although the risk is small within the medium-dose range.

- Comparator studies demonstrate significantly greater improvements with adding LABA to ICS compared to other adjunctive therapies.
- Clinicians who administer omalizumab are advised to be prepared and equipped for the identification and treatment of anaphylaxis that may occur, to observe patients for an appropriate period of time following each omalizumab injection (the optimal length of the observation is not established), and to educate patients about the risks of anaphylaxis and how to recognize and treat it if it occurs (e.g., using prescription auto injectors for emergency self treatment, and seeking immediate medical care).

Managing Special Situations

Patients who have asthma may encounter situations that will require adjustments to their asthma management to keep their asthma under control, such as EIB, pregnancy, and surgery.

Exercise-Induced Bronchospasm

EIB should be anticipated in all asthma patients. A history of cough, shortness of breath, chest pain or tightness, wheezing, or endurance problems during exercises suggests EIB. An exercise challenge, in which a 15 percent decrease in PEF or FEV_1 (measured before and after exercise at 5-minute intervals for 20–30 minutes) will establish the diagnosis.

An important dimension of adequate asthma control is a patient's ability to participate in any activity he or she chooses without experiencing asthma symptoms. EIB should not limit either participation or success in vigorous activities.

Recommended treatments for EIB include:

- **Long-term control therapy, if appropriate.** Frequent or severe EIB may indicate the need to initiate or step up long-term control medications.
- **Pretreatment before exercise:**

— Inhaled beta$_2$-agonists will prevent EIB for more than 80 percent of patients. SABA used shortly before exercise may be helpful for 2–3 hours. LABA can be protective up to 12 hours, but there is some shortening of the duration of protection when LABA is used on a daily basis. Frequent or chronic use of LABA as pretreatment for EIB is discouraged, as it may disguise poorly controlled persistent asthma.

— LTRAs, with an onset of action generally hours after administration, can attenuate EIB in up to 50 percent of patients.

— Cromolyn or nedocromil taken shortly before exercise is an alternative treatment, but it is not as effective as SABAs.

— A warmup period before exercise may reduce the degree of EIB.

— A mask or scarf over the mouth may attenuate cold-induced EIB.

Pregnancy

Maintaining asthma control during pregnancy is important for the health and well-being of both the mother and her baby. Maintaining lung function is important to ensure oxygen supply to the fetus. Uncontrolled asthma increases the risk of perinatal mortality, preeclampsia, preterm birth, and low-birth-weight infants. It is safer for pregnant women to be treated with asthma medications than to have asthma symptoms and exacerbations.

- **Monitor the level of asthma control and lung function during prenatal visits.** The course of asthma improves in one-third of women and worsens for one-third of women during pregnancy. Monthly evaluations of asthma will allow the opportunity to step up therapy if necessary and to step down therapy if possible.

- **Albuterol is the preferred SABA.** The most data related to safety during human pregnancy are available for abuterol.
- **ICSs are the preferred long-term control medication. Budesonide is the preferred ICS** because more data are available on using budesonide in pregnant women than are available on other ICSs, and the data are reassuring. However, no data indicate that the other ICS preparations are unsafe during pregnancy.

Surgery

Patients who have asthma are at risk for complications during and after surgery. These complications include acute bronchoconstriction triggered by intubation, hypoxemia and possible hypercapnia, impaired effectiveness of cough, atelectasis, and respiratory infection, and, if a history of sensitivity is present, reactions to latex exposure or some anesthetic agents.

The following actions are recommended to reduce the risk of complications during surgery:

- Before surgery, review the level of asthma control, medication use (especially oral systemic corticosteroids within the past 6 months), and pulmonary function.
- Provide medications before surgery to improve lung function if lung function is not well controlled. A short course of oral systemic corti costeroids may be necessary.
- For patients receiving oral systemic corticosteroids during the 6 months prior to surgery and for selected patients on long-term high-dose ICS, give 100 mg hydrocortisone every 8 hours intravenously during the surgical period, and reduce the dose rapidly within 24 hours after surgery.

Disparities

Multiple factors contribute to the higher rates of poorly controlled asthma and asthma deaths among Blacks and Latinos compared to Whites. These factors include socioeconomic disparities in access to quality medical care, underprescription and underutilization of long-term control medication, cultural beliefs and practices about asthma management, and perhaps biological and pathophysiological differences that affect the underlying severity of asthma and response to treatment. **Heightened awareness of disparities and cultural barriers, improving access to quality care, and improving communication strategies between clinicians and ethnic or racial minority patients regarding use of asthma medications may improve asthma outcomes.**

FIGURE 11. CLASSIFYING ASTHMA SEVERITY AND INITIATING THERAPY IN CHILDREN

Components of Severity		Classifying Asthma Severity and Initiating Therapy in Children							
		Intermittent		Persistent: Mild		Persistent: Moderate		Persistent: Severe	
		Ages 0–4	Ages 5–11	Ages 0–4	Ages 5–11	Ages 0–4	Ages 5–11	Ages 0–4	Ages 5–11
Impairment	Symptoms	≤2 days/week		>2 days/week but not daily		Daily		Throughout the day	
	Nighttime awakenings	0	≤2x/ month	1–2x/month	3–4x/ month	3–4x/ month	>1x/week but not nightly	>1x/ week	Often 7x/week
	Short-acting beta$_2$-agonist use for symptom control	≤2 days/week		>2 days/week but not daily		Daily		Several times per day	
	Interference with normal activity	None		Minor limitation		Some limitation		Extremely limited	
	Lung Function		Normal FEV_1 between exacerbations						
	• FEV_1 (predicted) or peak flow (personal best)	N/A	>80%	N/A	>80%	N/A	60–80%	N/A	<60%
	• FEV_1/FVC		>85%		>80%		75–80%		<75%
Risk	Exacerbations requiring oral systemic corticosteroids (consider severity and interval since last exacerbation)	0–1/year (see notes)		≥2 exacerbations in 6 months requiring oral systemic corticosteroids, or ≥4 wheezing episodes/1 year lasting >1 day AND risk factors for persistent asthma	≥2x/year (see notes) Relative annual risk may be related to FEV_1				
Recommended Step for Initiating Therapy (See "Stepwise Approach for Managing Asthma" for treatment steps.) The stepwise approach is meant to assist, not replace, the clinical decisionmaking required to meet individual patient needs.		Step 1 (for both age groups)		Step 2 (for both age groups)		Step 3 and consider short course of oral systemic cortico-steroids	Step 3: medium-dose ICS option and consider short course of oral systemic cortico-steroids	Step 3 and consider short course of oral systemic cortico-steroids	Step 3: medium-dose ICS option OR step 4 and consider short course of oral systemic cortico-steroids
		In 2–6 weeks, depending on severity, evaluate level of asthma control that is achieved. • Children 0–4 years old: If no clear benefit is observed in 4–6 weeks, stop treatment and consider alternative diagnoses or adjusting therapy. • Children 5–11 years old: Adjust therapy accordingly.							

Key: FEV_1, forced expiratory volume in 1 second; FVC, forced vital capacity; ICS, inhaled corticosteroids; ICU, intensive care unit; N/A, not applicable

Notes:

- Level of severity is determined by both impairment and risk. Assess impairment domain by caregiver's recall of previous 2–4 weeks. Assign severity to the most severe category in which any feature occurs.
- Frequency and severity of exacerbations may fluctuate over time for patients in any severity category. At present, there are inadequate data to correspond frequencies of exacerbations with different levels of asthma severity. In general, more frequent and severe exacerbations (e.g., requiring urgent, unscheduled care, hospitalization, or ICU admission) indicate greater underlying disease severity. For treatment purposes, patients with ≥2 exacerbations described above may be considered the same as patients who have persistent asthma, even in the absence of impairment levels consistent with persistent asthma.

FIGURE 12. ASSESSING ASTHMA CONTROL AND ADJUSTING THERAPY IN CHILDREN

Components of Control		Assessing Asthma Control and Adjusting Therapy in Children					
		Well Controlled		Not Well Controlled		Very Poorly Controlled	
		Ages 0–4	Ages 5–11	Ages 0–4	Ages 5–11	Ages 0–4	Ages 5–11
Impairment	Symptoms	≤2 days/week but not more than once on each day		>2 days/week or multiple times on ≤2 days/week		Throughout the day	
	Nighttime awakenings	≤1x/month		>1x/month	≥2x/month	>1x/week	≥2x/week
	Interference with normal activity	None		Some limitation		Extremely limited	
	Short-acting $beta_2$-agonist use for symptom control (not prevention of EIB)	≤2 days/week		>2 days/week		Several times per day	
	Lung function • FEV_1 (predicted) or peak flow personal best • FEV_1/FVC	N/A	>80% >80%	N/A	60–80% 75–80%	N/A	<60% <75%
Risk	Exacerbations requiring oral systemic corticosteroids	0–1x/year		2–3x/year	≥2x/year	>3x/year	≥2x/year
	Reduction in lung growth	N/A	Requires long-term followup	N/A		N/A	
	Treatment-related adverse effects	Medication side effects can vary in intensity from none to very troublesome and worrisome. The level of intensity does not correlate to specific levels of control but should be considered in the overall assessment of risk.					
Recommended Action for Treatment (See "Stepwise Approach for Managing Asthma" for treatment steps.) The stepwise approach is meant to assist, not replace, clinical decisionmaking required to meet individual patient needs.		• Maintain current step. • Regular followup every 1–6 months. • Consider step down if well controlled for at least 3 months.		Step up 1 step	Step up at least 1 step	• Consider short course of oral systemic corticosteroids, • Step up 1–2 steps	
				• **Before step up:** Review adherence to medication, inhaler technique, and environmental control. If alternative treatment was used, discontinue it and use preferred treatment for that step. • **Reevaluate the level of asthma control in 2–6 weeks to achieve control; every 1–6 months to maintain control.** **Children 0–4 years old:** If no clear benefit is observed in 4–6 weeks, consider alternative diagnoses or adjusting therapy. **Children 5–11 years old:** Adjust therapy accordingly. • **For side effects,** consider alternative treatment options.			

Key: EIB, exercise-induced bronchospasm, FEV_1, forced expiratory volume in 1 second; FVC, forced vital capacity; ICU, intensive care unit; N/A, not applicable

Notes:

- The level of control is based on the most severe impairment or risk category. Assess impairment domain by patient's or caregiver's recall of previous 2–4 weeks. Symptom assessment for longer periods should reflect a global assessment, such as whether the patient's asthma is better or worse since the last visit.
- At present, there are inadequate data to correspond frequencies of exacerbations with different levels of asthma control. In general, more frequent and intense exacerbations (e.g., requiring urgent, unscheduled care, hospitalization, or ICU admission) indicate poorer disease control.

FIGURE 13. STEPWISE APPROACH FOR MANAGING ASTHMA LONG TERM IN CHILDREN, 0–4 YEARS OF AGE AND 5–11 YEARS OF AGE

Step up if needed (first check inhaler technique, adherence, environmental control, and comorbid conditions)

Assess control

Step down if possible (and asthma is well controlled at least 3 months)

Children 0–4 Years of Age

	Step 1	Step 2	Step 3	Step 4	Step 5	Step 6
	Intermittent Asthma	Persistent Asthma: Daily Medication Consult with asthma specialist if step 3 care or higher is required. Consider consultation at step 2.				
Preferred	SABA PRN	Low-dose ICS	Medium-dose ICS	Medium-dose ICS + LABA *or* Montelukast	High-dose ICS + LABA *or* Montelukast	High-dose ICS + LABA or Montelukast + Oral corticosteriods ICS
Alternative		Cromolyn *or* Montelukast				
	Each Step: Patient Education and Environmental Control					
Quick-Relief Medication	• SABA as needed for symptoms. Intensity of treatment depends on severity of symptoms. • With viral respiratory symptoms: SABA q 4–6 hours up to 24 hours (longer with physician consult). Consider short course of oral systemic corticosteroids if exacerbation is severe or patient has history of previous severe exacerbations. Caution: Frequent use of SABA may indicate the need to step up treatment. See text for recommendations on initiating daily long-term-control therapy.					

Notes

- The stepwise approach is meant to assist, not replace, the clinical decisionmaking required to meet individual patient needs.
- If an alternative treatment is used and response is inadequate, discontinue it and use the preferred treatment before stepping up.
- If clear benefit is not observed within 4–6 weeks, and patient's/family's medication technique and adherence are satisfactory, consider adjusting therapy or an alternative diagnosis.
- Studies on children 0–4 years of age are limited. Step 2 preferred therapy is based on Evidence A. All other recommendations are based on expert opinion and extrapolation from studies in older children.
- Clinicians who administer immunotherapy should be prepared and equipped to identify and treat anaphylaxis that may occur.

Key: Alphabetical listing is used when more than one treatment option is listed within either preferred or alternative therapy. ICS, inhaled corticosteroid; LABA, inhaled long-acting beta$_2$-agonist; LTRA, leukotriene receptor antagonist; oral corticosteroids, oral systemic corticosteroids; SABA, inhaled short-acting beta$_2$-agonist

Children 5–11 Years of Age

	Step 1	Step 2	Step 3	Step 4	Step 5	Step 6
	Intermittent Asthma	Persistent Asthma: Daily Medication Consult with asthma specialist if step 4 care or higher is required. Consider consultation at step 3.				
Preferred	SABA PRN	Low-dose ICS	Low-dose ICS + LABA, LTRA, *or* Theophylline *OR*	Medium-dose ICS + LABA	High-dose ICS + LABA	High-dose ICS + LABA + Oral corticosteroids
Alternative		Cromolyn, LTRA, Nedocromil, *or* Theophylline	Medium-dose ICS	Medium-dose ICS + LTRA *or* Theophylline	High-dose ICS + LTRA *or* Theophylline	High-dose ICS + LTRA *or* Theophylline + oral corticosteroids
	Each Step: Patient Education, Environmental Control, and Management of Comorbidities Steps 2–4: Consider subcutaneous allergen immunotherapy for patients who have persistent, allergic asthma.					
Quick-Relief Medication	• SABA as needed for symptoms. Intensity of treatment depends on severity of symptoms: up to 3 treatments at 20-minute intervals as needed. Short course of oral systemic corticosteroids may be needed. Caution: Increasing use of SABA or use >2 days a week for symptom relief (not prevention of EIB) generally indicates inadequate control and the need to step up treatment.					

Notes

- The stepwise approach is meant to assist, not replace, the clinical decisionmaking required to meet individual patient needs.
- If an alternative treatment is used and response is inadequate, discontinue it and use the preferred treatment before stepping up.
- Theophylline is a less desirable alternative due to the need to monitor serum concentration levels.
- Steps 1 and 2 medications are based on Evidence A. Step 3 ICS and ICS plus adjunctive therapy are based on Evidence B for efficacy of each treatment and extrapolation from comparator trials in older children and adults—comparator trials are not available for this age group; steps 4–6 are based on expert opinion and extrapolation from studies in older children and adults.
- Immunotherapy for steps 2–4 is based on Evidence B for house-dust mites, animal danders, and pollens; evidence is weak or lacking for molds and cockroaches. Evidence is strongest for immunotherapy with single allergens. The role of allergy in asthma is greater in children than adults.
- Clinicians who administer immunotherapy should be prepared and equipped to identify and treat anaphylaxis that may occur.

Key: Alphabetical listing is used when more than one treatment option is listed within either preferred or alternative therapy. ICS, inhaled corticosteroid; LABA, inhaled long-acting beta$_2$-agonist; LTRA, leukotriene receptor antagonist; SABA, inhaled short-acting beta$_2$-agonist

FIGURE 14. CLASSIFYING ASTHMA SEVERITY AND INITIATING TREATMENT IN YOUTHS 12 YEARS OF AGE AND ADULTS

Assessing severity and initiating treatment for patients who are not currently taking long-term control medications

Components of Severity		Classification of Asthma Severity ≥12 years of age			
		Intermittent	Persistent: Mild	Persistent: Moderate	Persistent: Severe
Impairment Normal FEV_1/FVC: 8–19 yr 85% 20 –39 yr 80% 40 –59 yr 75% 60 –80 yr 70%	Symptoms	≤2 days/week	>2 days/week but not daily	Daily	Throughout the day
	Nighttime awakenings	≤2x/month	3–4x/month	>1x/week but not nightly	Often 7x/week
	Short-acting $beta_2$-agonist use for symptom control (not prevention of EIB)	≤2 days/week	>2 days/week but not daily, and not more than 1x on any day	Daily	Several times per day
	Interference with normal activity	None	Minor limitation	Some limitation	Extremely limited
	Lung function	• Normal FEV_1 between exacerbations • FEV_1 >80% predicted • FEV_1/FVC normal	• FEV_1 >80% predicted • FEV_1/FVC normal	• FEV_1 >60% but <80% predicted • FEV_1/FVC reduced 5%	• FEV_1 <60% predicted • FEV_1/FVC reduced >5%
Risk	Exacerbations requiring oral systemic corticosteroids	0–1/year (see note)	≥2/year (see note) →		
		← Consider severity and interval since last exacerbation. → Frequency and severity may fluctuate over time for patients in any severity category. Relative annual risk of exacerbations may be related to FEV_1.			
Recommended Step for Initiating Treatment (See "Stepwise Approach for Managing Asthma" for treatment steps.)		Step 1	Step 2	Step 3 and consider short course of oral systemic corticosteroids	Step 4 or 5
		In 2–6 weeks, evaluate level of asthma control that is achieved and adjust therapy accordingly.			

Key: EIB, exercise-induced bronchospasm, FEV1, forced expiratory volume in 1 second; FVC, forced vital capacity; ICU, intensive care unit

Notes:

- The stepwise approach is meant to assist, not replace, the clinical decisionmaking required to meet individual patient needs.
- Level of severity is determined by assessment of both impairment and risk. Assess impairment domain by patient's/caregiver's recall of previous 2–4 weeks and spirometry. Assign severity to the most severe category in which any feature occurs.
- At present, there are inadequate data to correspond frequencies of exacerbations with different levels of asthma severity. In general, more frequent and intense exacerbations (e.g., requiring urgent, unscheduled care, hospitalization, or ICU admission) indicate greater underlying disease severity. For treatment purposes, patients who had ≥2 exacerbations requiring oral systemic corticosteroids in the past year may be considered the same as patients who have persistent asthma, even in the absence of impairment levels consistent with persistent asthma.

FIGURE 15. ASSESSING ASTHMA CONTROL AND ADJUSTING THERAPY IN YOUTHS ≥12 YEARS OF AGE AND ADULTS

Components of Control		Classification of Asthma Control (≥12 years of age)		
		Well Controlled	Not Well Controlled	Very Poorly Controlled
Impairment	Symptoms	≤2 days/week	>2 days/week	Throughout the day
	Nighttime awakenings	≤2x/month	1–3x/week	≥4x/week
	Interference with normal activity	None	Some limitation	Extremely limited
	Short-acting beta$_2$-agonist use for symptom control (not prevention of EIB)	≤2 days/week	>2 days/week	Several times per day
	FEV_1 or peak flow	>80% predicted/ personal best	60–80% predicted/ personal best	<60% predicted/ personal best
	Validated questionnaires ATAQ ACQ ACT	 0 ≤0.75* ≥20	 1–2 ≥1.5 16–19	 3–4 N/A ≤15
Risk	Exacerbations requiring oral systemic corticosteroids	0–1/year	≥2/year (see note)	
		Consider severity and interval since last exacerbation		
	Progressive loss of lung function	Evaluation requires long-term followup care.		
	Treatment-related adverse effects	Medication side effects can vary in intensity from none to very troublesome and worrisome. The level of intensity does not correlate to specific levels of control but should be considered in the overall assessment of risk.		
Recommended Action for Treatment (See "Stepwise Approach for Managing Asthma" for treatment steps.)		• Maintain current step. • Regular followup at every 1–6 months to maintain control. • Consider step down if well controlled for at least 3 months.	• Step up 1 step. • Reevaluate in 2–6 weeks. • For side effects, consider alternative treatment options.	• Consider short course of oral systemic corticosteroids. • Step up 1–2 steps. • Reevaluate in 2 weeks. • For side effects, consider alternative treatment options.

*ACQ values of 0.76–1.4 are indeterminate regarding well-controlled asthma.

Key: EIB, exercise-induced bronchospasm; ICU, intensive care unit

Notes:

- The stepwise approach is meant to assist, not replace, the clinical decisionmaking required to meet individual patient needs.
- The level of control is based on the most severe impairment or risk category. Assess impairment domain by patient's recall of previous 2–4 weeks and by spirometry/or peak flow measures. Symptom assessment for longer periods should reflect a global assessment, such as inquiring whether the patient's asthma is better or worse since the last visit.
- At present, there are inadequate data to correspond frequencies of exacerbations with different levels of asthma control. In general, more frequent and intense exacerbations (e.g., requiring urgent, unscheduled care, hospitalization, or ICU admission) indicate poorer disease control. For treatment purposes, patients who had ≥2 exacerbations requiring oral systemic corticosteroids in the past year may be considered the same as patients who have not-well-controlled asthma, even in the absence of impairment levels consistent with not-well-controlled asthma.

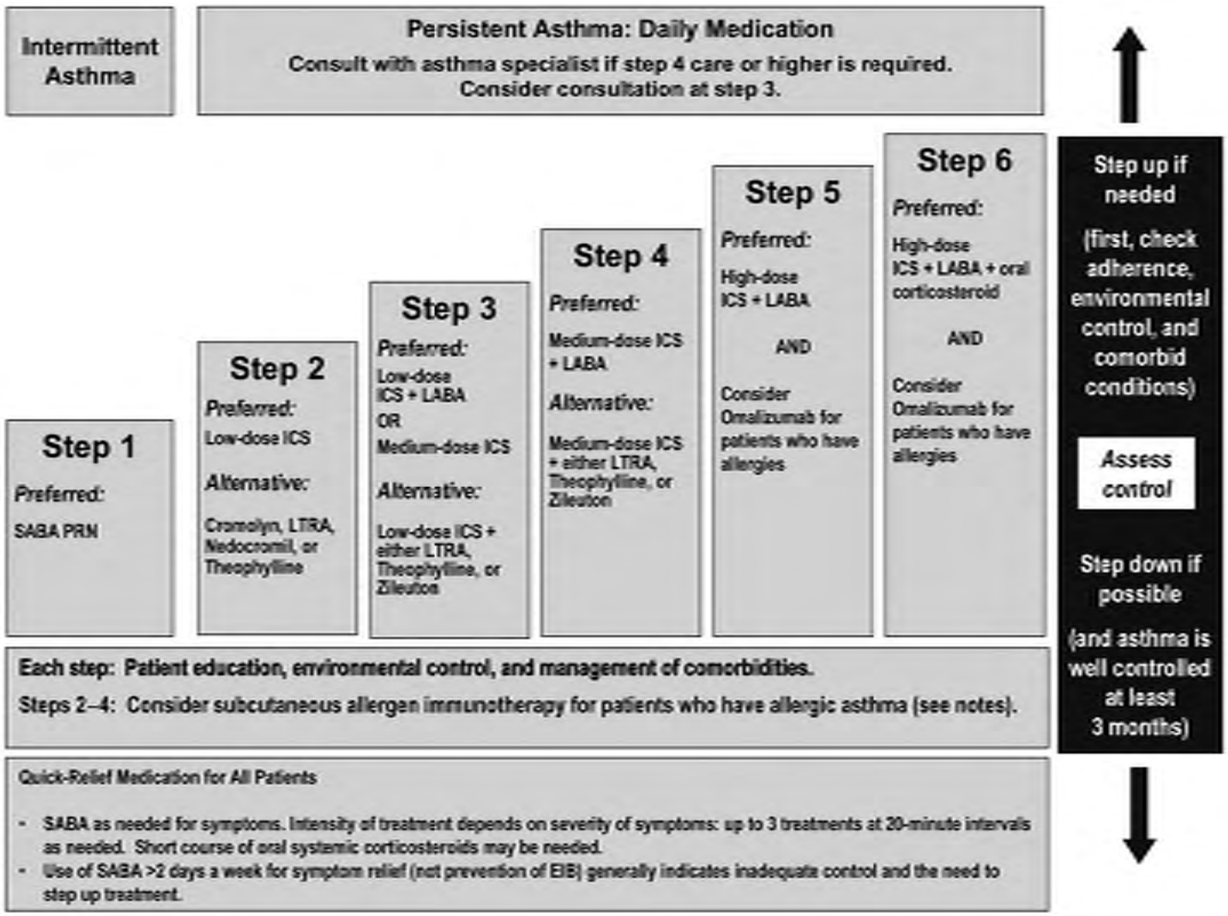
  ATAQ = Asthma Therapy Assessment Questionnaire©
  ACQ = Asthma Control Questionnaire©
  ACT = Asthma Control Test™
  Minimal Important
  Difference: 1.0 for the ATAQ; 0.5 for the ACQ; not determined for the ACT.

Before step up in therapy:

— Review adherence to medication, inhaler technique, environmental control, and comorbid conditions.

— If an alternative treatment option was used in a step, discontinue and use the preferred treatment for that step.

FIGURE 16. STEPWISE APPROACH FOR MANAGING ASTHMA IN YOUTHS ≥12 YEARS OF AGE AND ADULTS



Key: **Alphabetical order is used when more than one treatment option is listed within either preferred or alternative therapy.** ICS, inhaled corticosteroid; LABA, long-acting inhaled beta$_2$-agonist; LTRA, leukotriene receptor antagonist; SABA, inhaled short-acting beta$_2$-agonist

Notes:

- The stepwise approach is meant to assist, not replace, the clinical decisionmaking required to meet individual patient needs.
- If alternative treatment is used and response is inadequate, discontinue it and use the preferred treatment before stepping up.
- Zileuton is a less desirable alternative due to limited studies as adjunctive therapy and the need to monitor liver function. Theophylline requires monitoring of serum concentration levels.
- In step 6, before oral corticosteroids are introduced, a trial of high-dose ICS + LABA + either LTRA, theophylline, or zileuton may be considered, although this approach has not been studied in clinical trials.
- Step 1, 2, and 3 preferred therapies are based on Evidence A; step 3 alternative therapy is based on Evidence A for LTRA, Evidence B for theophylline, and Evidence D for zileuton. Step 4 preferred therapy is based on Evidence B, and alternative therapy is based on Evidence B for LTRA and theophylline and Evidence D zileuton. Step 5 preferred therapy is based on Evidence B. Step 6 preferred therapy is based on (EPR—2 1997) and Evidence B for omalizumab.
- Immunotherapy for steps 2–4 is based on Evidence B for house-dust mites, animal danders, and pollens; evidence is weak or lacking for molds and cockroaches. Evidence is strongest for immunotherapy with single allergens. The role of allergy in asthma is greater in children than in adults.
- Clinicians who administer immunotherapy or omalizumab should be prepared and equipped to identify and treat anaphylaxis that may occur.

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Exhibit A40-2

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FIGURE 17. USUAL DOSAGES FOR LONG-TERM CONTROL MEDICATIONS*

Medication	0–4 Years of Age	5–11 Years of Age	≥12 Years of Age and Adults	Potential Adverse Effects	Comments (not all inclusive)
Inhaled Corticosteroids (See Figure 18, "Estimated Comparative Daily Dosages for ICSs.")					
Oral Systemic Corticosteroids					**(Apply to all three corticosteriods.)**
Methylprednisolone 2, 4, 8, 16, 32 mg tablets Prednisolone 5 mg tablets, 5 mg/5 cc, 15 mg/5 cc Prednisone 1, 2.5, 5, 10, 20, 50 mg tablets; 5 mg/cc, 5 mg/5 cc	0.25–2 mg/kg daily in single dose in a.m. or qod as needed for control Short-course "burst": 1–2 mg/kg/day, maximum 60 mg/day for 3–10 days	0.25–2 mg/kg daily in single dose in a.m. or qod as needed for control Short-course "burst": 1–2 mg/kg/day, maximum 60 mg/day for 3–10 days	7.5–60 mg daily in a single dose in a.m. or qod as needed for control Short-course "burst": to achieve control, 40–60 mg per day as single or 2 divided doses for 3–10 days	■ Short-term use: reversible abnormalities in glucose metabolism, increased appetite, fluid retention, weight gain, mood alteration, hypertension, peptic ulcer, and rarely aseptic necrosis. ■ Long-term use: adrenal axis suppression, growth suppression, dermal thinning, hypertension, diabetes, Cushing's syndrome, cataracts, muscle weakness, and—in rare instances—impaired immune function. ■ Consideration should be given to coexisting conditions that could be worsened by systemic corticosteroids, such as herpes virus infections, varicella, tuberculosis, hypertension, peptic ulcer, diabetes mellitus, osteoporosis, and Strongyloides	■ For long-term treatment of severe persistent asthma, administer single dose in a.m. either daily or on alternate days (alternate-day therapy may produce less adrenal suppression). ■ Short courses or "bursts" are effective for establishing control when initiating therapy or during a period of gradual deterioration. ■ There is no evidence that tapering the dose following improvement in symptom control and pulmonary function prevents relapse. ■ Children receiving the lower dose (1 mg/kg/day) experience fewer behavioral side effects, and it appears to be equally efficacious. ■ For patients unable to tolerate the liquid preparations, dexamethasone syrup at 0.4 mg/kg/day may be an alternative. Studies are limited, however, and the longer duration of activity increases the risk of adrenal suppression.
Inhaled Long-Acting Beta$_2$-Agonists (LABAs)					**(Apply to both LABAs.)**
Salmeterol DPI 50 mcg/blister	NA	1 blister q 12 hours	1 blister q 12 hours	■ Tachycardia, skeletal muscle tremor, hypokalemia, prolongation of QTc interval in overdose. ■ A diminished bronchoprotective effect may occur within 1 week of chronic therapy. Clinical significance has not been established. ■ Potential risk of uncommon, severe, life-threatening or fatal exacerbation; see text for additional discussion regarding safety of LABAs.	■ **Should not be used for acute symptom relief or exacerbations. Use only with ICSs.** ■ Decreased duration of protection against EIB may occur with regular use. ■ Most children <4 years of age cannot provide sufficient inspiratory flow for adequate lung delivery. ■ Do not blow into inhaler after dose is activated. ■ Each capsule is for single use only; additional doses should not be administered for at least 12 hours. ■ Capsules should be used only with the inhaler and should not be taken orally.
Formoterol DPI 12 mcg/single-use capsule	NA	1 capsule q 12 hours	1 capsule q 12 hours		

Key: DPI, dry powder inhaler; EIB, exercise-induced broncospasm; HFA, hydrofluoroalkane; ICS, inhaled corticosteroids; IgE, immunoglobulin E; MDI, metered-dose inhaler; NA, not available (either not approved, no data available, or safety and efficacy not established for this age group); SABA, short-acting beta$_2$-agonist

***Note:** Dosages are provided for those products that have been approved by the U.S. Food and Drug Administration or have sufficient clinical trial safety and efficacy data in the appropriate age ranges to support their use.

FIGURE 17. USUAL DOSAGES FOR LONG-TERM CONTROL MEDICATIONS* (continued)

Medication	0–4 Years of Age	5–11 Years of Age	≥12 Years of Age and Adults	Potential Adverse Effects	Comments (not all inclusive)
Combined Medication					
Fluticasone/Salmeterol				■ See notes for ICS and LABA.	■ There have been no clinical trials in children <4 years of age. ■ Most children <4 years of age cannot provide sufficient inspiratory flow for adequate lung delivery. ■ Do not blow into inhaler after dose is activated. ■ 100/50 DPI or 45/21 HFA for patients who have asthma not controlled on low- to medium-dose ICS ■ 250/50 DPI or 115/21 HFA for patients who have asthma not controlled on medium to high dose ICS.
DPI 100 mcg/50 mcg, 250 mcg/50 mcg, or 500 mcg/ 50 mcg	NA	1 inhalation bid, dose depends on level of severity or control	1 inhalation bid; dose depends on level of severity or control		
HFA 45 mcg/21 mcg 115 mcg/21 mcg 230 mcg/21 mcg					
Budesonide/ Formoterol				■ See notes for ICS and LABA.	■ There have been no clinical trials in children <4 years of age. ■ Currently approved for use in youths ≥12 years of age. Dose for children 5–12 years of age based on clinical trials using DPI with slightly different delivery characteristics. ■ 80/4.5 for patients who have asthma not controlled on low- to medium-dose ICS. ■ 160/4.5 for patients who have asthma not controlled on medium- to high-dose ICS.
HFA MDI 80 mcg/4.5 mcg 160mcg/4.5 mcg	NA	2 puffs bid, dose depends on level of severity or control	2 puffs bid; dose depends on level of severity or control		
Cromolyn/Nedocromil					
Cromolyn				■ Cough and irritation. ■ 15–20 percent of patients complain of an unpleasant taste from nedocromil.	■ One dose of cromolyn before exercise or allergen exposure provides effective prophylaxis for 1–2 hours. Not as effective as inhaled beta$_2$-agonists for EIB as SABA.
MDI 0.8 mg/puff	NA	2 puffs qid	2 puffs qid		
Nebulizer 20 mg/ampule	1 ampule qid NA <2 years of age	1 ampule qid	1 ampule qid	■ Safety is the primary advantage of these	■ 4- to 6-week trial of cromolyn or nedocromil may be needed to determine maximum benefit. ■ Dose by MDI may be inadequate to affect hyperresponsiveness. ■ Once control is achieved, the frequency of dosing may be reduced.
Nedocromil					
MDI 1.75 mg/puff	NA <6 years of age	2 puffs qid	2 puffs qid		

FIGURE 17. USUAL DOSAGES FOR LONG-TERM CONTROL MEDICATIONS* (continued)

Medication	0–4 Years of Age	5–11 Years of Age	≥12 Years of Age and Adults	Potential Adverse Effects	Comments (not all inclusive)
Immunomodulators					
Omalizumab (Anti IgE) Subcutaneous injection, 150 mg/ 1.2 mL following reconstitution with 1.4 mL sterile water for injection	NA	NA	150–375 mg SC q 2–4 weeks, depending on body weight and pretreatment serum IgE level	■ Pain and bruising of injection sites in 5–20 percent of patients. ■ Anaphylaxis has been reported in 0.2% of treated patients. ■ Malignant neoplasms were reported in 0.5 percent of patients compared to 0.2 percent receiving placebo; relationship to drug is unclear.	■ Do not administer more than 150 mg per injection site. ■ Monitor patients following injections; be prepared and equipped to identify and treat anaphylaxis that may occur. ■ Whether patients will develop significant antibody titers to the drug with long-term administration is unknown.
Leukotriene Modifiers					
Leukotriene Receptor Antagonists (LTRAs) Montelukast 4 mg or 5 mg chewable tablet 4 mg granule packets 10 mg tablet	4 mg qhs (1–5 years of age)	5 mg qhs (6–14 years of age)	10 mg qhs	■ No specific adverse effects have been identified. ■ Rare cases of Churg-Strauss have occurred, but the association is unclear.	■ Montelukast exhibits a flat dose-response curve. Doses >10 mg will not produce a greater response in adults. ■ No more efficacious than placebo in infants ages 6–24 months. ■ As long-term therapy may attenuate exercise-induced bronchospasm in some patients, but less effective than ICS therapy.
Zafirlukast 10 mg tablet 20 mg tablet	NA	10 mg bid (7–11 years of age)	40 mg daily (20 mg tablet bid)	■ Postmarketing surveillance has reported cases of reversible hepatitis and, rarely, irreversible hepatic failure resulting in death and liver transplantation.	■ For zafirlukast, administration with meals decreases bioavailability; take at least 1 hour before or 2 hours after meals. ■ Zarfirlukast is a microsomal P450 enzyme inhibitor that can inhibit the metabolism of warfarin. Doses of these drugs should be monitored accordingly. ■ Monitor hepatic enzymes (ALT). Warn patients to discontinue use if they experience signs and symptoms of liver dysfunction.
5-Lipoxygenase Inhibitor Zileuton 600 mg tablet	NA	NA	2,400 mg daily (give tablets qid)	■ Elevation of liver enzymes has been reported. Limited case reports of reversible hepatitis and hyperbilirubinemia.	■ For zileuton, monitor hepatic enzymes (ALT). ■ Zileuton is a microsomal P450 enzyme inhibitor that can inhibit the metabolism of warfarin and theophylline. Doses of these drugs should be monitored accordingly.
Methylxanthines					
Theophylline Liquids, sustained-release tablets, and capsules	Starting dose 10 mg/kg/day; usual maximum: ■ <1 year of age: 0.2 (age in weeks) + 5 = mg/kg/day ■ ≥1 year of age: 16 mg/kg/day	Starting dose 10 mg/kg/day; usual maximum: 16 mg/kg/day	Starting dose 10 mg/kg/day up to 300 mg maximum; usual maximum: 800 mg/day	■ Dose-related acute toxicities include tachycardia, nausea and vomiting, tachyarrhythmias (SVT), central nervous system stimulation, headache, seizures, hematemesis, hyperglycemia, and hypokalemia. ■ Adverse effects at usual therapeutic doses include insomnia, gastric upset, aggravation of ulcer or reflux, increase in hyperactivity in some children, difficulty in urination in elderly males who have prostatism.	■ Adjust dosage to achieve serum concentration of 5–15 mcg/mL at steady state (at least 48 hours on same dosage). ■ Due to wide interpatient variability in theophylline metabolic clearance, routine serum theophylline level monitoring is essential. ■ Patients should be told to discontinue if they experience toxicity. ■ Various factors (diet, food, febrile illness, age, smoking, and other medications) can affect serum concentrations. See EPR—3 Full Report 2007 and package inserts for details.

FIGURE 18. ESTIMATED COMPARATIVE DAILY DOSAGES FOR INHALED CORTICOSTEROIDS

Drug	Low Daily Dose			Medium Daily Dose			High Daily Dose		
	Child 0–4 Years of Age	Child 5–11 Years of Age	≥12 Years of Age and Adults	Child 0–4 Years of Age	Child 5–11 Years of Age	≥12 Years of Age and Adults	Child 0–4 Years of Age	Child 5–11 Years of Age	≥12 Years of Age and Adults
Beclomethasone HFA 40 or 80 mcg/puff	NA	80–160 mcg	80–240 mcg	NA	>160–320 mcg	>240–480 mcg	NA	>320 mcg	>480 mcg
Budesonide DPI 90, 180, or 200 mcg/inhalation	NA	180–400 mcg	180–600 mcg	NA	>400–800 mcg	>600–1,200 mcg	NA	>800 mcg	>1,200 mcg
Budesonide Inhaled Inhalation suspension for nebulization	0.25–0.5 mg	0.5 mg	NA	>0.5–1.0 mg	1.0 mg	NA	>1.0 mg	2.0 mg	NA
Flunisolide 250 mcg/puff	NA	500–750 mcg	500–1,000 mcg	NA	1,000–1,250 mcg	>1,000–2,000 mcg	NA	>1,250 mcg	>2,000 mcg
Flunisolide HFA 80 mcg/puff	NA	160 mcg	320 mcg	NA	320 mcg	>320–640 mcg	NA	≥640 mcg	>640 mcg
Fluticasone **HFA/MDI:** 44, 110, or 220 mcg/puff	176 mcg	88–176 mcg	88–264 mcg	>176–352 mcg	>176–352 mcg	>264–440 mcg	>352 mcg	>352 mcg	>440 mcg
DPI: 50, 100, or 250 mcg/inhalation	NA	100–200 mcg	100–300 mcg	NA	>200–400 mcg	>300–500 mcg	NA	>400 mcg	>500 mcg
Mometasone DPI 200 mcg/inhalation	NA	NA	200 mcg	NA	NA	400 mcg	NA	NA	>400 mcg
Triamcinolone acetonide 75 mcg/puff	NA	300–600 mcg	300–750 mcg	NA	>600–900 mcg	>750–1,500 mcg	NA	>900 mcg	>1,500 mcg

Key: DPI, dry power inhaler; HFA, hydrofluoroalkane; MDI, metered-dose inhaler; NA, not available (either not approved, no data available, or safety and efficacy not established for this age group)

Therapeutic Issues:

- The most important determinant of appropriate dosing is the clinician's judgment of the patient's response to therapy. The clinician must monitor the patient's response on several clinical parameters and adjust the dose accordingly. Once control of asthma is achieved, the dose should be carefully titrated to the minimum dose required to maintain control.
- Preparations are not interchangeable on a mcg or per puff basis. This figure presents estimated comparable daily doses. See EPR—3 Full Report 2007 for full discussion.
- Some doses may be outside package labeling, especially in the high-dose range. Budesonide nebulizer suspension is the only inhaled corticosteroid (ICS) with FDA-approved labeling for children <4 years of age.
- For children <4 years of age: The safety and efficacy of ICSs in children <1 year has not been established. Children <4 years of age generally require delivery of ICS (budesonide and fluticasone HFA) through a face mask that should fit snugly over nose and mouth and avoid nebulizing in the eyes. Wash face after each treatment to prevent local corticosteroid side effects. For budesonide, the dose may be administered 1–3 times daily. Budesonide suspension is compatible with albuterol, ipratropium, and levalbuterol nebulizer solutions in the same nebulizer. Use only jet nebulizers, as ultrasonic nebulizers are ineffective for suspensions. For fluticasone HFA, the dose should be divided 2 times daily; the low dose for children <4 years of age is higher than for children 5–11 years of age due to lower dose delivered with face mask and data on efficacy in young children.

Potential Adverse Effects of Inhaled Corticosteroids:

- Cough, dysphonia, oral thrush (candidiasis).
- Spacer or valved holding chamber with non-breath-actuated MDIs and mouthwashing and spitting after inhalation decrease local side effects.
- A number of the ICSs, including fluticasone, budesonide, and mometasone, are metabolized in the gastrointestinal tract and liver by CYP 3A4 isoenzymes. Potent inhibitors of CYP 3A4, such as ritonavir and ketoconazole, have the potential for increasing systemic concentrations of these ICSs by increasing oral availability and decreasing systemic clearance. Some cases of clinically significant Cushing syndrome and secondary adrenal insufficiency have been reported.
- In high doses, systemic effects may occur, although studies are not conclusive, and clinical significance of these effects has not been established (e.g., adrenal suppression, osteoporosis, skin thinning, and easy bruising). In low-to-medium doses, suppression of growth velocity has been observed in children, but this effect may be transient, and the clinical significance has not been established.

FIGURE 19. USUAL DOSAGES FOR QUICK-RELIEF MEDICATIONS*

Medication	<5 Years of Age	5–11 Years of Age	≥12 Years of Age and Adults	Potential Adverse Effects	Comments (not all inclusive)
Inhaled Short-Acting Beta$_2$-Agonists					
	Dose applies to Albuterol.	***Dose applies to Albuterol/and Levalbuterol.***	***Dose applies to all four SABAs***		***Apply to all four (SABAs)***
MDI					
Albuterol CFC 90 mcg/puff, 200 puffs/canister	1–2 puffs 5 minutes before exercise	2 puffs 5 minutes before exercise	2 puffs 5 minutes before exercise	■ Tachycardia, skeletal muscle tremor, hypokalemia, increased lactic acid, headache, hyperglycemia. Inhaled route, in general, causes few systemic adverse effects. Patients with preexisting cardiovascular disease, especially the elderly, may have adverse cardiovascular reactions with inhaled therapy.	■ Drugs of choice for acute bronchospasm. ■ Differences in potencies exist, but all products are essentially comparable on a puff per puff basis. ■ An increasing use or lack of expected effect indicates diminished control of asthma. ■ Not recommended for long-term daily treatment. Regular use exceeding 2 days/week for symptom control (not prevention of EIB) indicates the need for additional long-term control therapy. ■ May double usual dose for mild exacerbations. ■ For levalbuterol, prime the inhaler by releasing 4 actuations prior to use. ■ For HFA: periodically clean HFA actuator, as drug may plug orifice. ■ For autohaler: children <4 years of age may not generate sufficient inspiratory flow to activate an auto-inhaler. ■ Nonselective agents (i.e., epinephrine, isoproterenol, metaproterenol) are not recommended due to their potential for excessive cardiac stimulation, especially in high doses.
Albuterol HFA 90 mcg/puff, 200 puffs/canister	2 puffs every 4–6 hours, as needed for symptoms	2 puffs every 4–6 hours, as needed for symptoms	2 puffs every 4–6 hours, as needed for symptoms		
Levalbuterol HFA 45 mcg/puff, 200 puffs/canister	NA <4 years of age				
Pirbuterol CFC Autohaler 200 mcg/puff, 400 puffs/canister	NA	NA			
Nebulizer solution					■ May mix with cromolyn solution, budesonide inhalant suspension, or ipratropium solution for nebulization. May double dose for severe exacerbations.
Albuterol 0.63 mg/3 mL 1.25 mg/3 mL 2.5 mg/3 mL 5 mg/mL (0.5%)	0.63–2.5 mg in 3 cc of saline q 4–6 hours, as needed	1.25–5 mg in 3 cc of saline q 4–8 hours, as needed	1.25–5 mg in 3 cc of saline q 4–8 hours, as needed	(Same as with MDI)	■ Does not have FDA-approved labeling for children <6 years of age. ■ Compatible with budesonide inhalant suspension. The product is a sterile-filled preservative-free unit dose vial.
Levalbuterol (R-albuterol) 0.31 mg/3 mL 0.63 mg/3 mL 1.25 mg/0.5 mL 1.25 mg/3 mL	0.31–1.25 mg in 3 cc q 4–6 hours, as needed for symptoms	0.31–0.63 mg, q 8 hours, as needed for symptoms	0.63 mg–1.25 mg q 8 hours, as needed for symptoms	(Same as with MDI)	

Key: CFC, chlorofluorocarbon; ED, emergency department; EIB, exercise-induced bronchospasm; HFA, hydrofluoroalkane; IM, intramuscular; MDI, metered-dose inhaler; NA, not available (either not approved, no data available, or safety and efficacy not established for this age group); PEF, peak expiratory flor; SABA, short-acting beta$_2$-agonist

*Dosages are provided for those products that have been approved by the U.S. Food and Drug Administration (FDA) or have sufficient clinical trial safety and efficacy data in the appropriate age ranges to support their use.

FIGURE 19. USUAL DOSAGES FOR QUICK-RELIEF MEDICATIONS* (continued)

Medication	<5 Years of Age	5–11 Years of Age	≥12 Years of Age and Adults	Potential Adverse Effects	Comments (not all inclusive)
Anticholinergics					
Ipratropium HFA					
MDI					
17 mcg/puff, 200 puffs/canister	NA	NA	2–3 puffs q 6 hours	■ Drying of mouth and respiratory secretions, increased wheezing in some individuals, blurred vision if sprayed in eyes. If used in the ED, produces less cardiac stimulation than SABAs.	■ Multiple doses in the emergency department (not hospital) setting provide additive benefit to SABA. ■ Treatment of choice for bronchospasm due to beta-blocker medication. ■ Does not block EIB. ■ Reverses only cholinergically mediated bronchospasm; does not modify reaction to antigen. ■ May be an alternative for patients who do not tolerate SABA. ■ Has not proven to be efficacious as long-term control therapy for asthma.
Nebulizer solution					
0.25 mg/mL (0.025%)	NA	NA	0.25 mg q 6 hours		
Ipratropium with albuterol					
MDI					
18 mcg/puff of ipratropium bromide and 90 mcg/puff of albuterol	NA	NA	2–3 puffs q 6 hours		
200 puffs/canister					
Nebulizer solution					
0.5 mg/3 mL ipratropium bromide and 2.5 mg/3 mL albuterol	NA	NA	3 mL q 4–6 hours		■ Contains EDTA to prevent discoloration of the solution. This additive does not induce bronchospasm.
Systemic Corticosteroids					
	Dosages apply to first three corticosteroids.				***(Applies to the first three corticosteroids.)***
Methylprednisolone 2, 4, 6, 8, 16, 32 mg tablets Prednisolone 5 mg tablets, 5 mg/5 cc, 15 mg/5 cc Prednisone 1, 2.5, 5, 10, 20, 50 mg tablets; 5 mg/cc, 5 mg/5 cc	Short course "burst:" 1–2 mg/kg/day, maximum 60 mg/day, for 3–10 days	Short course "burst": 1-2 mg/kg/day maximum 60 mg/day for 3–10 days	Short course "burst": 40–60 mg/day as single or 2 divided doses for 3–10 days	■ Short-term use: reversible abnormalities in glucose metabolism, increased appetite, fluid retention, weight gain, facial flushing, mood alteration, hypertension, peptic ulcer, and rarely aseptic necrosis. ■ Consideration should be given to coexisting conditions that could be worsened by systemic corticosteroids, such as herpes virus infections, varicella, tuberculosis, hypertension, peptic ulcer, diabetes mellitus, osteoporosis, and *Strongyloides*.	■ Short courses or "bursts" are effective for establishing control when initiating therapy or during a period of gradual deterioration. Action may begin within an hour. ■ The burst should be continued until patient achieves 80 percent PEF personal best or symptoms resolve. This usually requires 3–10 days but may require longer. There is no evidence that tapering the dose following improvement prevents relapse in asthma exacerbations. ■ Other systemic corticosteroids such as hydrocortisone and dexamethasone given in equipotent daily doses are likely to be as effective as prednisolone.

FIGURE 19. USUAL DOSAGES FOR QUICK-RELIEF MEDICATIONS* (continued)

Medication	<5 Years of Age	5–11 Years of Age	≥12 Years of Age and Adults	Potential Adverse Effects	Comments (not all inclusive)
Systemic Corticosteroids (continued)					
Repository injection (Methylprednisolone acetate) 40 mg/mL 80 mg/mL	7.5 mg/kg IM once	240 mg IM once	240 mg IM once		■ May be used in place of a short burst of oral steroids in patients who are vomiting or if adherence is a problem.

Managing Exacerbations

Asthma exacerbations are acute or subacute episodes of progressively worsening shortness of breath, cough, wheezing, and chest tightness, or some combination of these symptoms. Exacerbations are characterized by decreases in expiratory airflow; objective measures of lung function (spirometry or PEF) are more reliable indicators of severity than symptoms are. Individuals whose asthma is well controlled with ICSs have decreased risk of exacerbations. However, these patients can still be vulnerable to exacerbations, for example, when they have viral respiratory infections.

Effective management of exacerbations incorporates the same four components of asthma management used in managing asthma long term: assessment and monitoring, patient education, environmental control, and medications.

Classifying Severity

Do not underestimate the severity of an exacerbation. Severe exacerbations can be life threatening and can occur in patients at any level of asthma severity—i.e., intermittent, or mild, moderate, or severe persistent asthma. See figure 20, "Classifying Severity of Asthma Exacerbations in the Urgent or Emergency Care Setting."

Patients at high risk of asthma-related death require special attention—particularly intensive education, monitoring, and care. Such patients should be advised to seek medical care early during an exacerbation. Risk factors for asthma-related death include:

- Previous severe exacerbation (e.g., intubation or ICU admission for asthma)
- Two or more hospitalizations or >3 ED visits in the past year
- Use of >2 canisters of SABA per month
- Difficulty perceiving airway obstruction or the severity of worsening asthma
- Low socioeconomic status or inner-city residence
- Illicit drug use
- Major psychosocial problems or psychiatric disease
- Comorbidities, such as cardiovascular disease or other chronic lung disease

Home Management

Early treatment by the patient at home is the best strategy for managing asthma exacerbations. Patients should be instructed how to:

- **Use a written asthma action plan** that notes when and how to treat signs of an exacerbation. A peak flow-based plan may be particularly useful for patients who have difficulty perceiving airflow obstruction or have a history of severe exacerbations.
- **Recognize early indicators of an exacerbation,** including worsening PEF.
- **Adjust their medications** by increasing SABA and, in some cases, adding a short course of oral systemic corticosteroids. Doubling the dose of ICSs is not effective.
- **Remove or withdraw from allergens or irritants** in the environment that may contribute to the exacerbation.
- **Monitor response to treatment and promptly communicate with the clinician about any serious deterioration** in symptoms or PEF or about decreased responsiveness to SABA treatment, including decreased duration of effect.

The following home management techniques are not recommended because no studies demonstrate their effectiveness and they may delay patients from obtaining necessary care: drinking large volumes of liquids; breathing warm, moist air; or using over-the-counter products, such as antihistamines or cold remedies. Pursed-lip and other forms of breathing may help to maintain calm, but these methods do not improve lung function.

FIGURE 20. CLASSIFYING SEVERITY OF ASTHMA EXACERBATIONS IN THE URGENT OR EMERGENCY CARE SETTING

Note: Patients are instructed to use quick-relief medications if symptoms occur or if PEF drops below 80 percent predicted or personal best. If PEF is 50–79 percent, the patient should monitor response to quick-relief medication carefully and consider contacting a clinician. If PEF is below 50 percent, immediate medical care is usually required. In the urgent or emergency care setting, the following parameters describe the severity and likely clinical course of an exacerbation.

	Symptoms and Signs	Initial PEF (or FEV1)	Clinical Course
Mild	Dyspnea only with activity (assess tachypnea in young children)	PEF ≥ 70 percent predicted or personal best	■ Usually cared for at home ■ Prompt relief with inhaled SABA ■ Possible short course of oral systemic corticosteroids
Moderate	Dyspnea interferes with or limits usual activity	PEF 40–69 percent predictedor personal best	■ Usually requires office or ED visit ■ Relief from frequent inhaled SABA ■ Oral systemic corticosteroids; some symptoms last for 1–2 days after treatment is begun
Severe	Dyspnea at rest; interferes with conversation	PEF <40 percent predicted or personal best	■ Usually requires ED visit and likely hospitalization ■ Partial relief from frequent inhaled SABA ■ Oral systemic corticosteroids; some symptoms last for >3 days after treatment is begun ■ Adjunctive therapies are helpful
Subset: Life threatening	Too dyspneic to speak; perspiring	PEF <25 percent predicted or personal best	■ Requires ED/hospitalization; possible ICU ■ Minimal or no relief from frequent inhaled SABA ■ Intravenous corticosteroids ■ Adjunctive therapies are helpful

Key: ED, emergency department; FEV_1, forced expiratory volume in 1 second; ICU, intensive care unit; PEF, peak expiratory flow; SABA, short-acting $beta_2$-agonist

Management in the Urgent or Emergency Care and Hospital Settings

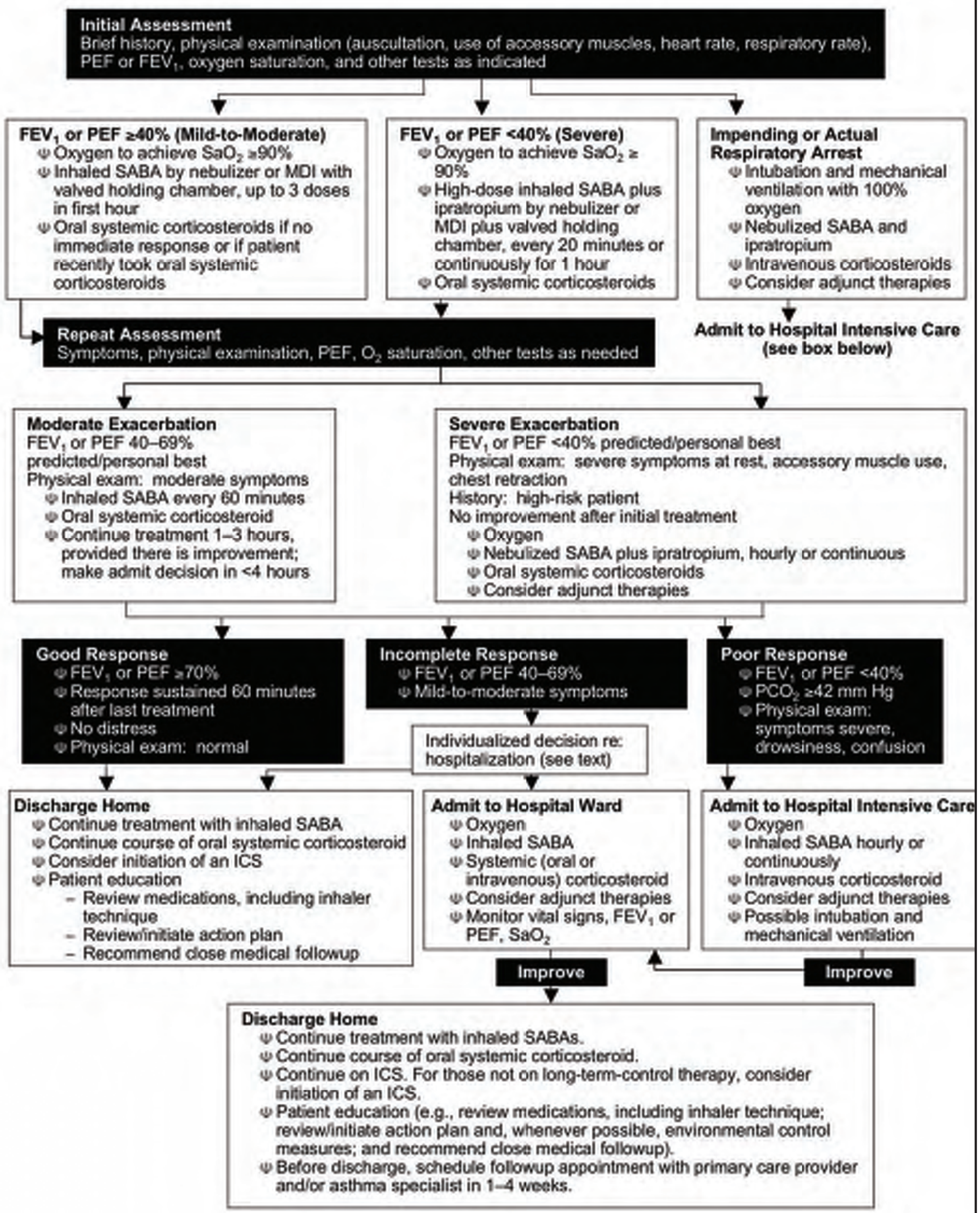
Emergency medical services providers should have prehospital protovols that allow administration of SABA, supplemental oxygen, and (with appropriate medical oversight) anticholinergics and oral systemic corticosteriods to patients who have signs or symptoms of an asthma exacerbation.

Treatment strategies for managing moderate or severe exacerbations in the urgent or emergency care setting are described below. Also see figure 21 for a detailed sequence of recommended actions for monitoring and treatment and figure 22 for dosages of drugs for asthma exacerbations.

- **Administer supplemental oxygen** to correct significant hypoxemia in moderate or severe exacerbations.
- **Administer repetitive or continuous administration of SABA** to reverse airflow obstruction rapidly.
- **Administer oral systemic corticosteroids** to decrease airway inflammation in moderate or severe exacerbations or for patients who fail to respond promptly and completely to SABA treatment.
- **Monitor response to therapy with serial assessments.**

  — For children:

FIGURE 21. MANAGEMENT OF ASTHMA EXACERBATIONS: EMERGENCY DEPARTMENT AND HOSPITAL-BASED CARE



Key: FEV_1, forced expiratory volume in 1 second; ICS, inhaled corticosteroid; MDI, metered-dose inhaler; PCO2, partial pressure carbon dioxide; PEF, peak expiratory flow; SABA, short-acting $beta_2$-agonist; SaO2, oxygen saturation

FIGURE 22. DOSAGES OF DRUGS FOR ASTHMA EXACERBATIONS

	Dosage		
Medication	**Child Dose***	**Adult Dose**	**Comments (not all inclusive)**
Inhaled Short-Acting Beta$_2$-Agonists (SABA)			
Albuterol Nebulizer solution (0.63 mg/3 mL, 1.25 mg/3 mL, 2.5 mg/3 mL, 5.0 mg/mL)	0.15 mg/kg (minimum dose 2.5 mg) every 20 minutes for 3 doses then 0.15–0.3 mg/kg up to 10 mg every 1–4 hours as needed, or 0.5 mg/kg/hour by continuous nebulization.	2.5–5 mg every 20 minutes for 3 doses, then 2.5–10 mg every 1–4 hours as needed, or 10–15 mg/hour continuously.	Only selective beta$_2$ agonists are recommended. For optimal delivery, dilute aerosols to minimum of 3 mL at gas flow of 6–8 L/min. Use large volume nebulizers for continuous administration. May mix with ipratropium nebulizer solution.
MDI (90 mcg/puff)	4–8 puffs every 20 minutes for 3 doses, then every 1–4 hours inhalation maneuver as needed. Use VHC; add mask in children <4 years.	4–8 puffs every 20 minutes up to 4 hours, then every 1–4 hours as needed.	In mild-to-moderate exacerbations, MDI plus VHC is as effective as nebulized therapy with appropriate administration technique and coaching by trained personnel.
Bitolterol Nebulizer solution (2 mg/mL)	See albuterol dose; thought to be half as potent as albuterol on mg basis.	See albuterol dose.	Has not been studied in severe asthma exacerbations. Do not mix with other drugs.
MDI (370 mcg/puff)	See albuterol MDI dose.	See albuterol MDI dose.	Has not been studied in severe asthma exacerbations.
Levalbuterol (R-albuterol) Nebulizer solution (0.63 mg/3 mL, 1.25 mg/0.5 mL 1.25 mg/3 mL)	0.075 mg/kg (minimum dose 1.25 mg) every 20 minutes for 3 doses, then 0.075–0.15 mg/kg up to 5 mg every 1–4 hours as needed.	1.25–2.5 mg every 20 minutes for 3 doses, then 1.25–5 mg every 1–4 hours as needed.	Levalbuterol administered in one-half the mg dose of albuterol provides comparable efficacy and safety. Has not been evaluated by continuous nebulization.
MDI (45 mcg/puff)	See albuterol MDI dose	See albuterol MDI dose.	
Pirbuterol MDI (200 mcg/puff)	See albuterol MDI dose; thought to be half as potent as albuterol on a mg basis.	See albuterol MDI dose.	Has not been studied in severe asthma exacerbations
Systemic (Injected) Beta$_2$-Agonists			
Epinephrine 1:1,000 (1 mg/mL)	0.01 mg/kg up to 0.3–0.5 mg every 20 minutes for 3 doses sq.	0.3–0.5 mg every 20 minutes for 3 doses sq.	No proven advantage of systemic therapy over aerosol.
Terbutaline (1 mg/mL)	0.01 mg/kg every 20 minutes for 3 doses then every 2–6 hours as needed sq.	0.25 mg every 20 minutes for 3 doses sq.	No proven advantage of systemic therapy over aerosol.
Anticholinergics			
Ipratropium bromide Nebulizer solution (0.25 mg/mL)	0.25–0.5 mg every 20 minutes for 3 doses, then as needed	0.5 mg every 20 minutes for 3 doses, then as needed	May mix in same nebulizer with albuterol. Should not be used as first-line therapy; should be added to SABA therapy for severe exacerbations. The addition of ipratropium has not been shown to provide further benefit once the patient is hospitalized.
MDI (18 mcg/puff)	4–8 puffs every 20 minutes as needed up to 3 hours	8 puffs every 20 minutes as needed up to 3 hours	Should use with VHC and face mask for children <4 years. Studies have examined ipratropium bromide MDI for up to 3 hours.

FIGURE 22. DOSAGES OF DRUGS FOR ASTHMA EXACERBATIONS (continued)

Medication	Dosage: Child Dose*	Dosage: Adult Dose	Dosage: Comments (not all inclusive)
Anticholinergics (continued)			
Ipratropium with albuterol Nebulizer solution (Each 3 mL vial contains 0.5 mg ipratropium bromide and 2.5 mg albuterol.)	1.5-3 mL every 20 minutes for 3 doses, then as needed	3 mL every 20 minutes for 3 doses, then as needed	May be used for up to 3 hours in the initial management of severe exacerbations. The addition of ipratropium to albuterol has not been shown to provide further benefit once the patient is hospitalized.
MDI (Each puff contains 18 mcg ipratropium bromide and 90 mcg of albuterol.)	4–8 puffs every 20 minutes as needed up to 3 hours	8 puffs every 20 minutes as needed up to 3 hours	Should use with VHC and face mask for children <4 years.
Systemic Corticosteroids (Apply to all three corticosteriods.)			
Prednisone Methylprednisolone Prednisolone	1-2 mg/kg in 2 divided doses (maximum = 60 mg/day) until PEF is 70 percent of predicted or personal best	40–80 mg/day in 1 or 2 divided doses until PEF reaches 70 percent of predicted or personal best	For outpatient "burst," use 40–60 mg in single or 2 divided doses for total of 5–10 days in adults (children: 1–2 mg/ kg/day maximum 60 mg/day for 3–10 days).

* Children ≤ 12 years of age

Key: ED, emergency department; MDI, metered-dose inhaler; PEF, peak expiratory flow, VHC, valved holding chamber

Notes:
- There is no known advantage for higher doses of corticosteroids in severe asthma exacerbations, nor is there any advantage for intravenous administration over oral therapy provided gastrointestinal transit time or absorption is not impaired.
- The total course of systemic corticosteroids for an asthma exacerbation requiring an ED visit of hospitalization may last from 3 to 10 days. For corticosteroid courses of less than 1 week, there is no need to taper the dose. For slightly longer courses (e.g., up to 10 days), there probably is no need to taper, especially if patients are concurrently taking ICSs.
- ICSs can be started at any point in the treatment of an asthma exacerbation.

- No single measure is best for assessing severity or predicting hospital admission.
- Lung function measures (FEV_1 or PEF) may be useful for children ≥5 years of age, but these measures may not be obtainable during an exacerbation.
- Pulse oximetry may be useful for assessing the initial severity; a repeated measure of pulse oximetry of <92–94 percent after 1 hour is predictive of the need for hospitalization.
- Signs and symptoms scores may be helpful. Children who have signs and symptoms after 1–2 hours of initial treatment and who continue to meet the criteria for a moderate or severe exacerbation have a >84 percent chance of requiring hospitalization.

— For adults:

- Repeated lung function measures (FEV_1 or PEF) at 1 hour and beyond are the strongest single predictor of hospitalization. Such measures may not be helpful, or easily obtained, during severe exacerbations.
- Pulse oximetry is indicated for patients who are in severe distress, have FEV_1 or PEF <40 percent predicted, or are unable to perform lung function measures. Only repeat assessments after initial treatment, not a single assessment upon admission, are useful for predicting the need for hospitalization.
- Signs and symptoms scores at 1 hour after initial treatments improve the ability to predict need for hospitalization. The presence of drowsiness is a useful predictor of impending respiratory failure and is reason to consider immediate transfer to a facility equipped to offer ventilatory support.

- **Consider adjunctive treatments, such as intravenous magnesium sulfate or heliox,** in severe exacerbations, if patients are unresponsive to the initial treatments listed above (e.g., FEV_1 or PEF <40 percent predicted or personal best after initial treatments).
- **Provide the following to prevent relapse of the exacerbation** and recurrence of another exacerbation:
  - — Referral to followup asthma care within 1–4 weeks. In addition, encourage the patient to contact (e.g., by telephone) his/her asthma care provider during the first 3–5 days after discharge. A followup visit is essential to review the patient's written asthma action plan, adherence, and environmental control and to consider a step up in therapy. If appropriate, consider referral to an asthma self-management education program.
  - — An ED asthma discharge plan. See figure 23a, b "Emergency Department—Asthma Discharge Plan."
  - — Review of inhaler technique whenever possible.
  - — Consideration of initiating ICS.
- **Treatments that are not recommended in the emergency care or hospital setting include:** methylxanthines, antobiotics (except as needed for comorbid conditions), aggressive hydration, chest physical therapy, mucolytics, or sedation. Inhaled ipratropium bromide is a helpful adjunctive therapy in the emergency care setting, but does not provide additional benefit after a patient is hospitalized for a severe exacerbation.

FIGURE 23a. EMERGENCY DEPARTMENT—ASTHMA DISCHARGE PLAN

EMERGENCY DEPARTMENT—ASTHMA DISCHARGE PLAN

Name: ___________________________ was seen by **Dr.**_________________ on ___/___/___

- Take your prescribed medications as directed—do not delay!
- -term treatment plan.
- Even when you feel well, you may need daily medicine to keep your asthma in good control and prevent attacks.
- Visit your doctor or other health care provider as soon as you can to discuss how to control your asthma and to develop *your own* action plan.

Your followup appointment with ________________ is on: ___/___/___. **Tel:** ____________

YOUR MEDICINE FOR THIS ASTHMA ATTACK IS:

Medication	Amount	Doses per day, for # days
Prednisone/prednisolone (oral corticosteroid)		_____ a day for _____ days Take the entire prescription, even when you start to feel better.
Inhaled albuterol		_____ puffs every 4 to 6 hours if you have symptoms, for _____days

YOUR DAILY MEDICINE FOR LONG-TERM CONTROL AND PREVENTING ATTACKS IS:

Medication	Amount	Doses per day
Inhaled corticosteroids		

YOUR QUICK-RELIEF MEDICINE WHEN YOU HAVE SYMPTOMS IS:

Medication	Amount	Number of doses/day
Inhaled albuterol		

ASK YOURSELF 2 TO 3 TIMES PER DAY, EVERY DAY, FOR AT LEAST 1 WEEK:

"How good is my asthma compared to when I left the hospital?"

If you feel much better:	**If you feel better, but still need your quick-relief inhaler often:**	**If you feel about the same:**	**If you feel worse:**
• Take your daily long-term control medicine.	• Take your daily long-term control medicine. • See your doctor as soon as possible.	• Use your quick-relief inhaler. • Take your daily long-term control medicine. • See your doctor as soon as possible—don't delay.	• Use your quick-relief inhaler. • Take your daily long-term control medicine. • Immediately go to the emergency department or call 9–1–1.

YOUR ASTHMA IS UNDER CONTROL WHEN YOU:

① Can be active daily and sleep through the night.	② Need fewer than 4 doses of quick-relief medicine in a week.	③ Are free of shortness of breath, wheeze, and cough.	④ Achieve an acceptable "peak flow" (discuss with your health care provider).

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Source: Camargo CA Jr, Emond SD, Boulet L, Gibson PG, Kolbe J, Wagner CW, Brenner BE. Emergency Department Asthma Discharge Plan. Developed at "Asthma Education in the Adult Emergency Department: A Multidisciplinary Consensus Conference," New York Academy of Medicine, New York, NY; 2001 April 1–5. Boston, MA: Massachusetts General Hospital, 2001. 2 pp.

FIGURE 23b. EMERGENCY DEPARTMENT—ASTHMA DISCHARGE PLAN: HOW TO USE YOUR METERED-DOSE INHALER

Using an inhaler seems simple, but most patients do not use it the right way. When you use your inhaler the wrong way, less medicine gets to your lungs.

For the next few days, read these steps aloud as you do them or ask someone to read them to you. Ask your doctor, nurse, other health care provider, or pharmacist to check how well you are using your inhaler.

Use your inhaler in one of the three ways pictured below (A or B are best, but C can be used if you have trouble with A and B). (Your doctor may give you other types of inhalers.)

Steps for Using Your Inhaler

Getting ready

1. Take off the cap and shake the inhaler.
2. Breathe out all the way.
3. Hold your inhaler the way your doctor said (A, B, or C below).

Breathe in slowly

4. As you start breathing in slowly through your mouth, press down on the inhaler one time. (If you use a holding chamber, first press down on the inhaler. Within5 seconds, begin to breathe in slowly.)
5. Keep breathing in slowly, as deeply as you can.

Hold your breath

6. Hold your breath as you count to 10 slowly, if you can.
7. For inhaled quick-relief medicine (short-acting beta$_2$ agonists), wait about 15–30 seconds between puffs. There is no need to wait between puffs for other medicines.

A. Hold inhaler 1 to 2 inches in front of your mouth (about the width of two fingers).

B. Use a spacer/holding chamber. These come in many shapes and can be useful to any patient.

C. Put the inhaler in your mouth. Do not use for steroids.

Clean your inhaler as needed, and know when to replace your inhaler. For instructions, read the package insert or talk to your doctor, other health care provider, or pharmacist.

For More Information

The National Heart, Lung, and Blood Institute (NHLBI) Health Information Center (HIC) is a service of the NHLBI of the National Institutes of Health. The NHLBI HIC provides information to health professionals, patients, and the public about the HIC treatment, diagnosis, and prevention of heart, lung, and blood diseases and sleep disorders. For more information, contact:

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U.S. Department of Health and Human Services
National Institutes of Health

National Heart
Lung and Blood Institute
People Science Health

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SHORT COMMUNICATION

The scope for biased recall of risk-factor exposure in case-control studies: Evidence from a cohort study of Scottish men

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Abstract

Aims: Case-control studies are prone to recall bias, a participant's case-control status influencing their recall of exposure to risk factors. We aimed to demonstrate empirically the scope for this bias. *Methods:* Two thousand five hundred and fifty men without coronary heart disease at enrolment to a prospective cohort study underwent two health assessments, about 5 years apart. The association between the development of coronary heart disease in the intervening period and changes in reported stress and cigarette smoking were investigated. *Results:* Men admitted to hospital with coronary heart disease reported a greater increase in psychological stress ($p=0.032$) and greater cessation of smoking (22% vs. 10%; $p=0.007$) than men not admitted. Consequently, when exposure data are collected at the end rather than at the start of the follow-up period, coronary heart disease is observed to be more strongly associated with psychological stress, and more weakly associated with smoking. ***Conclusions:* At the time when a case-control study is conducted, levels of exposure to risk factors will have been influenced by disease development. When participants are asked about their level of exposure for a previous time period, recall is likely to be influenced by present outcome and exposure status, especially when psychological states are being investigated.**

Key Words: *Bias (epidemiology), case-control studies, coronary disease, psychological stress, risk factors, smoking*

Background

Case-control studies are prone to recall bias, such that a participant's case-control status influences their recall of exposure to risk factors. We have previously suggested [1] that a recent case-control study has overestimated the effect of psychological stress on the occurrence of myocardial infarction, due to people being asked to recall their previous exposure to stress several days after the infarction [2]. In that situation, reports of higher stress exposure among patients may have more to do with the effect of a first heart attack on a person's mental state (myocardial infarction influencing the recall of stress) than with any pathophysiological process triggered by stress (stress causing myocardial infarction).

This report uses data from a prospective cohort study to determine empirically the scope for recall bias. Focusing on men who completed a health questionnaire and physical examination on two occasions, we investigate how the development of coronary heart disease in the intervening 5-year period influences the reporting of psychological stress and cigarette smoking. Cigarette smoking is included as being a more established risk factor for coronary heart disease, and as being measured more objectively than psychological stress. Subsequently, we discuss how the observed associations between risk factors and coronary heart disease are affected by the time of measurement.

Material and methods

Participants

The data for this analysis come from the West of Scotland Collaborative Study [3,4]. In brief, 6022

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men and 1006 women were recruited from a variety of workplaces in the west of Scotland between 1970 and 1973. At enrolment, all members of the cohort were invited to complete a questionnaire and undergo a physical examination. The present analysis is based upon 2550 men aged between 35 and 64 years, without evidence of ischaemia on a six-lead electrocardiogram [3] at enrolment, who underwent a second health screening in 1977, and who provided full data on the variables used in the present analysis. Women were excluded from this analysis because they formed a minority of the cohort and few developed coronary heart disease in the study period.

Exposure measurement

Psychological stress was measured using the Reeder Stress Inventory [5] (Table I), a measure of daily stress that we have described in detail elsewhere [6]. Current cigarette smokers included men who reported having given up less than 1 year previously [3].

Outcome measurement

Completion of the Rose Angina Questionnaire [7] (Table I) at the second health screening allowed men who reported symptoms consistent with "definite angina" to be identified. For analyses using this outcome, 122 men reporting definite angina at the first health screening were excluded. A record linkage with the Scottish Morbidity Records identified those men admitted to hospital between screening assessments, and receiving a hospital discharge diagnosis of coronary heart disease (ICD-9: 410–414).

Statistical analysis

Logistic regression analyses were used to investigate associations between exposures and outcomes. Adjustment for age at first screening assessment was achieved by including two dummy covariates distinguishing three age groups: <50, 50–54 and 55+ years. Adjustment for additional confounders was not undertaken, as the varying associations between a confounder and, for example, stress at the first assessment, stress at the second assessment and change in stress may have obscured comparisons between the different models required for this investigation. Stata statistical software, version 9, was used for all analyses (StataCorp, College Station, TX, USA).

Table I. Descriptions of the two questionnaire measures used in this study.

Reeder Stress Inventory

Please indicate by a tick in the appropriate box in each of the following sections which description fits you best.

1. In general, I am usually tense or nervous.
   THIS DESCRIBES ME:
2. There is a great amount of nervous strain connected with my daily activities.
   THIS DESCRIBES MY SITUATION:
3. At the end of the day I am completely exhausted mentally and physically.
   THIS DESCRIBES ME:
4. My daily activities are extremely trying and stressful.
   THIS DESCRIBES MY ACTIVITIES:

Response options for each item are "Exactly", "To some extent", "Not very accurately", or "Not at all". Possible total scores range from 1 to 8, with higher scores indicating greater daily stress.

Rose Angina Questionnaire

1. Have you ever had any pain or discomfort in your chest?
   [] Yes [] No (if no, respondent is directed to skip the following questions)
2. Do you get this pain or discomfort when you walk uphill or hurry?
   [] Yes [] No
3. Do you get it when you walk at an ordinary pace on the level?
   [] Yes [] No
4. When you get any pain or discomfort in your chest what do you do?
   [] Stop [] Slow down [] Continue at the same pace
5. Does it go away when you stand still?
   [] Yes [] No
6. How soon?
   [] 10 minutes or less [] More than 10 minutes
7. Where do you get this pain or discomfort? Mark the place(s) with X on the diagram (diagram of the abdomen)

Definite angina is recorded when responses are YES to question 1, YES to question 2, STOP or SLOW DOWN to question 4, YES to question 5, 10 MINUTES OR LESS to question 6, and the sternum or both left chest and left arm indicated on the diagram. Question 3 distinguishes grade II (YES) and grade I (NO) angina.

Results

The mean age of the 2550 men was 48 years (standard deviation 6 years). The mean interval between the two health screens was 5 years (90% range: 4–6 years). At the second health screening, 141 of 2428 men (5.8%) reported symptoms of angina, and 51 of 2550 men (2.0%) had been admitted with coronary heart disease.

An association between the development of angina symptoms and higher psychological stress was apparent whether stress was reported at the onset or conclusion of follow-up (Table II). There was, however, no association between these newly reported symptoms and a greater increase in stress reported at the end of follow-up (p=0.64). The expected greater increase in reported stress was observed in those admitted with coronary heart disease, relative to men not so admitted (p=0.032). Consequently, very weak evidence of a protective effect of psychological stress measured at the start of follow-up becomes very weak evidence of a harmful effect of psychological stress when measured at the end of follow-up (Table II).

There was evidence of an association between the development of coronary heart disease, whether ascertained from symptoms of angina or hospital admission, and smoking status as reported at the start of the follow-up period (Table II). These associations were weaker with smoking status reported at the end of follow-up, as there was a higher rate of smoking cessation among men reporting symptoms of angina, or admitted with coronary heart disease, than among other men. However, only the latter association was supported by strong statistical evidence (p=0.007).

Discussion

This analysis demonstrates the potential for recall bias in case-control studies, hospital admission with coronary heart disease being followed by reports of higher psychological stress and greater smoking cessation. Consequently, there were discernable differences in the associations between coronary heart disease and these risk factors, depending upon whether risk-factor exposure was measured before or after admission. There was no evidence of angina symptoms impacting upon the reported exposure to stress or smoking, consistent with previous research suggesting that the likelihood of smoking cessation is proportional to the severity of smoking-related disease [8,9].

The experience of heart disease is known to be a source of substantial distress in itself [10], and admission for coronary heart disease is likely to be followed by reports of increased psychological stress. This [11] and the long-held popular assumption of a causal association between psychological stress and heart disease [12] are likely to influence attempts to recall preadmission levels of psychological stress. There may be a greater effect for the recall of cigarette smoking, given that a causal relationship between smoking and heart disease risk has been well known for many years and that this has let to growing social disapproval of smoking [13–15], especially for smokers requiring treatment for smoking-related illness [13,16–18].

This study adds to the sparse empirical data on the scope for recall bias in case-control studies. The development of cardiovascular disease is associated with increases in reported psychological stress and with a high rate of smoking cessation. Current

Table II. Mean (standard deviation) psychological stress and percentage of smokers at the two screening assessments by outcome (symptoms or admission), plus the change in reported exposure between assessments. For each outcome in turn, age-adjusted odds ratios (ORs) indicate the effect of higher exposure at the stated screening assessment[a], or of a greater increase in stress or a greater smoking cessation rate between assessments.

	Angina symptoms at screen 2 (n=141/2428[b])					CHD admission between screen 1 and 2 (n=51/2550[c])				
	Yes	No	OR	95% CI	p	Yes	No	OR	95% CI	p
Stress										
Screen 1	4.04 (1.76)	3.76 (1.66)	1.12	(1.00–1.24)	0.041	3.51 (1.64)	3.82 (1.67)	0.90	(0.76–1.06)	0.20
Screen 2	4.16 (1.62)	3.85 (1.72)	1.13	(1.02–1.26)	0.016	4.04 (1.57)	3.90 (1.71)	1.06	(0.90–1.25)	0.51
Screen 2–Screen 1	0.12 (1.54)	0.12 (1.54)	1.03	(0.92–1.15)	0.64	0.53 (1.47)	0.08 (1.55)	1.21	(1.02–1.44)	0.032
Smoking										
Screen 1	61.7%	52.1%	1.54	(1.08–2.19)	0.016	74.5%	53.1%	2.63	(1.39–4.97)	0.003
Screen 2	49.7%	43.1%	1.33	(0.94–1.87)	0.10	52.9%	44.0%	1.44	(0.83–2.51)	0.20
Ex-smokers	12.8%	9.9%	1.39	(0.83–2.32)	0.22	21.6%	10.0%	2.55	(1.29–5.05)	0.007

CHD, coronary heart disease; CI, confidence interval. [a]ORs are for one unit greater stress and smoking vs. not smoking. [b]Excludes men with electrocardiogram ischaemia or Rose "definite angina" at screen 1. [c]Excludes men with electrocardiogram ischaemia at screen 1.

psychological state is likely to influence attempts to recall psychological state for previous periods. Consequently, recent case-control studies that rely upon recall of pre-disease psychological stress are likely to have overestimated the association between psychological stress and coronary heart disease [2,19,20].

The present study is limited in that it indicated the scope for recall bias with different risk factors, but did not assess men's ability to recall their exposure level for a previous time period. A cohort of women with breast cancer was found to be more likely to underestimate past alcohol consumption than a control group, although the bias was small in magnitude [21]. Furthermore, our second measure of psychological stress was taken some time after admission, and we may have observed a greater effect had we measured stress pre-discharge, as in two recent case-control studies [2,19,20].

Conclusion

We conclude that case-control studies that have relied upon retrospective recall of risk-factor exposure may give biased estimates when that exposure is modified following the development of disease, with an overestimate of associations between disease and psychological risk factors being particularly likely. In consequence, the need for and nature of policies to address psychological risk factors for disease cannot be fully informed by data from case-control studies alone.

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Exhibit A40-3

Scand J Work Environ Health – online first

Pesticide exposure and risk of Parkinson's disease – a population-based case–control study evaluating the potential for recall bias

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Rugbjerg K, Harris MA, Shen H, Marion SA, Tsui JKC, Teschke K. Pesticide exposure and risk of Parkinson's disease – a population-based case–control study evaluating the potential for recall bias. *Scand J Work Environ Health* – online first

Objective The aim of this study was to investigate whether pesticide exposure was associated with Parkinson's disease in a population-based case–control study in British Columbia, Canada.

Methods Patients reimbursed for anti-parkinsonian agents were identified and screened for eligibility as cases. Controls were selected from the universal health insurance database, frequency-matched to the case sample on birth year, gender, and geographic region. A total of 403 cases and 405 controls were interviewed about their job, medical and personal habits histories, and beliefs about disease risk factors. Among those reporting pesticide exposure, an occupational hygiene review selected participants exposed "beyond background" (ie, above the level expected in the general population). Unconditional logistic regression was used to estimate associations for different pesticide categories.

Results Of the cases, 74 (18%) self-reported pesticide exposure and 37 (9%) were judged to be exposed beyond background. Self-reported exposure was associated with increased risk [odds ratio (OR) 1.76, 95% confidence interval (95% CI) 1.15   2.70], however the risk estimate was reduced following the hygiene review when restricted to those considered exposed (OR, 1.51, 95% CI, 0.85   2.69). When agricultural work was added to the model, the risk for hygiene-reviewed pesticide exposure was not elevated (OR 0.83, 95% CI 0.43   1.61), but agricultural work was (OR 2.47, 95% CI 1.18   5.15). More than twice as many cases as controls thought chemicals cause Parkinson's disease.

Discussion This study provides little support for pesticide exposure as a cause of Parkinson's disease. The observed pattern of step-wise decreases in risk estimates might indicate differential recall by case status. The relationship to agricultural jobs suggests that farming exposures - other than pesticides - should be considered as risk factors for Parkinson's disease.

Key terms agricultural job; British Columbia; Canada; job history; self-report.

The etiology of Parkinson's disease is partly unknown, though 5–10% of the cases are attributed to genetic mutations (1). Parkinson's disease is thought to result from an interplay between genetic susceptibility and environmental risk factors (2). An association between pesticides and Parkinson's disease was first suspected in 1983, when the chemical 1-methyl-4-phenyl-1,2,3,6-tetrahydropyridine (MPTP), which has a chemical structure similar to the herbicide paraquat, was observed to cause acute Parkinsonism (3). Since then, exposure to pesticides and subsequent development of Parkinson's disease has been studied intensively (eg, 4–17) and many studies (4–8, 12–17) have confirmed associations, though some were weak and not significant, and other studies have not found an effect (9, 10).

Methods of pesticide exposure ascertainment have varied from study to study, but it would be extraordinarily difficult to include direct exposure measurement due to the rarity and late-life incidence of Parkinson's disease. Retrospective self-reporting of exposures is the most commonly used method for estimation of pesticide exposure (4–10); however, this method has the

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potential for recall bias (11). Some studies have gathered self-report of exposure prospectively (12, 13) or used more objective methods, such as job exposure matrices (14–16) or combinations of geographic information and historical data on pesticide use (17).

Here we report the results of a population-based case–control study of the relationship between pesticide exposure and Parkinson's disease. Self reports in combination with an occupational hygiene review were used to estimate exposures. We also investigated whether study participants believed that chemicals, including pesticides, cause Parkinson's disease and whether such a belief may have confounded exposure–response relationships.

Methods

Study population

Cases and controls were sampled from two areas of the province of British Columbia, Canada: Metro Vancouver representing an urban area (2.1 million people, population density ~735 per km^2); and all of Vancouver Island, except Greater Victoria, representing a rural area (400 000 people, population density ~10 per km^2). The rural area was included to increase the diversity of occupations. Persons between the ages of 40–69 years inclusive (as of 31 December 2002) who were alive and residing in the study area at the time of interview and who were able to communicate with the interviewer in English were eligible. Subjects in the age group 40 69 years were chosen because they were less likely to suffer from dementia or other illnesses that could complicate an interview and because they were in, or close to, their working years and therefore more likely to recall exposures correctly.

Potential cases were identified using the PharmaCare database of the provincial prescription payment plan, which included all those who had more than CAN$800 in prescription costs in a given year. For inclusion, individuals had to have had at least one prescription for anti-parkinsonian drugs for at least one calendar year from 1995–2002 inclusive. The following were defined as anti-parkinsonian drugs: levodopa, bromocriptine mesylate, pergolide mesylate, levodopa/benserazide hydrochloride, levodopa/carbidopa, or seligiline hydrochloride. The populations meeting the potential case definition were identified on two occasions: in 2001 (data from 1995–1998) and 2005 (data from 1999–2002). To blind the data extractors, the extract was supplemented with a 20% "camouflage" sample of other individuals in the database.

All potential cases were verified by an initial screening phone interview about chronic diseases, anti-parkinsonian drugs taken, and the reason for their use. This screened out those taking the drugs for much different purposes (eg, bromocriptine for lactation cessation or levodopa for restless legs syndrome). Those taking the drugs for known or suspected Parkinson's disease had an in-person physical assessment employing a checklist and record of symptoms, reviewed by a neurologist with a specialty in movement disorders. The following clinical criteria for Parkinson's disease were used: (i) two of the following symptoms present on examination: Parkinsonian tremor, rigidity, bradykinesia, masked facies, micrographia, or postural imbalance; (ii) absence of specific signs of other diseases that would account for these findings. Dates of Parkinson's disease diagnosis, first symptoms, and first treatment were also recorded.

The control sample was frequency-matched to the case sample on birth year (six 5-year periods), gender, and geographic region. Controls were selected using stratified random sampling from the British Columbia (BC) Ministry of Health Services client registry, which includes all individuals covered by provincial medical insurance and represents 97.5% of the population. All potential controls were screened by phone for eligibility, including a question about whether they had any chronic diseases. Anyone who indicated Parkinson's disease were excluded.

Subject contact procedure

This study was required to use a two-stage consent process. The BC Ministry of Health Services sent out invitation letters asking potential subjects to contact the University of BC team. If no response was received within two weeks of the mailing date, a clerk at the Ministry of Health Services phoned to ask the potential subject if their name could be released to the study team. Those who agreed were then contacted by the study coordinator who conducted the screening interview and requested study participation.

Questionnaire information on pesticide exposure

The questionnaire was pre-tested in several steps on a sample of 40 people selected to represent the age range of the subjects. The interviewers underwent formal training about all aspects of the interview, questionnaire, and clinical examination, and were observed during mock and initial interviews to ensure consistency.

In an in-person interview, participants were asked about their job, medical, and personal habits histories. The following questions were asked for all jobs: "During this job, did you use or were you exposed to any chemicals, for example, solvents, oils, plastics, paints, metals or pesticides?" As an aid to recall, an interview guide was sent to the participants prior to the interview and was referred to during the interview. It listed chemicals with an a priori hypothesis and included common and brand names (see the Appendix for the list of pesticides). If a participant answered "yes", the following questions were asked: "Was this substance (i) breathed in, (ii) on skin, (iii) both, (iv) no direct contact, (v) don't know"; and "What operations were you performing when you were exposed to this substance?" for which a list of about 90 operations was provided in the interview guide. Participants were asked about weeks exposed per year, hours exposed per week, and start and end date of the exposure in that job. At the end of the interview, participants were asked: "What do you think causes Parkinson's disease?"

Each participant's job history was reviewed by an occupational hygienist (blind to case status) for sensitivity (ie, to check whether potential exposures of interest commonly associated with an occupation were reported). Where exposures were missed, the participant was phoned and asked about the exposures noted by the hygienist.

Assigning exposure to pesticides

After all interviews were completed, the self-reported exposures were again reviewed, blind to case status, this time for specificity. Using defined criteria and the information on job title, job duties, mode of exposure, operations conducted during exposure, and duration of exposure, assessments were made about whether self-reported pesticide exposures were likely to be "beyond background" or above the level expected in the general population. Of 121 persons who self-reported pesticide exposures, 53 were excluded because the reported exposure was judged to be limited. For example, sales personnel handling closed containers, construction workers occasionally handling wood treated with preservatives, and restaurant workers, security guards, administrative personnel, and care aides in locations where pesticides were occasionally applied by others were all judged to have limited exposure. In comparison, those judged to have exposures above background were mainly farmers, farm workers, forestry personnel, sawmill workers applying antisapstain fungicides, florists, and kennel and stable hands. Among those judged unlikely to be exposed beyond background, only 34% named a specific pesticide, whereas among those judged exposed, 73% did. A further 8 persons were excluded due to missing information on hours per week exposed (N=7) and whether the exposure was every week (N=1); on checking the job duties, it was likely that the information was missing because the exposure was rare in the job (eg, public health nurse applying lindane for lice)." Among those reporting exposure to pesticides, 60 were judged to be exposed beyond background.

Categorizing pesticides

Since most previous studies have categorized pesticides according to function (insecticides, herbicides, fungicides, and wood preservatives), for comparison purposes we did the same.

We also created categories by chemical class: organochlorines and organophosphates. Finally, we grouped specific pesticides reported by the participants into two categories based on neurotoxicity (18–20): (i) pesticides with evidence of human neurotoxicity: allethrin, azinphosmethyl, diazinon, dichlorodiphenyltrichloroethane (DDT), 2,4-dichlorophenoxyacetic acid (2,4-D), dieldrin, glyphosate, lindane, malathion, 2-methyl-4-chlorophenoxyacetic acid (MCPA), nicotine, paraquat, pentachlorophenol, rotenone, tetrachlorophenol, and 2,4,5-trichlorophenoxyacetic acid (2,4,5-T); and (ii) pesticides with limited or no evidence of neurotoxicity: borax, brodifacoum, calcium polysulfide, captan, copper oxychloride, creosote, chromate copper arsenate, didecyl dimethyl ammonium chloride, lime sulphur, mineral oil, simazine, and sulphur. These categories were based on available evidence for neurotoxicity in case studies, animal studies, and in vitro studies (18–20).

Statistical analysis

Unconditional logistic regression was used to estimate associations with Parkinson's disease for different categories of pesticides: functional groups (insecticide, herbicide, fungicide, wood preservative); chemical groups (organophosphates, organochlorines); neurotoxic pesticides; and any specific pesticide reported by at least ten participants. In all analyses, persons reporting exposure to pesticides other than those relevant in the specific analysis were excluded.

Analyses were conducted for self-reported exposure and for hygiene-reviewed exposures beyond background. Analyses were performed for exposure via any job operation and for the subgroup reporting pesticide spraying operations. We also estimated risks with exposure duration and with censoring of exposures five and ten years prior to the date of diagnosis or the corresponding date for controls.

Finally, we estimated Parkinson's disease risk among those with agricultural jobs. Two adjustment models were used: model 1 adjusted for gender, birth year (5-year age groups), and smoking (cumulative pack-years); and model 2 adjusted for the same variables as model 1 in addition to a variable indicating whether the subject believed Parkinson's disease has a chemical cause.

Analyses were performed with SAS software version 9.1 (SAS Institute, Cary, NC, USA).

Results

A total of 3783 potential subjects were initially sent letters from the Ministry of Health Services. Figure 1 is a participation flowchart showing the classification of potential subjects. A large proportion of potential cases did not have Parkinson's disease (most used anti-parkinsonian drugs for other indications). The multi-stage consent process resulted in uncertainty about the proportion of potential subjects who were eligible to participate. However, if we assume that the proportion of contacted subjects who were eligible (554/1580=0.35 for cases and 603/726=0.83 for controls) was the same in the initially extracted samples, we can calculate the "potentially eligible" numbers (0.35×2261=791 for cases; 0.83×1522=1264 for controls) and use these as denominators for the calculation of the participation rate. Using this method, the estimated participation rate was 403/791 (51%) for cases and 405/1264 (32%) for controls. The characteristics of the final study sample of 403 cases and 405 controls are summarized in table 1.

Pesticide exposure

Among cases, 74 (18%) self-reported pesticide exposure and 37 (9%) were judged to be exposed beyond background following the hygiene review. In the control group, 47 (12%) self-reported pesticide exposure and 23 (6%) were judged to be exposed beyond background. In both the case and control groups, insecticides and herbicides were the most frequently reported types of pesticides (table 1).

Table 2, model 1 (adjusted for birth year, gender and smoking) shows the results for both self-reported and hygiene-reviewed pesticide exposure via any job operation and spraying operations. For self-reported pesticide exposure, we found a significantly increased risk of Parkinson's disease. Among those judged exposed beyond background after the hygiene review, the odds ratio (OR) was lower than among those self-reporting exposure. In the hygiene-reviewed group, exposure via spraying pesticides had a higher risk estimate than via any job operation, though neither of these risk estimates were statistically significant. The

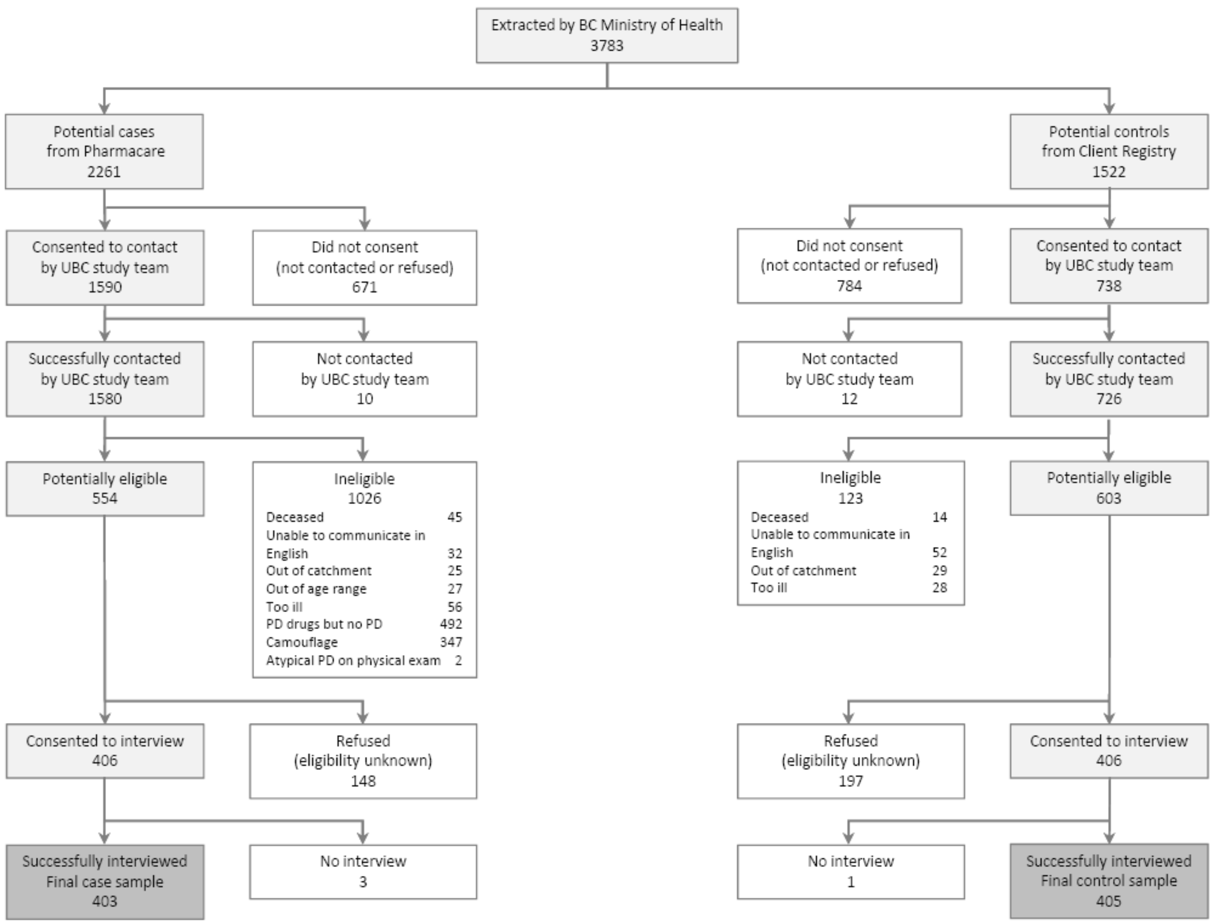

Figure 1. Flow chart showing the classification of potential participants in a case control study of Parkinson's disease in British Columbia, Canada. Potential cases were those with a prescription for antiparkinsonian drugs during the study period.

Table 1. Characteristics of the study population: 403 patients with Parkinson's disease and 405 controls. [SD=standard deviation.]

Characteristic	Cases				Controls			
	N	%	Mean	SD	N	%	Mean	SD
Men	266	66.0	·	·	204	50.4	·	·
Women	137	34.0	·	·	201	49.6	·	·
Birth year								
1929–1938	245	60.8	·	·	175	43.2	·	·
1939–1948	131	32.5	·	·	129	31.9	·	·
1949–1958	27	6.7	·	·	101	25.0	·	·
Geographic region: Metro Vancouver	263	62.3	·	·	242	59.8	·	·
Self-reported pesticide exposure	74	18.3	·	·	47	11.6	·	·
Hygiene-reviewed pesticide exposure	37	9.2	·	·	23	5.7	·	·
Insecticides	18	4.5	·	·	13	3.2	·	·
Herbicides	17	4.2	·	·	13	3.2	·	·
Fungicides	7	1.7	·	·	6	1.5	·	·
Wood preservatives	10	2.5	·	·	5	1.2	·	·
No pesticide exposure	329	81.6	·	·	358	88.4	·	·
Ever smoker [a]	184	45.7	·	·	226	55.8	·	·
Named chemicals as cause of Parkinson's disease	111	27.5	·	·	43	10.6	·	·
Smoking, cumulative pack-years			11.4	20.4	·	·	15.4	22.4
Mean age at diagnosis of Parkinson's disease (years)			56.0	7.1	·	·	·	·
Mean age at the time of interview (years)			65.0	6.6	·	·	62.2	9.0

[a] At least 100 cigarettes in the period prior to Parkinson's disease diagnosis and a corresponding period for controls.

risk estimates for subcategories of pesticides tended to follow similar patterns: the highest risk estimates were for self-reports; the hygiene review resulted in reductions in risk estimates; and there were slightly higher risk estimates for spraying exposures. None of the OR for pesticide subcategories were statistically significant, except self-reported insecticide exposure. Risk estimates for hygiene-reviewed pesticide exposures were slightly above 1.0 in all categories of pesticides, except for organophosphates, organochlorines and DDT, however, most risk estimates had wide 95% confidence intervals (95% CI) (table 2). Censoring exposures five and ten years prior to diagnosis did not change the risk estimates markedly (data not shown) and analyses including duration of pesticide exposure showed no significant associations with Parkinson's disease (data not shown).

We also examined the relationship between agricultural work and Parkinson's disease: 36 cases and 17 controls reported an agricultural job. Of these, 20 cases and 7 controls were exposed to pesticides. Participants who reported agricultural jobs had a significantly increased risk of Parkinson's disease (OR 2.36, 95% CI 1.23 4.55, adjusted for gender, birth year and smoking). When the hygiene-reviewed pesticide exposures were added to this model, the elevated and statistically significant OR for agricultural work remained (OR 2.47, 95% CI 1.18 5.15), but the risk for pesticide exposure was no longer elevated (OR 0.83, 95% CI 0.43 1.61). A similar pattern held for each pesticide category: when added to a model with agricultural job, the elevated risk for the job remained, but the risk estimate for the pesticide was always <1.0. There were no significant interactions between agricultural job and any of the pesticide categories.

The analyses reported above suggest that differences in exposure recall between cases and controls may have contributed to the higher risk estimates for self-reported pesticide exposures, so we examined the responses to the question about what causes Parkinson's disease. A total of 154 participants reported "chemicals" as a suspected cause of Parkinson's disease (111 cases and 43 controls). Most did not name a specific class of chemical, however 21 participants specifically mentioned "pesticides" and all of these were cases. To see whether beliefs about causes of the disease might alter the association with pesticides, we conducted an additional set of analyses with adjustment for the participants' beliefs that chemicals are a cause of Parkinson's disease (table 2, model 2). The OR for pesticides in the model 2 analyses were consistently lower than those of model 1, and none were statistically significant. In contrast, in analyses of agricultural job with adjustment for participants' beliefs that chemicals are a cause of the disease, the increased risk persisted (OR 2.28, 95% CI 1.16 4.47).

Table 2. Odds ratios (OR) and 95% confidence intervals (95% CI) for Parkinson's disease among persons who self-reported pesticide exposure and among those judged - by a hygiene review - to have pesticide exposure beyond background. Statistically significant OR **in bold**. [DDT= dichlorodiphenyltrichloroethane.]

Pesticide category	Model 1 [a]									Model 2 [b]								
	Self-reported exposure, via any job operation			Hygiene-reviewed exposure, via any job operation			Hygiene-reviewed exposure, spraying operations			Self-reported exposure, via any job operation			Hygiene-reviewed exposure, via any job operation			Hygiene-reviewed exposure, spraying operations		
	N	OR	95 % CI	N	OR	95 % CI	N	OR	95 % CI	N	OR	95 % CI	N	OR	95 % CI	N	OR	95 % CI
Pesticides		**1.76**	**1.15–2.70**		1.51	0.85–2.69		1.91	0.82–4.49		1.49	0.96–2.32		1.18	0.65–2.14		1.38	0.56–3.40
Cases	74			37			20			74			37			20		
Controls	47			23			9			47			23			9		
Insecticides		**1.80**	**1.03–3.15**		1.26	0.58–2.74		1.86	0.66–5.24		1.44	0.81–2.58		0.86	0.38–1.93		1.24	0.42–3.65
Cases	40			18			13			40			18			13		
Controls	26			13			6			26			13			6		
Herbicides		1.82	0.97–3.40		1.33	0.60–2.97		1.60	0.53–4.87		1.59	0.84–3.00		1.16	0.51–2.60		1.49	0.47–4.71
Cases	33			17			10			33			17			10		
Controls	19			13			6			19			14			6		
Fungicides		0.94	0.38–2.32		1.18	0.35–4.00		·	..		0.80	0.31–2.03		0.95	0.27–3.31		·	..
Cases	11			7			3 [c]			11			7			3 [c]		
Controls	11			6			2 [c]			11			6			2 [c]		
Wood preservatives		2.20	0.90–5.34		1.56	0.51–4.77		·	..		1.80	0.70–4.62		1.34	0.42–4.28		·	..
Cases	17			10			4 [c]			17			10			4 [c]		
Controls	9			5			0 [c]			9			5			0 [c]		
Organo-phosphates		1.57	0.53–4.64		0.74	0.20–2.78		·	..		1.47	0.49–4.45		0.72	0.19–2.68		·	..
Cases	10			5			4 [c]			10			5			4 [c]		
Controls	6			5			3 [c]			6			5			3 [c]		
Organo-chorines		1.23	0.53–2.85		0.62	0.19–2.00		·	..		1.05	0.44–2.52		0.38	0.11–1.31		·	..
Cases	16			6			5 [c]			16			6			5 [c]		
Controls	10			6			4 [c]			10			6			4 [c]		
Pesticides with neuro-toxic effects		1.76	0.95–3.25		1.08	0.49–2.36		1.34	0.53–3.40		1.48	0.78–0.80		0.86	0.38–1.93		1.06	0.40–2.82
Cases	35			17			14			35			17			14		
Controls	19			13			8			19			13			8		
DDT		1.32	0.55–3.18		0.76	0.22–2.62		·	..		1.09	0.44–2.75		0.45	0.12–1.65		·	..
Cases	15			6			5 [c]			15			6			5 [c]		
Controls	9			5			3 [c]			9			5			3 [c]		

[a] Model 1: Adjusted for gender, birth year (5-year age groups), smoking (cumulative pack-years).
[b] Model 2: Adjusted for gender, birth year (5-year age groups), smoking (cumulative pack-years), and naming chemicals as a cause of Parkinson's disease.
[c] Fewer than ten subjects exposed, odds ratios and confidence intervals not reported.

Discussion

In this study, we observed significantly increased risks of Parkinson's disease with self-reported pesticide or insecticide exposures, but reductions in risk for those considered exposed based on the hygiene review, and when more specific categories of pesticides are mentioned. There were no increases in risk with censoring of exposures five and ten years prior to diagnosis, nor increasing risks with increasing duration of exposure. Only one pattern was suggestive of an association: the increases in risk for hygiene-reviewed exposures from "any job operation" to "spraying operations," though none of these OR were statistically significant. In analyses with agricultural job, pesticide exposures no longer had elevated OR. This pattern of results does not add convincing support to the proposed association between pesticides and Parkinson's disease, and for the most part, was counter to what would be expected to support pesticides as a cause.

Two patterns suggested the potential for recall bias to explain at least a portion of the observed associations between pesticide exposure and Parkinson's disease: decreases in risk between self-reported and hygiene-reviewed exposures and decreases in risk after adjustment for participants' belief that chemicals were a cause. In our study, 27.5% of cases with Parkinson's disease reported chemicals (including pesticides) as a cause of Parkinson's disease; the corresponding percentage for controls was 10.6%. This difference indicates a greater suspicion of a chemical cause among cases than controls; the risk estimates for pesticide exposures decreased when controlling for this factor, meaning that suspecting a chemical cause was also associated with reporting pesticide exposure.

Evidence of recall bias in case–control studies has generally been sparse, except with open-ended questioning of exposure or where participants suspect a disease cause (22, 23). Difficulties in recall of pesticides have been shown to differ between cases and controls in a general population sample (24). Adjusting for suspicions of hypothesized causation may be inadvisable as a routine practice, particularly if knowledge is causally related to exposure or if exposed cases become knowledgeable about the hypotheses post-diagnosis (25). The former seems unlikely in our study, although the latter is possible, so we cannot know with certainty that the effect we observed was indeed due to recall bias.

Our results raise the question of whether the prior studies may have been subject to recall bias. Previous studies that, like ours, obtained information on exposure to pesticides from interviews have this potential (4–11, 21). Nevertheless, two cohort studies using prospective self-reports of exposure, which should not be prone to recall bias, found associations between exposure to pesticides as a group and risk of Parkinson's disease (12, 13).

Non-differential misclassification of exposure to pesticides is also an important issue, which could exist in our study and thus bias our results towards the null (26). Reducing non-differential misclassification of exposure was one of the purposes of the industrial hygiene review of exposures. We expected risk estimates to be higher for hygiene-reviewed than self-reported exposures, but the opposite was the case, initiating our suspicion of recall bias.

Agricultural employment versus pesticide exposure: what is measured?

We observed a significantly increased risk of Parkinson's disease among those reporting an agricultural job, with a risk estimate higher than those for pesticides. The finding for agricultural jobs was little influenced by adjustment for pesticide exposure or participants' beliefs that chemicals are a cause.

This raises the question of whether there is something else about agricultural work that might be related to Parkinson's disease. A number of studies (27–29), though not all (30), have reported associations between agricultural jobs and Parkinson's disease. Most investigators have related these associations to the use of pesticides in these jobs. However, a recent Australian study investigated the extent to which farm-related jobs indicated pesticide exposure (31) and found that only 22% likely had exposure. In our study, 51% of those in agricultural jobs were classified as "pesticide exposed". Farming jobs may share many other potential exposures, including solvents, fuels, fuel exhaust, dusts, micro-organisms, and traumatic injuries, many of which would be useful to examine in the context of Parkinson's disease. An exposure of particular interest could be endotoxin, a lipopolysaccharide component of gram-negative bacterial cell walls. Lange and coworkers (32) are among the researchers who have posited that part of the elevated risk of Parkinson's disease associated with agriculture could be explained by exposure to endotoxin, because exposure is common in the agricultural sector and there is mechanistic support from animal experiments (33).

It would be worthwhile to consider the potential for other etiological exposures to explain at least some portion of the increased risks of Parkinson's disease observed among farmers or those assessed as being exposed to pesticide due to farming jobs (12, 14–16).

Recent case–control studies

In other recent case–control studies, the diversity of results related to pesticide exposures and agricultural work has continued. Elbaz and colleagues (4) found increased risks with professional pesticide use, especially insecticides, though they mentioned the possibility of increased awareness among cases of the possible link between Parkinson's disease and pesticides (4). Tanner et al (8) found increased risks for self-reported use of pesticides, increasing when restricted to eight specific pesticides with high neurotoxic plausibility (very similar to our classification), but agricultural work was not found to be a risk factor. Firestone and colleagues (10) found no significant association between self-reported exposure to pesticides or agricultural work and Parkinson's disease. Regional differences in exposure patterns between study populations and methodological differences (eg, different methods of ascertaining exposure) might partly explain these inconsistent results.

Despite the large number of studies investigating the possible association between pesticide exposure and Parkinson's disease, few epidemiological studies have found associations between exposure to a specific pesticide and Parkinson's disease. In a study using geographic information systems and historic information on pesticide use, exposure to the pesticides maneb and paraquat was found to be associated with risk of Parkinson's disease (17). To pinpoint specific pesticides in an interview based case–control study, the participants' memories need to be exceptional and the number of study participants needs to be very large. To illustrate the number of subjects needed to detect a significantly increased risk of Parkinson's disease for a specific pesticide, we calculated the sample size needed, using the pesticide with the highest proportion of controls exposed in this study [DDT (5 of 405)]. With a significance level of 5%, power of 80% and equal numbers of cases and controls, 1500 cases and controls would be needed to detect an OR of 2.0.

Strengths and limitations

Like most case–control studies, we had in-person physical assessment of potential cases and included assessments of participants' lifestyle habits to allow control for smoking's negative association with Parkinson's disease (34). The assessment of pesticide exposure collected detailed information on the type of contact and operations performed enabling two hygiene reviews on sensitivity and specificity, respectively, both blind to case status. A list of pesticides with common names and brand names were provided to participants in advance to improve recall (see appendix) (22). Our study appears to be the only one to date that has attempted to evaluate recall bias based on participants' beliefs about the causes of Parkinson's disease.

A limitation of our study was the potential for participation bias, since those agreeing to take part in the study might differ from those refusing. Our study population was restricted to those in the age group 40 69 years, potentially limiting the generalizability of our results to older Parkinson's patients.

Further, our study was underpowered to detect 2-fold-difference associations between subcategories of pesticide exposure with a prevalence of <4% in controls. Most of our pesticide groups had sufficient power, but the number of participants who reported exposure to individual pesticides was very small, preventing analyses of most individual pesticides. The diversity of pesticide active ingredients used by this study sample reflects the diversity of farming in the province, including fruit (apple, peaches, cherries, grapes, plums, blueberries, raspberries, cranberries), market vegetable (lettuce, tomatoes, sweet peppers, cucumbers, mushrooms), grain, and flower crop farming, as well as cattle ranching and dairy farming. The resulting variety of pesticides used is another factor that lessens the likelihood that pesticides are an important cause of Parkinson's disease in this population; there is little specificity of the chemicals. In addition, few of the study subjects had exposures to the pesticides used in animal models of Parkinson's disease (35): one case and four controls reported exposure to rotenone; three cases and three controls reported exposure to paraquat; and no one reported exposure to maneb.

In summary, the results of this study do not lend support to an association between pesticide exposure and Parkinson's disease. Our results emphasize the importance of considering recall bias, via a hygiene review to ensure specificity of exposure ascertainment, and by considering the participants' beliefs about the disease cause. The results related to agricultural work suggest that it would be valuable for future studies to explore other exposures of this occupational group that may be related to Parkinson's disease, such as bacterial endotoxin (32, 36).

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Appendix. List of pesticides sent out to the participants prior to the interview.

Chemical name	Brand and common names
Fungicides	
Captan	Agrox D-L Plus, Orthocide
Chlorothalonil	Bravo, daconil 2787, Exotherm Termil, Termil
Copper oxychloride	Basicop, Coprantol, Fixed copper, mar-cop, neutron-Cop, Tri-Cop
Dodine	Cyprex, Equal
Formaldehyde	Formalin, Methanol
Lime sulphur or calcium polysulphide	Orthorix
Mancozeb	Dithane M-45, manzate 200
Maneb	Co-op DP, Ditane M-22, Mantox, Manzae, Mergamma, Pool NM Dual, Tersan LSRF
Metam	Pole-Fume, SMDC, Unifume Soil, Vapam, VPM, Woodfume
Metiram	Polyram
Quintozene	Brassicol, PCNB, terrachlor
Sulphur	Flortex, Giant Destroyer, Gopher Gasser, Kolodust, Kolospray, Magnetic 6, Ortho Flotox, Woodchuck Bombs
Ziram	Zerate
Herbicides and plant growth regulators	
2,4,5-T	Dacamine-4T, Esteron 2,4,5-T, Poison Ivy and Brush Killer, Reddox, Trinoxol, Veon, Verton 2T, Weedone 2,4,5-T
2,4-D	2,4-D, Amkil, Aqua-Kleen, Calmix, Chlorxone, Dacamine, Desormone 7, Diachlorprop, Driamine, Estakil, Estasol, Estemine 500, Esteron, Esteron 64, Foestamine, For-ester, Formula 40-F, Herbate, Hoe-Grass, Kilmor, Rustler, Salvo, Silvaprop, Sure-Shot Forest amine, Target, Ten-Ten, Verton, Weedar, Weedar-64, Weedaway, Weed-B-Gone, Weedex, Weedone, Weed-Rhap
Atrazine	Aatrex, Atra-Mix, Eramox 80W, gesaprim, Laddox, Marzone, Primatol A, Primextra, Vectal Atrazine
Bifenox	Modown
Chlormequat	Cycocel
Difenzoquat	Avenge
Diquat	Reglone, Reglone-A, Weedrite
Ethalfluralin	Edge
Glyfosate	Roundup, Rustler, Side-Kick, Vision
MCPA amine	Agritox, Agroxone, Bromox, Buctril, Estemine MCPA, Estakil MCPA, MCP, Mephanac, Methoxone Amine 500, No Weed, Sabre, Weedar MCPA, Weedgone MCPA
Metolachlor	Dual, Primextra
Morfamquat	Morfoxone
Norflurazon	Evitol, Zorial
Paraquat	Gramoxone, Gramoxone S, Paraquat CL, Sweep, Terraklene, Weed Rite
Simazine	Gestatop, Primatol S, Princep, Simmaprim, Simadex
Sodium chlorate	Atlacide, Atratol, Chlorax, Monobor-Chlorate, Ureabor
Sodium metaborate tetrahydrate	Borate, Ureabor
Triallate	Avadex-BW
Insecticides	
Allethrin	Allethrin, Synthetic Pyrethrin
Azinphos-methyl	APM, Gurhion
Cypermethrin	Ripcord
Dichlorodiphenyltrichloroethane	DDT
Diazinon	Basudin
Dieldrin	Dieldrin
Heptachlor	Heptachlor
Lindane	Agrox D-L Plus, Benolin, Co-op DP, Gamma BHC, Gammasan, Mergamma, Pool NM Dual, Thiralin, Vitaflo DP, Vitavax
Malathion	Cythion
Mineral oil	Agricultural Weedkiller #1, Dormant Oils, Petroleum Oils, Petroleum Solvents, Stoddart Solvents, Summer Oil, Superior Oil, Supreme Oil, Volck Oil, Weed Oils
Nicotine	Black Leaf 40, Nicotine, Nicotine Sulfate
Rotenone	Atox, Deritox, Derris, Noxfish Fish Toxicant, Rotenone Fish Poison
Wood preservatives	
3-iodo-2-propyl butyl carbamate	IPBC, NP-1, Troysan Polyphase P 100, Troysan Polyphase
Borax	Borascu, Boron, Ecobrite, Ecobrite A, Ecobrite B, Ecobrite C, Ecobrite II, Ecobrite III, F-2, Pole-Peg
Chromated copper arsenate	CCA
Creosote	Coal Tar Creosote, Pole-Peg
Didecyl dimethyl ammonium chloride	DDAC, Ecobrite III, F-2, NP-1, Timbercote II, Timbercote 2000
Pentachlorophenol	Alchem, Dowwicide, Diatox, PCP, Penta, Pole-Peg, Santobrite, Woodbrite, Woodsheath
Sodium carbonate	Ecobrite, Ecobrite A, Ecobrite B, Ecobrite C, Ecobrite II, SCB
Rodenticides	
Brodifacoum	Ratak, Talon
Bromadiolone	
Fumigants	
Methyl bromide	Brom-O-Gas, Dowfume, Dowfume MC-2, Meth-O-Gas, Sanex MB-C-2, Terr-O-Gas 67
Carbon disulfide	Dowfume, FIA 80-2, Kenfume bin fumigant, Sanifume
Hydrogen cyanide	Cyanogas, calcium cyanide, HCN

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ENVIRONMENTAL HEALTH

RESEARCH **Open Access**

Self-reported chemicals exposure, beliefs about disease causation, and risk of breast cancer in the Cape Cod Breast Cancer and Environment Study: a case-control study

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Abstract

Background: Household cleaning and pesticide products may contribute to breast cancer because many contain endocrine disrupting chemicals or mammary gland carcinogens. This population-based case-control study investigated whether use of household cleaners and pesticides increases breast cancer risk.

Methods: Participants were 787 Cape Cod, Massachusetts, women diagnosed with breast cancer between 1988 and 1995 and 721 controls. Telephone interviews asked about product use, beliefs about breast cancer etiology, and established and suspected breast cancer risk factors. To evaluate potential recall bias, we stratified product-use odds ratios by beliefs about whether chemicals and pollutants contribute to breast cancer; we compared these results with odds ratios for family history (which are less subject to recall bias) stratified by beliefs about heredity.

Results: Breast cancer risk increased two-fold in the highest compared with lowest quartile of self-reported combined cleaning product use (Adjusted OR = 2.1, 95% CI: 1.4, 3.3) and combined air freshener use (Adjusted OR = 1.9, 95% CI: 1.2, 3.0). Little association was observed with pesticide use. In stratified analyses, cleaning products odds ratios were more elevated among participants who believed pollutants contribute "a lot" to breast cancer and moved towards the null among the other participants. In comparison, the odds ratio for breast cancer and family history was markedly higher among women who believed that heredity contributes "a lot" (OR = 2.6, 95% CI: 1.9, 3.6) and not elevated among others (OR = 0.7, 95% CI: 0.5, 1.1).

Conclusions: Results of this study suggest that cleaning product use contributes to increased breast cancer risk. However, results also highlight the difficulty of distinguishing in retrospective self-report studies between valid associations and the influence of recall bias. Recall bias may influence higher odds ratios for product use among participants who believed that chemicals and pollutants contribute to breast cancer. Alternatively, the influence of experience on beliefs is another explanation, illustrated by the protective odds ratio for family history among women who do not believe heredity contributes "a lot." Because exposure to chemicals from household cleaning products is a biologically plausible cause of breast cancer and avoidable, associations reported here should be further examined prospectively.

Background

Pesticides, household cleaners, and air fresheners are of interest in breast cancer research because many contain ingredients that are mammary gland carcinogens in animals [1] or endocrine disrupting compounds (EDCs), including compounds that affect growth of estrogen-sensitive human breast cancer cells [2] or affect mammary gland development [3]. Mammary gland tumors have been observed in animal studies of pesticides such as dichlorvos, captafol, and sulfallate; methylene chloride (in some fabric cleaners); nitrobenzene (soaps, polishes); and perfluorinated compounds (stain-resistant, waterproof coatings) [1,4,5]. Phthalates, alkylphenols, parabens, triclosan, and polycyclic musks used as

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surfactants, solvents, preservatives, antimicrobials, and fragrances have shown weak estrogenic or anti-androgenic effects in both *in vitro* and *in vivo* tests [4-16]. Pesticides identified as EDCs include dichlorodiphenyl trichloroethane (DDT), chlordane, methoxychlor, atrazine, lindane (lice control), vinclozolin and benomyl (fungicides), and several current use insecticides such as cypermethin [6-13]. When given early in life, atrazine, nonylphenol, perfluorinated compounds, and the plastics monomer bisphenol A influence rat mammary gland development in a way that may affect tumor susceptibility [14-18]. These chemicals are widely used and many have been detected in blood and urine from a representative sample of the US population; concentrations vary over several orders of magnitude [19-26]. In household air and dust and women's urine tested in the Cape Cod Breast Cancer and Environment Study, we detected an average of 26 EDCs per home, including 27 pesticides and a variety of estrogenic phenols from household cleaners [27]. Taken together, the laboratory studies of biological activity and evidence of widespread human exposure suggest that use of products containing mammary gland carcinogens or EDCs may contribute to breast cancer in humans.

No epidemiological studies we know of have reported on the relationship between cleaning product use and breast cancer, and previous breast cancer studies of pesticides have been largely limited to organochlorine compounds [28]. Organochlorine studies have been mostly null, but interpretation is limited because proxies of exposure were measured in blood taken years after the compounds were banned in the US, often in older women and after diagnosis [29]. In a study that avoids these limitations by using archived blood collected from young women in 1959 to 1967, Cohn et al. [30] reported five-fold higher breast cancer risk among women who had the highest residues of DDT and were exposed before they were 14 years old. In addition, the Long Island Breast Cancer Study found 30% higher breast cancer risk among women who reported the highest home pesticide use [31]. Self-reported product use, such as the Long Island measures, has the potential to represent exposure over many years to a wide range of compounds; although retrospective reports may be biased by differential reporting accuracy between cases and controls [32].

To investigate the relationship between use of cleaning and pesticide products and risk of breast cancer, while considering possible recall bias, we conducted a case-control study of breast cancer and self-reported product use on Cape Cod, Massachusetts, in which we also measured beliefs about breast cancer causation, a possible source of recall bias. Cape Cod is a coastal peninsula where breast cancer incidence has been elevated. Annual female breast cancer incidence in 2002 - 2006 was 151.0 per 100,000 (95% CI 142.6 - 159.8) [33]. The pattern of higher incidence in Cape Cod towns than elsewhere in Massachusetts dates to the initiation of the state cancer registry in 1982 [34]. In the Collaborative Breast Cancer Study, risk was elevated among Cape Cod women compared with other Massachusetts participants after controlling for breast cancer risk factors [35]. In the Cape Cod Breast Cancer and Environment Study case-control study, longer years of residence on Cape Cod was associated with higher risk after controlling for established breast cancer risk factors [36].

Methods

Study population

Details of the Cape Cod Study have been described previously [37]. Briefly, we conducted a case-control study of invasive breast cancer occurring on Cape Cod in 1988-1995. Cases were female permanent residents of Cape Cod for at least six months before a breast cancer diagnosis reported to the Massachusetts Cancer Registry (MCR). Controls were female permanent Cape Cod residents during the same years, had resided there at least six months, and were frequency matched to cases on decade of birth and vital status. Controls under 65 years of age were selected using random digit dialing; controls over 65 years of age were randomly selected from the Centers for Medicare and Medicaid Services (CMS).

The Cape Cod Study expands on a study of breast cancer and tetrachloroethylene (PCE) in drinking water [38]. Cases diagnosed in 1988-1993 in eight towns and their controls were interviewed in 1997-1998 in the PCE study. Cases diagnosed in 1994-1995 in those eight towns and in 1988-1995 in the remaining seven towns and their controls were interviewed in 1999-2000. Among 1,578 eligible living and deceased cases identified by MCR, 1,165 women (74%) or their proxies participated, 228 (14%) could not be located or contacted, and 185 (12%) refused to participate. Among 1,503 eligible controls, 1,016 (68%) participated.

For the present analysis, we excluded 368 cases and 287 controls who were interviewed by proxy, and 10 cases and eight controls who were missing data for one or more key analytic variables. Given that most women for whom we obtained proxy interviews were deceased, excluded women were older, and, consistent with being older, they were less educated. Within the included or excluded groups, cases and controls did not differ demographically, suggesting no selection bias. Exclusions left 787 cases and 721 controls for pesticide analyses. Cleaning product questions were asked only in 1999-2000 interviews, resulting in 413 cases and 403 controls for whom these data were available.

We obtained permission to use confidential data from MCR, CMS, and hospitals where cases were diagnosed. The Boston University Institutional Review Board and Massachusetts Department of Public Health Human Research Review Committee approved the study protocol. Participants were asked for informed consent at the outset of interviews.

Interviews

Trained telephone interviewers administered a structured questionnaire on established and hypothesized breast cancer risk factors including family history of breast cancer, menstrual and reproductive history, height, weight, alcohol and tobacco use, physical activity, pharmaceutical hormone use, and education. Information on residential cleaning product and pesticide use was obtained. Participants in 1999-2000 interviews were asked about five categories of cleaning products, including solid and spray air fresheners, surface cleaners, oven cleaners, and mold/mildew products. All participants were asked about use of 10 categories of pesticides in and around their homes, including insecticides, lawn care, herbicides, lice control, insect repellents, and pest control on pets. The 1999-2000 interviews asked about mothballs and treatments for termites and carpenter ants. Participants were first asked if the product was ever used in their home. Participants were then asked to estimate frequency of use using predefined categories. To exclude exposures after diagnosis or index year, participants were asked to report the first and last years of use for pesticides, and use before their diagnosis or index year for cleaning products. At the end of the interview, participants were asked about their beliefs about four factors that may contribute to breast cancer: heredity, diet, chemicals and pollutants in the air or water, and a woman's reproductive or breastfeeding history. Participants were asked whether each contributes to breast cancer "a lot, a little, or not at all." "Don't know" responses were coded. Interview questions can be viewed at http://silentspring.org/cape-cod-breast-cancer-and-environment-study-survey-instruments.

Statistical analysis

Unconditional logistic regression was used to calculate odds ratios (ORs) and 95% confidence intervals (CIs). The following "core" matching variables and potential confounders were included in adjusted odds ratio analyses based on *a priori* consideration of the research design and well-established breast cancer risk factors: age at diagnosis or index year, education, family history of breast cancer in a first degree female relative, breast cancer diagnosis prior to the current diagnosis or index year, and age at first live or still birth (≥ 30 years of age or nulliparous vs. < 30 years of age). Pesticide analyses were adjusted for study (PCE or Cape study). Missing values for family history for 45 (3%) participants were imputed as "no." The percent missing information on family history did not differ between cases and controls. The following potential confounders were evaluated: mammography use, medical radiation, lactation, hormone replacement therapy, oral contraceptive use, diethylstilbestrol exposure, body mass index, smoking, alcohol consumption, teen and adult physical activity, race, marital status, and religion. None of these variables changed the "core"-adjusted odds ratio estimates by ≥ 10%, so they were not included in final models.

We evaluated ever vs. never use and categorical variables reflecting frequency of use. "Never users" of each product type formed the reference group. If a participant reported ever using a product but the frequency was missing, frequency was imputed as the median for that product. To aggregate "like" exposures, three variables were constructed by summing frequency of use for two types of air fresheners, five types of cleaning products, and eight types of pesticides. Aggregated scores were divided into quartiles based on the distribution of controls. The lowest quartile constituted the reference group. Tests for trends were conducted by modeling ordinal terms for categories of product use or quartiles in the multivariate model.

Because participants' awareness of a hypothesis may bias exposure reporting [39], we evaluated differences in beliefs about disease causation between cases and controls using the chi square test. We evaluated differences in product-use odds ratios by beliefs about whether chemicals/pollutants contribute to breast cancer by 1) including an interaction term for beliefs and product use in the final model and 2) stratifying by beliefs. Beliefs were dichotomized as those who said chemicals/pollutants contribute to breast cancer "a lot" versus "a little," "not at all," or "don't know."

Weiss [40] notes that recall bias is not the only explanation for differences in odds ratios by knowledge or attitudes about a hypothesis; so to aid interpretation of product use results, we conducted a comparison analysis of differences in family history odds ratios by beliefs about whether heredity contributes "a lot" to breast cancer. This comparison is useful, because the accuracy of self-reported family history can be compared with medical records, and the relationship between family history and breast cancer is well-established independent of self-reports. As a sensitivity analysis, we also examined un-stratified and stratified family history odds ratios excluding those subjects who were missing information on family history.

All analyses were conducted in SAS version 9.1 (SAS Institute, Cary, NC). Figures were constructed in R software 2.6.1, (R Foundation for Statistical Computing, Vienna, Austria). Statistical significance was defined by a (two-sided) P -value of 0.05 or lower.

Results

Study participants were predominantly white (98%), 60-80 years of age (60%) with high school or higher education (94%); more cases (25%) than controls (19%) reported a family history of breast cancer. Characteristics of participants are shown in Table 1. Participants in this analysis of product use were demographically similar to characteristics previously reported for all cases and controls, except for being younger and more educated, due to exclusion of proxy interviews [37].

Table 1 Characteristics of Cape Cod Breast Cancer and Environment Study participants with completed pesticide use self-reports

	Cases (N = 787)		Controls (N = 721)	
Characteristic	**N**	**%**	**N**	**%**
Age at diagnosis or index year				
< 50	128	16	149	21
50-59	115	15	129	18
60-69	277	35	226	31
70-79	221	28	184	26
≥ 80	46	6	33	5
Education				
< High school graduate	36	5	48	7
High school graduate	241	31	226	31
1-3 years college/vocational school	253	32	230	32
College graduate	144	18	122	17
Graduate work/degree	113	14	95	13
Family history of breast cancer				
Yes	196	25	135	19
No	591	75	586	81
Prior history of breast cancer				
Yes	48	6	46	6
No	739	94	675	94
Age at first live or stillbirth				
< 20	171	22	122	17
20-29	104	13	80	11
> = 30	458	58	456	63
Nulliparous	54	7	63	9
Menopause status at diagnosis or index year				
Pre-menopause	144	19	194	28
Post-menopause	615	81	505	72

Data for 27 cases and 18 controls were missing for the "Family history of breast cancer" characteristic. Data for 28 cases and 22 controls were missing for the "Menopause status at diagnosis or index year" characteristic.

Products use

Breast cancer risk increased approximately two-fold in the highest compared with lowest quartile of combined cleaning product use (OR = 2.1, 95% CI: 1.4, 3.3) and combined air freshener use (OR = 1.9, 95% CI: 1.2, 3.0) (Table 2). Ever use of air freshener spray (OR = 1.2, 95% CI: 0.9, 1.8), solid air freshener (OR = 1.7, 95% CI: 1.2, 2.3) or mold/mildew control (OR = 1.7, 95% CI: 1.2, 2.3) was associated with higher risk, with evidence of positive dose response and significant P_{trend} for solid air freshener and mold/mildew control with bleach. Surface and oven cleaners were not associated with breast cancer risk.

Combined use of pesticide products was not associated with risk of breast cancer (Table 3). Odds ratios for individual pesticide types were null or slightly and nonsignificantly elevated, with the exception of insect repellent use (OR = 1.5, 95% CI: 1.0, 2.3 for most frequent insecticide use compared with never use; P_{trend} = 0.05).

Differences by beliefs about disease causation

Cases and controls differed significantly in beliefs about the role of heredity and of chemicals and pollutants in breast cancer (Table 4). Among controls, 66% said heredity contributes "a lot" compared with 42% of cases ($P < 0.01$); 57% of controls and 60% of cases said "chemicals and pollutants in the air or water" contribute "a lot" ($P < 0.05$).

In stratified analyses, odds ratios for cleaning products were consistently elevated within the group who said chemicals/pollutants contribute "a lot" to breast cancer, but associations moved towards the null in the other participants (Table 5). For example, the odds ratio for the highest quartile of combined cleaning product use was 3.2 (95% CI: 1.8, 5.9) among women who believed chemicals/pollutants contribute "a lot" compared to 1.2 (95% CI: 0.6, 2.6) among others. The interaction was not statistically significant ($P = 0.25$). (However, the interaction term does not detect departures from additivity.)

Similarly, odds ratios for pesticides were higher among participants who believed that chemicals/pollutants contribute "a lot" to breast cancer. For example, the odds ratio for most frequent insect repellent use was 2.0 (95% CI: 1.1, 3.4) in this belief group compared with 0.8 (95% CI: 0.4, 1.6) among others. Pesticide odds ratios stratified by beliefs are shown in Table 6.

In addition, a similar pattern was observed in the odds ratios for family history of breast cancer stratified by

Table 2 Adjusted odds ratios for breast cancer and reported cleaning product use, Cape Cod, Massachusetts, 1988-1995

Product category	Cases (No.)	Controls (No.)	Adjusted OR	95% CI	P_{trend}
Combined cleaning product use					
Quartile 1	91	99	1.0	Reference	
Quartile 2	100	107	1.1	0.8, 1.7	
Quartile 3	112	125	1.1	0.7, 1.7	
Quartile 4	104	70	2.1	1.4, 3.3	0.003
Combined air freshener use (sprays and solids)					
Quartile 1	74	77	1.0	Reference	
Quartile 2	113	117	1.1	0.7, 1.7	
Quartile 3	123	138	1.0	0.7, 1.6	
Quartile 4	101	71	1.9	1.2, 3.0	0.02
Air freshener spray					
Never use	90	95	1.0	Reference	
Any use	322	308	1.2	0.9, 1.8	
< Once a month	83	88	1.1	0.7, 1.7	
Monthly	47	41	1.3	0.8, 2.3	
Weekly	114	110	1.3	0.8, 1.9	
Daily	78	69	1.3	0.8, 2.1	0.15
Solid air freshener					
Never use	259	288	1.0	Reference	
Any use	153	115	1.7	1.2, 2.3	
< 2 times/year	50	41	1.4	0.9, 2.2	
2-6 times/year	77	58	1.7	1.2, 2.6	
≥ 7 times/year	26	16	2.0	1.0, 4.0	0.001
Oven cleaner					
Never use	33	33	1.0	Reference	
Any use	379	370	1.0	0.6, 1.7	
< 2 times/year	145	143	1.0	0.6, 1.8	
2-6 times/year	199	196	1.0	0.6, 1.7	
≥ 7 times/year	35	31	1.2	0.6, 2.3	0.80
Surface cleaner					
Never use	53	54	1.0	Reference	
Any use	359	348	1.1	0.7, 1.7	
< Once a month	61	60	1.0	0.6, 1.6	
Monthly	57	57	1.0	0.6, 1.8	
Weekly	186	171	1.2	0.8, 1.9	
Daily	55	60	1.2	0.7, 2.2	0.22

Table 2 Adjusted odds ratios for breast cancer and reported cleaning product use, Cape Cod, Massachusetts, 1988-1995 *(Continued)*

Mold/mildew control					
Never use	296	322	1.0	Reference	
Any use	114	81	1.7	1.2, 2.3	
Mold/mildew control with bleach					
Never use	320	334	1.0	Reference	
Any use	90	68	1.5	1.0, 2.1	
< Once a month	47	38	1.2	0.8, 2.0	
Monthly	14	11	1.5	0.7, 3.5	
≥ Weekly	29	19	2.0	1.1, 3.8	0.02

Odds ratios are adjusted for age at diagnosis/reference year, birth decade (six categories), previous breast cancer diagnosis, family history of breast cancer, age at first live or still birth (< 30, ≥ 30/nulliparous), education (five categories). "Combined cleaning product use" combines frequency of use across five product categories: air freshener spray, solid air freshener, oven cleaner, surface cleaner, and mold/mildew control with bleach.

beliefs about heredity as a cause. The odds ratio for breast cancer and family history was markedly higher among women who believed that heredity contributes "a lot" (OR = 2.6, 95% CI: 1.9, 3.6) and not elevated among others (OR = 0.7, 95% CI: 0.5, 1.1, interaction term P < 0.01). The parallel pattern of results for both cleaning products and family history when stratified by relevant beliefs is shown in Figure 1. (For all participants, the odds ratio for family history was 1.4 (95% CI: 1.1, 1.9)). The un-stratified and stratified effect estimates for family history of breast cancer in adjusted models remain virtually unchanged after removing subjects with imputed values for family history.

Discussion

Women with the highest combined cleaning product use had two-fold increased breast cancer risk compared to those with the lowest reported use. Use of air fresheners and products for mold and mildew control were associated with increased risk. To our knowledge, this is the first published report on cleaning product use and risk of breast cancer.

Some common ingredients of air fresheners and products for mold and mildew have been identified as EDCs or carcinogens, supporting the biological plausibility of the elevated odds ratios we observed [1,15,41-51]. EDCs such as synthetic musks and phthalates are commonly used in air fresheners [19,25-27,43,48,52-54] and antimicrobials, phthalates, and alkylphenolic surfactants are often in mold and mildew products [19,22-24,26,27,41,42,44,47,49,55]. In addition, air fresheners may contain: terpenes, which can react with background ozone to form formaldehyde, a human carcinogen [50]; benzene and styrene [51], which are animal mammary gland carcinogens [1]; and other chemicals whose mechanisms of action are not understood [56]. Although exposure levels may be low and EDCs are typically less potent than endogenous hormones, limited knowledge of product formulations, exposure levels, and the biological activity and toxicity of chemical constituents alone and in combination make it difficult to assess risks associated with product use. Additionally, the products we assessed may be proxies for other products that we did not include, and mold/mildew products may be proxies for exposure to mycotoxins, some of which are EDCs [2,57-59].

Our results do not corroborate the findings of a Long Island, NY, case-control study [31]. The Long Island study found increased breast cancer risk associated with self-reported overall pesticide use and use of lawn and garden pesticides, but we did not. Neither study found associations for nuisance pest control (roaches, ants, etc.). While we observed increased risk with frequent use of insect repellent, the Long Island study did not. Differences between the studies may be due to differences in pesticide practices in the two regions, greater statistical power in the Long Island study, or differences in the survey instruments. Phthalates and permethrins, which are in some insect repellents, have been identified as EDCs [10,13,46,60].

Using interviews to assess product-related exposures, as we did in this study, has several advantages. It is inexpensive, noninvasive, and integrates exposures over many years and to frequently-occurring chemical mixtures. Currently available biological measures cannot achieve these important characteristics.

However, self-reported exposures are subject to multiple sources of error resulting in misclassification. Our questions were cognitively demanding in that they asked participants to report behaviors occurring months to years before. Responses failed to capture use by others, including residues from before the participant moved into the

Table 3 Adjusted odds ratios for breast cancer and residential pesticide use, Cape Cod, Massachusetts, 1988-1995

Product category	Cases (no.)	Controls (no.)	Adjusted OR	(95% CI)	P_{trend}
Combined pesticide use					
Quartile 1	173	152	1.0	Reference	
Quartile 2	110	99	1.0	0.7, 1.5	
Quartile 3	169	143	1.1	0.8, 1.5	
Quartile 4	153	126	1.1	0.8, 1.6	0.52
Insect or bug control					
Never use	161	151	1.0	Reference	
Any use	569	514	1.1	0.9, 1.4	
Once or twice	161	155	1.0	0.7, 1.4	
3-10 times	203	188	1.1	0.8, 1.5	
> 10 times	205	171	1.2	0.8, 1.6	0.21
Termite or carpenter ant control					
Never use	293	265	1.0	Reference	
Any use	165	161	0.9	0.6,1.2	
Once or twice	105	85	1.0	0.7,1.5	
3-10 times	35	49	0.6	0.4,1.0	
> 10 times	25	27	0.8	0.4,1.4	0.11
Mosquito control					
Never use	314	312	1.0	Reference	
Any use	91	87	1.0	0.7, 1.5	
Once or twice	15	18	0.9	0.5. 1.9	
3-10 times	35	31	1.1	0.7, 1.9	
> 10 times	41	38	1.0	0.6, 1.7	0.79
Mothball control					
Never use	73	91	1.0	Reference	
Any use	340	312	1.2	0.8, 1.7	
< 5 times	92	90	1.2	0.8, 1.9	
5-10 times	62	73	0.9	0.6, 1.5	
> 10 times	186	149	1.3	0.9, 1.9	0.29
Lawn care					
Never use	316	286	1.0	Reference	
Any use	408	343	1.1	0.9, 1.3	
Once or twice	43	35	1.2	0.7, 1.9	
3-20 times	174	136	1.2	0.9, 1.6	

Table 3 Adjusted odds ratios for breast cancer and residential pesticide use, Cape Cod, Massachusetts, 1988-1995 *(Continued)*

> 20 times	191	172	1.0	0.7, 1.3	0.88
Outdoor and indoor plant care					
Never use	407	359	1.0	Reference	
Any use	334	300	1.0	0.8, 1.2	
Once or twice	33	26	1.1	0.6, 1.8	
3-20 times	158	146	1.0	0.7, 1.3	
> 20 times	143	128	1.0	0.7, 1.3	0.71
Insect repellent					
Never use	286	271	1.0	Reference	
Any use	482	428	1.2	0.9, 1.5	
Rarely	283	263	1.1	0.9, 1.5	
Sometimes	133	115	1.2	0.9, 1.7	
Often/Very often	66	50	1.5	1.0, 2.3	0.05
Lice control					
Never use	692	626	1.0	Reference	
Any use	89	83	1.2	0.8, 1.6	
Flea collar for pets					
No	257	238	1.0	Reference	
Yes	529	482	1.2	0.9, 1.5	
Flea control for pets					
Never use	465	395	1.0	Reference	
Any use	294	286	1.0	0.8, 1.2	
Once or twice	43	41	0.9	0.6, 1.5	
3-10 times	101	109	0.9	0.6, 1.2	
> 10 times	150	136	1.1	0.8, 1.4	0.95

Odds ratios are adjusted for age at diagnosis/reference year, birth decade (six categories), previous breast cancer diagnosis, family history of breast cancer, age at first live or still birth (< 30, ≥ 30/nulliparous), education (five categories), study (Cape, PCE). "Combined pesticide use" product category includes frequency data for: insect or bug control, lawn care, outdoor and indoor plant care, insect repellent, flea control on pets. Product use for termite or carpenter ant control, mosquito control, and mothball control not included because they were only assessed in study participants from the 1999-2000 interviews.

residence; exposures specific to critical periods such as adolescence; exposures outside the home; or all products that contain the chemicals of interest. Although we asked about the first and most recent years of pesticide use, we considered the quality of these data inadequate to evaluate effects of duration of use. Much of the error resulting from limitations in exposure measurement is likely nondifferential, biasing odds ratios toward the null.

Self-reports are also vulnerable to bias from differential recall between cases and controls. Women diagnosed with breast cancer may have searched their history for explanations, priming greater recall of product use than for controls. Werler [39], among others, hypothesizes that this type of bias occurs when cases are aware of the study hypothesis, resulting in higher exposure reporting and, consequently, an elevated odds ratio. We empirically investigated this possibility by stratifying odds ratios by beliefs about breast cancer causes, and, consistent with Werler's hypothesis, we observed higher odds ratios for product use among women who believe chemicals and pollution contribute "a lot" to breast cancer than among others.

Table 4 Beliefs about the causes of breast cancer by case status, Cape Cod, Massachusetts, 1988-1995

		Cases		Controls		
How much does ... contribute to breast cancer?		**No.**	**%**	**No.**	**%**	
Heredity	A lot	331	42	474	66	**
	A little	295	37	163	23	
	Not at all	99	13	36	5	
	Don't know	62	8	48	7	
Diet	A lot	217	28	205	28	
	A little	327	42	294	41	
	Not at all	160	20	125	17	
	Don't know	83	11	97	13	
Chemicals and pollutants in the air or water	A lot	476	60	412	57	*
	A little	188	24	203	28	
	Not at all	53	7	31	4	
	Don't know	70	9	75	10	
Women's reproductive or breast feeding history	A lot	67	9	70	10	
	A little	262	33	261	36	
	Not at all	245	31	225	31	
	Don't know	213	27	165	23	

Percentages may not add to 100% because of rounding. Two-sided P value calculated using chi square test; * indicates $P < 0.05$ and ** indicates $P < 0.001$.

However, the family history odds ratios stratified by beliefs suggest another interpretation. The much higher family history odds ratios for women who said heredity contributes "a lot" is unlikely to be primarily due to recall bias, given that self-reporting of first degree family members with breast cancer is generally accurate [61-66]. Previous research indicates that over-reporting of first degree breast cancer family history is negligible [63,65,66] and that some under-reporting by controls in comparison with cases is likely to occur (and could bias odds ratios), but this effect is unlikely to be substantial [64-66]. More likely, our results are primarily driven by cases who formed their belief that heredity does not contribute "a lot" after their own diagnosis, based on their own lack of relatives with breast cancer. Our data support this idea: 36% of cases with no family history said heredity contributes "a lot" to breast cancer compared with 61% of cases who did have a family history (Table 7). In this situation, an odds ratio for women who do not think heredity contributes "a lot" over-represents cases with no family history, lowering the effect estimate. Thus, our results support Weiss's argument [40] that limiting estimates to a subgroup based on beliefs about disease causation may introduce error. Among the group who do not believe heredity contributes "a lot" to breast cancer, the odds ratio of 0.7 (95% CI: 0.5, 1.1) contrasts sharply with the pooled odds ratio of 2.1 (95% CI: 2.0, 2.2) for first degree family history of breast cancer from previous studies [67]. Generally, Weiss argues, effect estimates based on one belief or knowledge subgroup lack precision and may underestimate the true effect, since they are limited to smaller numbers and not representative of the study population [40].

The divergent odds ratios in the stratified analysis for family history, which is not likely affected much by recall bias, warns us that the elevated odds ratios for cleaning products should not be too quickly dismissed as resulting from recall bias, since an alternative interpretation is that women's beliefs about disease causation result from their experience. Women who have been intensive product users and are then diagnosed with breast cancer may form the belief that chemicals influenced their risk, or they may be sensitized to news media stories about associations between chemicals and disease and form beliefs from this experience. Social scientists have studied the phenomenon of health beliefs formed from experience in a variety of settings, including the emergence of beliefs about environmental causation among breast cancer activists [68].

Furthermore, the substantial underestimate of risk for family history among women who said heredity does

Table 5 Adjusted odds ratios for breast cancer and cleaning product use stratified by disease causation beliefs

	Beliefs about environmental chemicals/pollutants and breast cancer									
	Contributes "a lot"					Does not contribute "a lot"				
Product category	**Cases (no.)**	**Controls (no.)**	**Adj. OR**	**95% CI**	**P_{trend}**	**Cases (no.)**	**Controls (no.)**	**Adj. OR**	**95% CI**	**P_{trend}**
Combined cleaning product use										
Quartile 1	39	55	1.0	Ref.		52	44	1.0	Ref.	
Quartile 2	58	69	1.4	0.8, 2.4		42	38	0.9	0.5, 1.8	
Quartile 3	71	74	1.6	0.9, 2.8		41	51	0.8	0.4, 1.4	
Quartile 4	77	47	3.2	1.8, 5.9	0.0001	27	23	1.2	0.6, 2.6	0.96
Combined air freshener use (sprays and solids)										
Quartile 1	34	43	1.0	Ref.		40	34	1.0	Ref.	
Quartile 2	67	71	1.3	0.7, 2.4		46	46	0.9	0.5, 1.7	
Quartile 3	76	86	1.3	0.7, 2.2		47	52	0.8	0.4, 1.6	
Quartile 4	69	46	2.4	1.3, 4.5	0.01	32	25	1.4	0.7, 3.0	0.53
Air freshener spray										
Never use	44	50	1.0	Ref.		46	45	1.0	Ref.	
Any use	203	196	1.3	0.8, 2.1		119	112	1.2	0.7, 2.0	
< Once a month	50	57	1.1	0.6, 2.0		33	31	1.1	0.6, 2.2	
Monthly	32	32	1.2	0.6, 2.3		15	9	1.9	0.7, 5.0	
Weekly	71	62	1.5	0.8, 2.6		43	48	1.0	0.6, 2.0	
Daily	50	45	1.4	0.8, 2.7	0.12	28	24	1.2	0.6, 2.6	0.66
Solid air freshener										
Never use	144	174	1.0	Ref.		115	114	1.0	Ref.	
Any use	102	72	1.9	1.3, 2.9		51	43	1.4	0.8, 2.3	
< 2/year	27	28	1.3	0.7, 2.3		23	13	1.9	0.9, 4.1	
2-6/year	58	32	2.6	1.6, 4.4		19	26	0.9	0.4, 1.8	
≥ 7/year	17	12	1.7	0.8, 3.9	0.0007	9	4	2.8	0.8, 10.2	0.31
Oven cleaner										
Never use	11	19	1.0	Ref.		22	14	1.0	Ref.	
Any use	236	227	1.8	0.8, 4.0		143	143	0.6	0.3, 1.2	
< 2/year	96	86	2.0	0.9, 4.6		49	57	0.4	0.1, 1.3	
2-6/year	112	121	1.5	0.6, 34		87	75	0.7	0.3, 1.5	
≥ 7/year	28	20	2.4	0.9, 6.5	0.58	7	11	0.4	0.1, 1.3	0.73
Surface cleaner										
Never use	29	36	1.0	Ref.		24	18	1.0	Ref.	
Any use	218	209	1.5	0.9,2.7		141	139	0.7	0.4,1.5	
< Once a month	23	30	0.9	0.4, 1.9		38	30	0.9	0.4, 2.0	
Monthly	39	36	1.5	0.7, 3.1		18	21	0.6	0.2, 1.4	
Weekly	120	103	1.7	1.0, 3.0		66	68	0.7	0.3, 1.5	

Table 5 Adjusted odds ratios for breast cancer and cleaning product use stratified by disease causation beliefs *(Continued)*

Daily	36	40	1.7	0.8, 3.6	0.02	19	20	0.8	0.3, 2.1	0.45
Mold/mildew control										
Never use	166	197	1.0	Ref.		130	125	1.0	Ref.	
Any use	80	49	2.1	1.4, 3.3		34	32	1.1	0.6, 2.0	
Mold/mildew control with bleach										
Never use	179	202	1.0	Ref.		141	132	1.0	Ref.	
Any use	67	44	1.8	1.2, 2.9		23	24	1.0	0.5, 2.0	
< Once a month	33	25	1.4	0.8, 2.5		14	13	1.1	0.5, 2.4	
Monthly	10	7	1.8	0.6, 5.1		4	4	1.1	0.3, 4.7	
≥ Weekly	24	12	3.2	1.4, 7.1	0.002	5	7	0.8	0.2, 2.7	0.83

Odds ratios are adjusted for age at diagnosis/reference year, birth decade (six categories), previous breast cancer diagnosis, family history of breast cancer, age at first live or still birth (< 30, ≥ 30/nulliparous), education (five categories). "Combined cleaning product use" product category combines frequency of use across five product categories: air freshener spray, solid air freshener, oven cleaner, surface cleaner, and mold/mildew control with bleach.

not contribute "a lot" cautions us against limiting product use analyses to a non-belief subgroup as a strategy for dealing with possible recall bias. In addition, the findings of elevated risk for some cleaning products and not others lends evidence that recall bias may not account for elevated risks, even if it contributes in part, since bias would be expected to similarly influence reporting for all the products.

Studies that rely on questionnaire data can sometimes assess the validity of self-reported data against another metric, such as chemical concentrations in relevant exposure media. For example, Colt et al. [69] found significant associations between self-reports of type of pest treated and concentrations of specific pesticides in house dust. We collected air, dust, and urine measurements for 120 homes and their residents, but comparison of these data with self-reports was not conducted for several reasons. The number of homes is small, the one-time environmental measurements may not correspond well with product use over years, measurements capture sources other than home product use, and our self-reports cover past residences as well as the sampled homes. Our ambiguous self-report findings point to the value of thoughtfully incorporating environmental chemical measurements into prospective cohort studies such as the National Children's Study and the Sister Study.

Overall strengths of our study are the population-based design with case identification from the MCR, extensive interviews allowing evaluation of possible confounding by established and hypothesized breast cancer risk factors, and assessment of exposures that extend years before diagnosis and encompass chemicals in use during the past 30 years as well as the more-studied banned organochlorines. Limitations include loss of information due to deaths of women with less treatable cancers. Also, we lack a truly unexposed reference group, limiting contrast in levels of exposure. The self-reported product use exposures have potential for differential and nondifferential error. We did not have adequate numbers to separately evaluate effects in younger women, though some other studies suggest that environmental pollutants may have greater influence on premenopausal disease [28].

To our knowledge, this is the first epidemiological study to suggest an association between cleaning product use, in particular air fresheners and products for mold and mildew control, and elevated breast cancer risk. This association is biologically plausible based on ingredients of these products, such as musks, antimicrobials, and phthalates [1-27,41-49,70-73], and these reported exposures may be proxies for other un-assessed causative exposures. The modest association and possibility of recall bias make interpretation tentative. Given widespread exposure to cleaning products and scented products, follow-up study is important. Prospective designs, which avoid differential recall, can be helpful. The difficulty of obtaining human evidence on environmental chemicals and breast cancer in the short-term means we must rely more on laboratory evidence as a basis for public health policies to control exposure.

Conclusions

Laboratory studies have found that many chemicals in home-use pesticides and household cleaning products are mammary gland carcinogens in rodents, influence

Table 6 Adjusted odds ratios for breast cancer and residential pesticide use stratified by disease causation beliefs

	Beliefs about environmental chemicals/pollutants and breast cancer									
	Contributes "a lot"					Does not contribute "a lot"				
Product category	**Cases (no.)**	**Controls (no.)**	**Adj. OR**	**95% CI**	**P_{trend}**	**Cases (no.)**	**Controls (no.)**	**Adj. OR**	**95% CI**	**P_{trend}**
Combined pesticide use										
Quartile 1	91	87	1.0	Ref.		82	65	1.0	Ref.	
Quartile 2	66	47	1.5	0.9, 2.5		44	52	0.7	0.4, 1.1	
Quartile 3	104	89	1.2	0.8, 1.9		65	54	1.0	0.6, 1.7	
Quartile 4	106	75	1.5	1.0, 2.4	0.16	47	51	0.7	0.4, 1.3	0.53
Insect or bug control										
Never use	81	78	1.0	Ref.		80	73	1.0	Ref.	
Any use	367	305	1.2	0.9, 1.8		202	209	0.9	0.6, 1.3	
Once or twice	105	90	1.1	0.7, 1.8		56	65	0.8	0.5, 1.3	
3-10 times	130	117	1.1	0.8, 1.7		73	71	1.0	0.6, 1.6	
> 10 times	132	98	1.4	0.9, 2.1	0.12	73	73	0.9	0.6, 1.4	0.86
Termites/carpenter ants										
Never use	161	146	1.0	Ref		132	119	1.0	Ref	
Any use	112	102	1.0	0.7, 1.4		53	59	0.7	0.4, 1.1	
Once or twice	68	54	1.1	0.7, 1.7		37	31	1.0	0.5, 1.7	
3-10 times	28	30	0.9	0.5, 1.6		7	19	0.2	0.1, 0.6	
> 10 times	16	18	0.8	0.4, 1.7	0.55	9	9	0.7	0.3, 2.1	0.06
Mosquito control										
Never use	176	186	1.0	Ref.		138	126	1.0	Ref.	
Any use	65	58	1.1	0.7, 1.7		26	29	0.8	0.4, 1.4	
Once or twice	10	11	1.2	0.7, 2.2		5	7	0.7	0.2, 2.3	
3-10 times	23	22	1.1	0.6, 2.1		12	9	1.2	0.5, 3.2	
> 10 times	32	25	1.2	0.7, 2.2	0.47	9	13	0.5	0.2, 1.4	0.33
Mothball control										
Never use	40	56	1.0	Ref.		33	35	1.0	Ref.	
Any use	207	190	1.3	0.8, 2.1		133	122	1.0	0.6,1.8	
< 5 times	50	55	1.2	0.7, 2.1		42	35	1.3	0.7, 2.7	
5-10 times	40	53	1.0	0.5, 1.8		22	20	0.9	0.4, 2.0	
> 10 times	117	82	1.6	1.0, 2.8	0.06	69	67	0.9	0.5, 1.7	0.41
Lawn care										
Never use	190	169	1.0	Ref.		126	117	1.0	Ref.	
Any use	250	196	1.1	0.8,1.5		158	147	1.1	0.8,1.5	
Once or twice	24	21	1.0	0.5, 2.0		19	14	1.4	0.7, 3.0	
3-20 times	115	83	1.2	0.8, 1.7		59	53	1.1	0.7, 1.8	

Table 6 Adjusted odds ratios for breast cancer and residential pesticide use stratified by disease causation beliefs *(Continued)*

> 20 times	111	92	1.0	0.7, 1.5	0.58	80	80	1.0	0.6, 1.5	0.98
Outdoor and indoor plant care										
Never use	235	198	1.0	Ref.		172	161	1.0	Ref.	
Any use	214	173	1.0	0.8, 1.4		120	127	0.8	0.6, 1.2	
Once or twice	18	12	1.2	0.5, 2.6		15	14	0.9	0.4, 2.0	
3-20 times	104	86	1.0	0.7, 1.5		54	60	0.8	0.5, 1.2	
> 20 times	92	75	1.0	0.7, 1.4	0.99	51	53	0.9	0.5, 1.4	0.39
Insect repellent										
Never use	153	134	1.0	Ref.		133	137	1.0	Ref.	
Any use	312	261	1.2	0.9, 1.6		170	167	1.2	0.8, 1.7	
Rarely	179	149	1.2	0.8, 1.6		104	114	1.1	0.7, 1.6	
Sometimes	85	85	1.0	0.6, 1.5		48	30	1.9	1.1, 3.4	
Often/Very often	48	27	2.0	1.1, 3.4	0.12	18	23	0.8	0.4, 1.6	0.45
Lice control										
Never use	414	344	1.0	Ref.		278	282	1.0	Ref.	
Any use	59	58	1.1	0.7, 1.7		30	25	1.4	0.8, 2.5	
Flea collar for pets										
No	132	122	1.0	Ref.		125	116	1.0	Ref.	
Yes	344	290	1.3	0.9, 1.8		185	192	1.0	0.7, 1.4	
Flea control for pets										
Never use	256	214	1.0	Ref.		209	181	1.0	Ref.	
Any use	196	177	1.1	0.8, 1.4		98	109	0.8	0.5,1.1	
Once or twice	23	23	0.9	0.5, 1.6		20	18	1.0	0.5, 2.1	
3-10 times	63	74	0.8	0.5, 1.2		38	35	0.9	0.6, 1.6	
> 10 times	110	80	1.4	0.9, 2.0	0.27	40	56	0.6	0.4, 1.0	0.07

Odds ratios are adjusted for age at diagnosis/reference year, birth decade (six categories), previous breast cancer diagnosis, family history of breast cancer, age at first live or still birth (< 30, ≥ 30/nulliparous), education (five categories), study (Cape, PCE). "Combined pesticide use" product category includes frequency data for: insect or bug control, lawn care, outdoor and indoor plant care, insect repellent, flea control on pets. Product use for termite or carpenter ant control, mosquito control, and mothball control not included because they were only assessed in study participants from the 1999-2000 interviews.

the proliferation of estrogen-sensitive cells, or affect mammary gland development following prenatal exposure. These findings suggest effects of pesticide and cleaning product use on breast cancer risk, so we undertook a case-control study of breast cancer and self-reported product use. We found increased breast cancer risk among women reporting the highest use of cleaning products and air fresheners. We found little association with home pesticide use. The self-reported product use measures we used have the advantage of integrating exposure over many years to chemical mixtures. However, these measures remain incomplete, likely resulting in nondifferential misclassification, and they are open to recall bias. Investigators sometimes try to avoid the influence of recall bias by limiting analyses to participants who do not subscribe to the study hypothesis, but our results show this may not be a good strategy, given that in our study it would obscure the well-established association between family history and breast cancer risk. In order to avoid possible recall bias, we

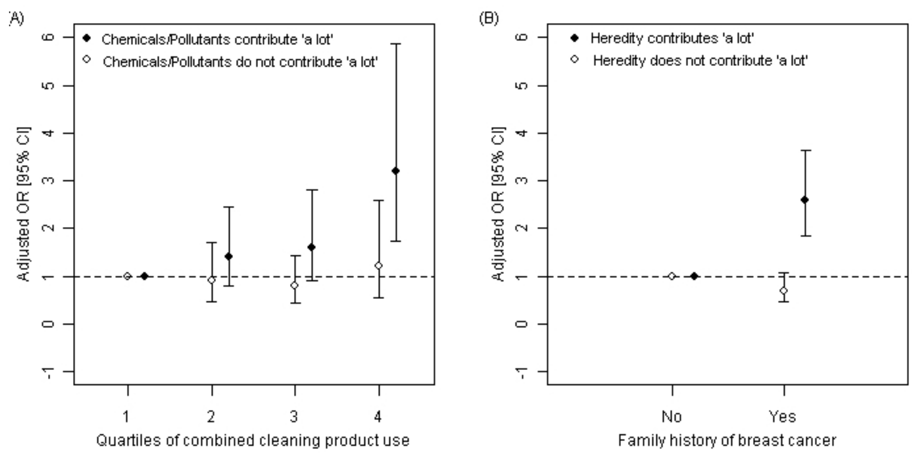

Figure 1 Cleaning product use, family history, and risk of breast cancer, stratified by beliefs about causation. Adjusted odds ratios are shown for breast cancer and A) combined cleaning product use stratified by beliefs about environmental chemicals and breast cancer and B) family history of breast cancer stratified by beliefs about heredity and breast cancer, among participants living in Cape Cod, Massachusetts, 1988-1995. Odds ratios are adjusted for age, previous breast cancer diagnosis, age at first birth, and education; additionally, Figure 1A is adjusted for family history of breast cancer and Figure 1B is adjusted for study.

Table 7 Beliefs about heredity as a cause of breast cancer by family history and case status

		Cases				Controls			
		Family history of breast cancer				Family history of breast cancer			
		Yes		No		Yes		No	
Belief		**N**	**%**	**N**	**%**	**N**	**%**	**N**	**%**
Heredity contributes "a lot" to breast cancer	Yes	120	61	211	36	83	61	391	67
	No	76	39	380	64	52	39	195	33

recommend further study of cleaning products and breast cancer using prospective self-reports and measurements in environmental and biological media.

Abbreviations

CI: confidence interval; CMS: Centers for Medicare and Medicaid Services; EDCs: endocrine-disrupting compounds; OR: odds ratio; MCR: Massachusetts Cancer Registry; PCE: tetrachloroethylene; Ref: reference; Adj OR: adjusted odds ratio; NY: New York; US: United States.

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Authors' contributions

ARZ conducted the statistical analyses and led drafting of the manuscript. AA designed and oversaw the PCE Study; contributed to the design, data collection, and epidemiological analysis of the Cape Cod Study; and collaborated on editorial issues. RAR contributed to the design, data collection, and analysis of the Cape Cod Study, particularly with respect to the toxicologic characteristics of exposures, and collaborated in drafting the manuscript. JGB led the design, implementation, and analysis of the Cape Cod Study and collaborated in drafting the manuscript; she conceptualized the comparative analysis of product use and family history odds ratios stratified by beliefs as a strategy for understanding possible response bias. All authors read and approved the final manuscript.

Competing interests

The authors declare that they have no competing interests.

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Review

The Placebo and Nocebo Phenomena: Their Clinical Management and Impact on Treatment Outcomes

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ABSTRACT

Purpose: This overview focuses on placebo and nocebo effects in clinical trials and routine care. Our goal was to propose strategies to improve outcomes in clinical practice, maximizing placebo effects and reducing nocebo effects, as well as managing these phenomena in clinical trials.

Methods: A narrative literature search of PubMed was conducted (January 1980–September 2016). Systematic reviews, randomized controlled trials, observational studies, and case series that had an emphasis on placebo or nocebo effects in clinical practice were included in the qualitative synthesis. Search terms included: *placebo, nocebo, clinical, clinical trial, clinical setting, placebo effect, nocebo effect, adverse effects*, and *treatment outcomes*. This search was augmented by a manual search of the references of the key articles and the related literature.

Findings: Placebo and nocebo effects are psychobiological events imputable to the therapeutic context. Placebo is defined as an inert substance that provokes perceived benefits, whereas the term nocebo is used when an inert substance causes perceived harm. Their major mechanisms are expectancy and classical conditioning. Placebo is used in several fields of medicine, as a diagnostic tool or to reduce drug dosage. Placebo/nocebo effects are difficult to disentangle from the natural course of illness or the actual effects of a new drug in a clinical trial. There are known strategies to enhance clinical results by manipulating expectations and conditioning.

Implications: Placebo and nocebo effects occur frequently and are clinically significant but are underrecognized in clinical practice. Physicians should be able to recognize these phenomena and master tactics on how to manage these effects to enhance the quality of clinical

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Key words: adverse effects, clinical trial, nocebo, pharmacology, placebo, treatment.

INTRODUCTION

The placebo effect has been studied extensively throughout history.[1,2] The nocebo effect, also called "the evil brother of the placebo effect," has been less studied, but in recent years has become a subject of growing interest.[3–5] Both phenomena are composed of several intertwined biological and environmental mechanisms, displaying a complex interaction. Their operative mechanisms not only are affected by the characteristics of the individuals but also on the context in which they operate; thus, the search for a simple equation to predict the effect of placebo and nocebo has been met with limited success.

A precise definition of the placebo and nocebo phenomena is difficult to pinpoint, as different researchers have used different definitions, often depending on the context. A starting definition would be psychobiological events attributable to the overall therapeutic context[6]; herein, placebo effect would be the benefits provoked by an inert substance, and the nocebo effect is the induction of true or perceived harm after treatment with an inactive substance. Thus, a response to treatment, not attributable to the known mechanism of action of the treatment, is the core feature of both phenomena. This means that the definition can also be applied to an active substance treatment, then referring to the (extra) effects it elicits and that are not explained by its pharmacologic action. Many disorders have a natural course of illness in which symptoms fluctuate, making it difficult to differentiate between a placebo or nocebo response and the natural course of illness at an individual patient level. Similarly, many "side effects" occur commonly with or without pharmacotherapies (eg, headache), making it often difficult to disentangle, at an individual patient level, between a treatment-emergent adverse event that is a nocebo response or one that has occurred independently of treatment.

Paradigmatically, the placebo and nocebo phenomena have been most extensively studied in analgesia[7–10] and irritable bowel syndrome (IBS).[11] These phenomena have been studied more recently in the field of dermatology[12–14] and in psychiatry, particularly in depression.[15]

The underpinnings of placebo and nocebo are psychological and neurobiological. Psychological mechanisms include expectancies, conditioning, learning, memory, motivation, somatic focus, reward, anxiety reduction and meaning, and "placebo-by-proxy" induced by clinicians and family members.[16] Two principal mechanisms are well supported. The first aspect involves expectancy: the administration of placebo creates expectations in future responses by using simple verbal cues as modulators of expectations. Researchers can nudge a subject's expectations and boost the placebo effect. The second aspect involves classical conditioning: repeated associations between a neutral stimulus and an unconditioned stimulus (active drug) can result in the ability of the neutral stimulus by itself to provoke a response characteristic of the unconditioned stimulus.[4,17,18] In a study of placebo/nocebo in thermal pain, neither conditioning nor expectation alone seemed to be able to elicit placebo or nocebo effects; however, the combination of experience (conditioning) and expectation resulted in significant placebo (analgesia) or nocebo (hyperalgesia) effects.[19]

Misattribution is the inappropriate attribution of improvement or worsening to a treatment when it was actually caused by the disorder's natural fluctuation of symptoms or other causes.[20] Misattribution may have a more significant role in nocebo effects than in placebo effects, although this theory remains a focus of active debate.[21,22]

The neurobiology of the response to placebo and nocebo has been studied mostly in the paradigmatic field of analgesia and has been shown to be mainly related to the opioid and dopaminergic pathways.[6,23,24] A companion paper published in this issue of *Clinical Therapeutics* reviews the theoretical and biological underpinnings of the nocebo and placebo phenomena.[25]

It is important to note that placebo and nocebo responses are highly variable across individuals. Some individual differences have been associated with genetic polymorphisms or underlying neurologic impairments. For example, patients with frontal lobe impairment, especially prefrontal lobe, have decreased expectancy and learning, and thus they partially or totally lose their placebo response. In a study of Alzheimer's disease and pain, patients with reduced Frontal Assessment Battery scores exhibited a reduced placebo component of the analgesic treatment.[26] In intellectually disabled patients, a higher intelligence quotient was positively related with placebo response.[27]

Catechol-O-methyl transferase is involved in dopamine degradation, affecting the prefrontal lobe. The catechol-O-methyl transferase Val^{158}Met polymorphism is a G to A mutation leading to amino acid substitution at codon 158 in the transmembrane form of the enzyme.[28] It was suggested as a biomarker of placebo response in IBS and a potential biomarker of placebo response in other conditions.[11] Thus, people who carry this polymorphism are more likely to experience the placebo effect.

The tryptophan hydroxylase-2 polymorphism (serotonin-related gene) seems a significant predictor of clinical placebo response in social anxiety disorder. Homozygosity for the G allele was associated with serotonergic modulation of amygdala activity and greater improvement in symptoms of anxiety.[29] People who experience anxiety disorder and carry this polymorphism are more likely to experience the placebo effect. Thus, psychological and neurobiological factors can predict individual differences in placebo and nocebo response.

The present review first focuses on the impact of placebo and nocebo effects in routine clinical settings as well as in clinical trials, and then offers strategies on how to use that knowledge to improve the quality of care and results in research.

MATERIALS AND METHODS

A literature search of PubMed was conducted for articles published between January 1980 and September 2016. Search terms included: *placebo, nocebo, clinical, clinical trial, clinical setting, placebo effect, nocebo effect, adverse effects,* and *treatment outcomes*. This search was augmented by a manual search of the references of the key articles and the related literature. Systematic reviews, randomized controlled trials (RCTs), observational studies, and case series were identified. Articles that had an emphasis on placebo or nocebo effects in clinical practice were selected for the qualitative synthesis.

CLINICAL APPLICATION

The clinical understanding of the placebo effect is a relevant issue. Placebo responses may be a major driver of clinical change after diverse therapies. Placebos are used in several fields of medicine (eg, neurology, psychiatry, rheumatology, pain management, ophthalmology), although ethical considerations limit their use in some areas. When surveyed, 45% of American physicians admitted to having used a placebo.[30] An English study found that only 12% of general practitioners use pure placebos (totally inert interventions) but the number was 97% for impure ones (interventions with clear efficacy for certain conditions but are prescribed for conditions in which their efficacy is unknown).[31] The most common reason to use a placebo was to tranquilize the patient (18%) and as a supplemental treatment (18%). Other reasons included "after 'unjustified' demand for medication" (15%), "for nonspecific complaints" (13%), "after all clinically indicated treatment possibilities were exhausted" (11%), "to control pain" (6%), "to get the patient to stop complaining" (6%), and "as a diagnostic tool" (4%).[30] It has been argued that the clinical benefits from many poorly evidence based complementary and alternative disciplines derive largely or even solely from cultivation of the factors that drive placebo effects.[32] Local regulations, however, preclude clinical use of placebos in some jurisdictions.

Patients need a greater dose of analgesic to achieve an equivalent outcome if their placebo response is impaired. When patients with postoperative pain were given intravenous saline (placebo), and buprenorphine was made available on request, the group told that the intravenous saline was a powerful painkiller took 33% less analgesia for the same pain compared with a control group (who were told they were receiving a rehydrating solution).[33]

CHALLENGES IN CLINICAL TRIALS

The placebo or nocebo response is related to common biochemical pathways that are activated both by social stimuli and therapeutic rituals on one hand and by drugs on the other. It has been shown that when an opioid agent is administered, it binds to μ-opioid receptors, but the very same μ-opioid receptors are activated by the patient's expectations about the drug.[34] This outcome is concordant with the finding that drugs without therapeutic rituals are less effective.[35] A suitable therapeutic setting can thus enhance the placebo response.[36]

The placebo effect has been well established in RCTs. In depression, its magnitude has been shown to vary depending on the investigators. Some propose that up to 75% of the drug effect is mediated by the placebo effect.[37,38] Others question these results, arguing that an unrepresentative subset of clinical trials (including many cases of mild to moderate depression) were analyzed, and therefore the data are not accurate.[39,40] This theory suggests that patients with less severe depression have a lower biological substrate and are more vulnerable to the placebo effect. In 2002,[41] a meta-analysis was conducted with US Food and Drug Administration data containing RCTs that had not been published. This study revealed a small significant difference between antidepressant drug and placebo but not a clinical difference; the mean difference between drug and placebo was ~2 points on the Hamilton Depression Rating Scale. An alternative hypothesis to explain this difference in antidepressant trials is "breached blind." Because of the side effects of the drugs, the RCT patients may know if they are in the placebo or the active group.[42] Furthermore, when another active antidepressant is used as the comparator, instead of placebo, there is a significant increase in the effectiveness of the drug.[43]

It remains controversial whether the placebo effect is increasing across time in RCTs of depression. It has been proposed that the placebo effect has progressively increased over time[44] within the general population as a result of inflation of baseline severity to meet threshold inclusion criteria; that is, trials with less ill people, in which regression to the mean is more likely, and more comprehensive and frequent assessment procedures. Others have argued that pharmaceutical companies try to select only severely depressed patients because pharmacotherapy RCTs for mild and moderate depression often do not show statistically significant separation between the treatment and placebo trial arms,[45] thus downplaying the role of decreased baseline depression severity as an explanation. In contrast, a recent meta-analysis using published and unpublished data found stable placebo responses in the last 25 years,[46] implying the increase across time effect may be an artifact.

PLACEBO/NOCEBO AND SEPARATION FROM THE NATURAL COURSE OF ILLNESS

Understanding the natural course of illness is essential before commencing a clinical trial design or trying to separate drug from placebo effects. Given the fact that symptom severity does not stay frozen in time when no intervention is applied, the spontaneous progress or improvement of a pathological process can obviously confound or pose as a placebo or nocebo effect. These types of studies present numerous challenges, especially as modern medicine shifts its attention from infectious disorders to chronic or mental disorders (which wax and wane, where the natural history of illness extends greatly in time or has poor or no biomarkers available).[47]

Prospective nonintervention studies are increasingly ethically challenging as fewer diseases are lacking effective treatment. Therefore, in many cases, it is impossible to include a nontreatment arm in a clinical trial to guide our interpretation of results and discount the influence of natural progression. A loophole to this problem was found in studies of psychotherapy efficacy on major depressive disorder that use a wait-list as a control group. A meta-analysis[48] found that "wait-listers" experience ~33% of the symptomatic improvement of treated patients and 40% of the ones receiving placebo. An important caveat is that a wait-list is thus a very poor control group for clinical trials, despite being used often. Some studies even found that wait-list results in nocebo effects.[49]

STRATEGIES (USING PLACEBO TO IMPROVE RESULTS)

Maximizing Placebo

Patient expectations contribute toward the outcome of several disorders. This has been demonstrated for analgesia, treatment of myocardial infarction and Parkinson's disease, deep brain stimulation, orthopedic surgery, and antidepressant treatment.[22] Positively influencing patients' beliefs about therapeutic success is one way to maximize the placebo effect.[50] However, being too optimistic is also ethically problematic and can be construed as disingenuous if one is not cautious. Manipulating a patient's expectations may not necessarily require lying or deceiving. In a study of IBS, patients were informed they were being treated with placebo and still developed a positive clinical response.[51]

A partial reinforcement paradigm, placebo-controlled drug reduction (PCDR) (use of a full dose of medication for a set period of time [acquisition period] followed by a maintenance or evocation period with interposed placebo) has been shown to lower the dose needed to elicit a therapeutic response. This finding opens the door for a panoply of chronic disorders treated with medications with substantial side effects (Table I). PCDR allowed children with attention-deficit/hyperactivity disorder to be effectively treated with 50% of their optimal stimulant dose[52] and reduced the corticosteroid dose needed in psoriasis.[53]

Table I. Strategies to maximize the placebo effect.

Managing Expectations	Conditioning
Screen for patients with negative beliefs	Placebo-controlled drug reduction (PCDR)
Hidden applications when discontinuing a drug expected to cause withdrawal symptoms	Use salient stimuli and constant context when administering treatment including sensorial cues, same room and time of day when giving treatment
Promote social contact with other successful patients	Use effective pretreatments
Reduce anxiety	Avoid extinction in long-term treatments Motivation strategies, changes in situational cues Enhance physician–patient relationship Empathic style, more time of contact Describe the procedure before executing to improve attention

Adapted from Enck et al.[22]

It is usually assumed that more complex, time-consuming, and invasive interventions are more likely to be associated with placebo effects than other interventions. For instance, different colors and sizes of a pill seem to influence the clinical outcome.[54] However, to our knowledge, only 1 systematic review[55] has found mixed evidence of more invasive placebos having larger effects (7 of 12 studies with >1 placebo found no difference, 4 found single-outcome differences, and 1 found a large effect; 2 of 4 studies designed to differentiate placebo intensity were positive). The extant data may not be sufficient to discount its influence. To design studies directly comparing very different placebo interventions (ie, pill vs injection) while ensuring blinding for both patients and researchers ranges from very difficult to impossible. Also, to try to design studies controlling for context or for patient or clinician bias in expectancies might be a Sisyphean-like task, as the differences in context and expectancies themselves may be the cause of the placebo effect.

Although the placebo could be more powerful, deliberately administering a more invasive or intense placebo may be both ethically challenging (especially one with potential to cause harm) and lacking in evidence. Conversely, a meta-analysis of 41 RCTs assessing the effects of antidepressant agents on major depressive disorder showed that the more follow-up observations that occur, the more intense are the placebo effects elicited.[56] The number of medical visits in clinical trials contrasts with the shorter contact in community settings. This strategy is well established and can be useful because it is nonharmful. Profiling or choosing the right person to try a placebo might be more problematic. There was limited evidence for the role of age or sex, at least in psychiatric disorders.[57] A stronger correlation was found for low symptom severity and short duration of illness. There were 2 studies in children reporting a higher placebo effect in those of non-white ethnic origin.[58,59]

Managing Placebo in Clinical Trials

When comparing a drug versus a placebo, the first thing to bear in mind is that the effect of an active drug includes in itself a placebo component. Furthermore, issues are further complicated because the relation of the effects between the placebo and drug groups may not always be additive; that is, the measured effect in the active drug arm may be more (or less) than expected just by adding the placebo

Table II. Strategies to optimize drug–placebo differences in clinical trials.

Avoid enrichment/multidosing studies
Aim for a 50/50 probability of receiving placebo
Use treatment-naive patients
Randomized run-in and withdrawal periods
Use active placebos
Incorporate "no-treatment" groups
Avoid comparative effectiveness trials
Prioritize outcome evaluation in the following order:
1. Death
2. Biomarkers
3. Physician assessment
4. Patient-reported outcomes

effect to the actual active drug effect.[22,60] Therefore, perhaps "optimizing the drug–placebo difference" (vs minimizing placebo) is a preferable denomination.

Designing clinical trials is a specialized field in its own right. Separating a drug effect from a placebo effect always at the core of a clinical trial design, so that general quality guidelines for a clinical trial usually will work to optimize the drug–placebo difference: standardizing for symptom severity; avoiding physician's selection bias; controlling for center effects and patient adherence; and ensuring effective blinding.

However, sometimes these strategies are accompanied by other undesirable effects. For example, if we identify drug responders during a run-in phase or preselect patients who were previously exposed to a similar drug, we may increase the drug–placebo difference, but we also risk limiting a drug indication and overestimating benefits. If the population of previous responders comprised a specific group (eg, women), the trial will never generate approval for men. Some strategies involve deceit and thus have ethical concerns. Cost and feasibility are concerns as well (eg, when considering augmenting sample size). Therefore, it is up to the researcher to weigh the risks and benefits of each strategy.

Because the chance of being in a treatment group increases the magnitude of placebo responses,[61] a study design of equal likelihood of receiving placebo or treatment (ie, avoid enrichment or multidosing studies) should be preferred. Contrary to common belief, trying to exclude placebo responders using run-in phases early in the study was not able to prevent later placebo response.[62] Randomized run-in (ie, in a double-blind manner, patients first start receiving placebo and are then switched to the active drug after a few days) and withdrawal periods seem to hold more promise.[63] Crossover designs may promote conditioning[64] and may lead to unblinding of the study due to perceived side effects. Using active placebos (drugs that mimic the active treatment side effects) is a possible perfect placebo that rarely exists, mimicking all the side effects without any of the active mechanisms of the drug being tested. Controlling for the natural progression of the disease should also be a concern, even if in many situations it is ethically challenging and may motivate subjects to drop out. A way around this is using Zelen's design,[65] in which patients are randomly divided into an observational group and an interventional group comprising the active drug and placebo branches, allowing to control for the natural course of illness.

Comparative effectiveness trials are usually used when an efficacious treatment already exists for ethical standards. The new drug must then prove superiority, equivalence, or noninferiority. However, it has been shown that a drug tested against an active comparator performs better.[61,66] The placebo effect is also reportedly stronger when patients report the outcome than when the physician performs the assessment,[67] which is itself stronger than a biomarker-based evaluation.[68] The most objective outcome possible is death or survival rate, but this approach obviously cannot be used for many disorder endpoints (Table II).

Minimizing Nocebo

In the case of nocebo, no overt ethical dilemma is present. The intention of the physician is always to minimize its risk and effects. Also, we can expect the factors and strategies used to minimize the nocebo effect to be a mirror of the ones in placebo.

Of major importance would be to identify individuals more prone to develop nocebo effects. Several studies have been conducted to identify "risk factors" of the nocebo effect. A systematic review[4] found "learning/social observation," "perceived dose," "verbal suggestions of arousal and symptoms," and "baseline symptom expectations" to be the strongest predictors of nocebo effects. Interestingly, the type of administration again did not appear to be relevant, nor did self-awareness during exposure. Symptom severity at

Table III. Strategies to minimize nocebo.

Managing Expectations	Conditioning
Avoid informed consent overly focused on side effects	Low-dose initial regimen (when possible)
Framing of information	Hidden tapering in when feasible
Focus on the positive effects of treatment	
Conjoint plan	
Sense of control and ownership of the decision-making process (by the patient)	
Empathic attitude	

Adapted from Data-Franco and Berk.[73]

baseline (one of the strongest associations with placebo) also produced mixed results. Demographic factors such as sex, age, and literacy did not change the risk of a nocebo response. One study found that female investigator subjects report nocebo effects twice as frequently as male subjects after a social suggestion paradigm, but these data could have been confounded by the study design (the social cue was presented by a female).[69] In modern health systems in which access is good, participants who volunteer for trials may have presented with poor response or have not tolerated standard therapy. This earlier adverse experience increases the likelihood of these subjects being primed for nocebo responses.[70]

Managing patients' beliefs and experiences are at the core of possible strategies. Framing of information is an effective way to put the benefits and risks of treatment in perspective, focusing on the positive possibilities.[71] A caring and empathic relationship is beneficial.[72] When the medical problem allows for a small delay in the start of therapy, a lower initial dose might be helpful. Similarly, in RCTs, if a patient does not know when exactly he or she is getting exposed, nocebo effects are reduced (Table III). Nevertheless, this approach may be rarely feasible in outpatient settings or even time- and resource-consuming in a hospital setting.

CONCLUSIONS

Clinically, placebo and nocebo effects are of major importance, being present in daily medical practice. The overall effect of a drug stems from its pharmacodynamic actions plus the psychological effect derived from the act of its administration. Although both placebo and nocebo have been widely studied, the full complexity of their mechanisms needs further definition. Thus, when correctly applied, there are a number of strategies that can improve responses and patients' quality of life, maximizing placebo and reducing nocebo in clinical practice, and enhancing results in clinical trials. It underlines the impact of creating a good physician–patient relationship, increasing empathic attitudes, exposing information suitably, decreasing expectations of adverse effects, and promoting social contact between successfully treated patients.

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CONFLICTS OF INTEREST

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Exhibit A40-4

NEUROSCIENCE

Nocebo effects can make you feel pain

Negative expectancies derived from features of commercial drugs elicit nocebo effects

By **Luana Colloca**

The mysterious phenomenon known as the nocebo effect describes negative expectancies. This is in contrast to positive expectancies that trigger placebo effects (*1*). In evolutionary terms, nocebo and placebo effects coexist to favor perceptual mechanisms that anticipate threat and dangerous events (nocebo effects) and promote appetitive and safety behaviors (placebo effects). In randomized placebo-controlled clinical trials, patients that receive placebos often report side effects (nocebos) that are similar to those experienced by patients that receive the investigational treatment (*2*). Information provided during the informed consent process and divulgence of adverse effects contribute to nocebo effects in clinical trials (*1*). Nocebo (and placebo) effects engage a complex set of neural circuits in the central nervous system that modulate the perception of touch, pressure, pain, and temperature (*1, 3, 4*). Commercial features of drugs such as price and labeling influence placebos (*5, 6*). On page 105 of this issue, Tinnermann *et al.* (*7*) show that price also influences nocebo effects.

Tinnermann *et al.* evaluated the responses of healthy participants who received two placebo creams labeled with two distinct prices and presented in two boxes that had marketing characteristics of expensive or cheap medication. The creams were described as products that relieve itch but induce local pain sensitization (hyperalgesia). All creams, including controls, were identical and contained no active ingredients. Nocebo hyperalgesic effects were larger for the "more expensive" cream than for the "cheaper" cream. Combined corticospinal imaging revealed that the expensive price value increased activity in the prefrontal cortex. Furthermore, brain regions such as the rostral anterior cingulate cortex (rACC) and the periaqueductal gray (PAG) encoded the differential nocebo effects between the expensive and cheaper treatments. Expectancies of higher pain-related side effects associated with the expensive cream may have triggered a facilitation of nociception processes at early subcortical areas and the spinal cord [which are also involved in placebo-induced reduction of pain (*8*)]. The rACC showed a deactivation and favored a subsequent activation of the PAG and spinal cord, resulting in an increase of the nociceptive inputs. This suggests that the rACC–PAG–spinal cord axis may orchestrate the effects of pricing on nocebo hyperalgesia.

The anticipation of painful stimulation makes healthy study participants perceive nonpainful and low-painful stimulations as painful and high-painful, respectively (*9*). Verbally induced nocebo effects are as strong as those induced through actual exposure to high pain (*9*). Moreover, receiving a placebo after simulating an effective analgesic treatment, compared to receiving the same placebo intervention after a treatment perceived as ineffective, produces a 49.3% versus 9.7% placebo-induced pain reduction, respectively (*10*). The relationship between prior unsuccessful or successful pain relief interventions and placebo analgesic effects is linked to a higher activation of the bilateral posterior insula and reduced activation of the right dorsolateral prefrontal cortex (*11*).

Informing patients that a treatment has been stopped, compared to a covert treatment interruption, alters the response to morphine, diazepam, or deep-brain stimulation in postoperative acute pain, anxiety, or idiopathic Parkinson's disease, respectively (*12*). Patients openly informed about the interruption of each intervention experience a sudden increase of pain, anxiety, or bradykinesia (a manifestation of Parkinson's disease), whereas patients undergoing a hidden interruption do not (*12*). Neuroimaging approaches support the clinical observation. For example, the action of the analgesic remifentanil is overridden by activation of the hippocampus that occurs when healthy participants that receive heat pain stimulations are misleadingly told that the remifentanil administration was interrupted (*13*). These findings provide evidence that communication of treatment discontinuation might, at least in part, lead to nocebo effects with aggravation of symptoms.

In placebo-controlled clinical trials, nocebo effects can influence patients' clinical outcomes and treatment adherence. It was shown in a clinical trial that atorvastatin induced in the same individuals an excess rate of muscle-related adverse events in the nonblinded (i.e., patients knew they were taking atorvastatin), nonrandomized 3-year follow-up phase but not in the initial blinded 5-year phase when patients and physicians were unaware of the treatment allocation (atorvastatin or placebo) (*14*). Furthermore, misleading information about side effects for statins via public claims has led to treatment discontinuation and an increase in fatal strokes and heart attacks (*14*).

Given that nocebo effects contribute to perceived side effects and may influence clinical outcomes and patients' adherence to medication, we should consider how to avoid them in clinical trials and practices (*15*)—for example, by tailoring patient-clinician communication to balance truthful information about adverse events with expectancies of outcome improvement, exploring patients' treatment beliefs and negative therapeutic history, and paying attention to framing (i.e., treatment description) and contextual effects (i.e., price). Through an understanding of the physiological mechanisms, strategies could be developed to reduce nocebo effects. ■

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Science

Nocebo effects can make you feel pain

Luana Colloca

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Review

A Review of the Theoretical and Biological Understanding of the Nocebo and Placebo Phenomena

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ABSTRACT

Purpose: Placebos are commonly used in experimental and patient populations and are known to influence treatment outcomes. The mechanism of action of placebos has been investigated by several researchers. This review investigates the current knowledge regarding the theoretical and biological underpinning of the nocebo and placebo phenomena.

Method: Literature was searched using PubMed using the following keywords: *nocebo*, *placebo*, *μ-opioid*, *dopamine*, *conditioning*, and *expectancy*. Relevant papers were selected for review by the authors.

Findings: The roles of conditioning and expectancy, and characteristics associated with nocebo and placebo responses, are discussed. These factors affect nocebo and placebo responses, although their effect sizes vary greatly, depending on inter-individual differences and different experimental paradigms. The neurobiology of the nocebo and placebo phenomena is also reviewed, emphasizing the involvement of reward pathways, such as the μ-opioid and dopamine pathways. Neurobiological pathways have been investigated in a limited range of experimental paradigms, with the greatest efforts on experimental models of placebo analgesia. The interconnectedness of psychological and physiological drivers of nocebo and placebo responses is a core feature of these phenomena.

Implications: Further research is needed to fully understand the underpinnings of the nocebo and placebo phenomena. Neurobiology pathways need to be investigated in experimental paradigms that model the placebo response to a broader range of pathologies. Similarly, although many psychological factors and inter-individual characteristics have been identified as significant mediators and moderators of nocebo and placebo responses, the factors identified to date are unlikely to be exhaustive. (*Clin Ther*. 2017;39:469–476) © 2017 Published by Elsevier HS Journals, Inc.

Key words: conditioning, dopamine, expectancy, μ-opioid, nocebo, pharmacology, placebo, treatment.

For the purpose of this review, a placebo response is an improvement in clinical symptoms when a person is administered an inert substance, whereas a nocebo response is a worsening of clinical symptoms or the experiencing of treatment-emergent adverse effects. Typically, a placebo tablet is administered in control arms of

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clinical trials and is manufactured to look identical to the tablet in the active arm of a trial. Nocebo and placebo responses are also sometimes used to describe unexpected responses to active treatments that are not explained by the known mechanism of action of the treatment. It may not be possible to discern at an individual participant level between true placebo or nocebo responses and fluctuations in symptom severity due to the natural progression of the illness; however, insightful placebo and nocebo response data can often be obtained at a cohort level. While the importance of the placebo effect is widely understood, this is much less so for the nocebo effect. The biological bases of the nocebo and placebo effects are only now beginning to be unraveled. Attempts to understand the causes of the placebo effect have increased in the last 50 years, as placebo-controlled clinical trials have become the only accepted method for efficacy testing of new pharmaceuticals and the problems associated with placebos have become more apparent. Insights have been gained from exploring theoretical causes and influencing factors of the effect, which have probed the mechanisms underlying the phenomenon. This article reviews the theoretical and biological underpinning of the nocebo and placebo phenomena. A separate article also published in this issue reviews the clinical importance of the nocebo and placebo phenomena.

PSYCHOLOGICAL UNDERPINNINGS

There are a multitude of psychological elements that have been identified as the leading factors underpinning the placebo and nocebo effects.

The most well-known theories pertaining to the placebo and nocebo phenomena are the conditioning and expectancy hypotheses. Conditioning can occur when a person was pre-exposed to an active substance and had a reaction that imprints in memory. When they are then given an inert substance, they might respond to the inert substance in the same or similar way as they would to the active substance. A conditioned response is a triggering of a memory loop and, therefore, is driven by learning and adaptation.[1] The effect is mediated by many variables. The conditioning hypothesis alone is insufficient to explain the placebo and nocebo phenomena, for example, the extinction phenomenon in classic conditioning does not necessarily occur with placebos.[1]

Expectancy occurs where a pre-existing belief, or information received before being given an inert substance (or before reporting a response[2]), elicits a response to the inert substance predicated on what the person thinks will happen. It is not necessary to have ever been exposed to an active substance to have an expectation of response. This may be responding to a treatment that is not pharmacologically active because of a pre-existing belief that the treatment either works or might cause a specific reaction, and can be an important factor in alternative therapies in which pharmacologically active compounds are not included in the treatment.[3] Similarly, expectation can be a driver of inappropriate or over-prescription of some medications, including antibiotics, in a phenomenon that shares much in common with the placebo effect.[4] As with conditioning, expectancy also requires learning, which may come through direct receipt of information, suggestion, social cues, or the interaction of all these learning modalities.[5] Suggestion has also been used experimentally to extinguish a conditioned placebo response.[6] Extinction of a conditioned response requires learning, which in the case of a placebo response can be facilitated by suggestion, but may not necessarily occur solely through repeated administration of a placebo.

Hope for improvement has also been suggested as a driver of the placebo effect[1] and this has face validity; however, data have not been presented to support this theory. A corollary, where despair is suggested to drive the nocebo effect, has not been proposed in peer-reviewed literature. However, personality traits have been associated with placebo response,[7] leaving the possibility open to an association between personality traits, such as optimism and pessimism, being factors in the placebo and nocebo phenomena. However, considerable work needs to be done to unravel the relationship between personality and placebo response, including expanding the theoretic underpinnings of the association through hypothesis-driven research in addition to the current works that have focused on association between personality measures and placebo response.[8] State and trait variance are a limitation with personality measures[9] and may be relevant for the placebo response, for example, where there is variance in dependence.

The nature of the therapeutic alliance may also be a driver of the nocebo effect, with a hostile–dependent relationship being an exemplar. This relationship pattern occurs when one party is dependent on another, and the former is hostile or mistrusting of other people. This is a not uncommon but poorly recognized pattern in clinical practice, where people with insecure attachment styles are forced into trusting a clinician, and their interactional style makes this difficult Figure.

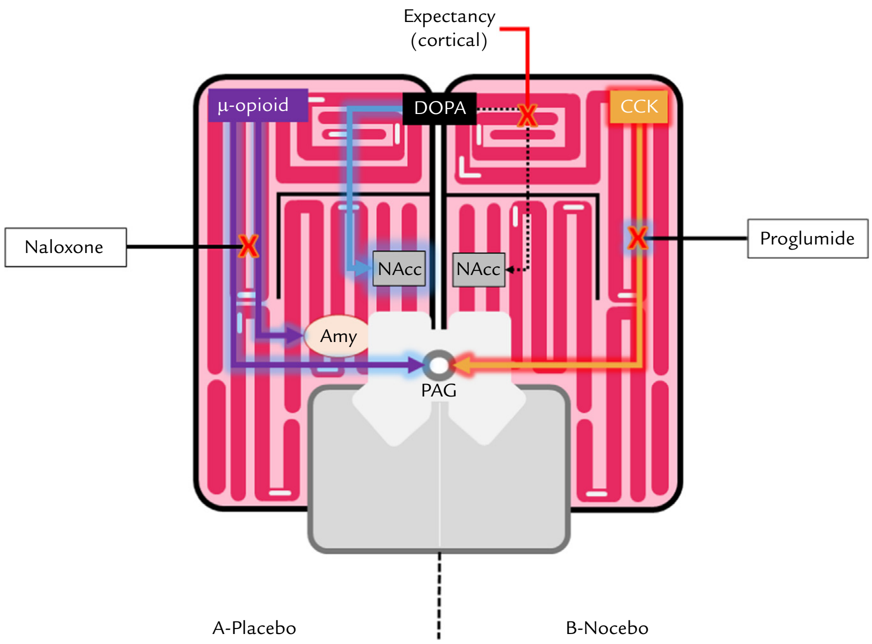

Figure. Summary of regions, circuits, and neurotransmitters implicated in placebo and nocebo. A-Placebo: Expectation activates cortical area signaling of dopamine to the nucleus accumbens and μ-opioid to the periaqueductal gray and elsewhere in the brain (the amygdala and other regions: not shown). The placebo effect is blocked by naloxone. B-Nocebo: Negative expectation has the opposite effect in the dopamine signaling and also activates cholecystokinin from the prefrontal cortex to the periaqueductal gray. The nocebo effect is blocked by proglumide. Amy = amygdala; CCK = cholecystokinin; DOPA = dopamine; NAcc = nucleus accumbens; PAG = periaqueductal gray.

In an open-labeled study, 80 women with irritable bowel syndrome were randomly assigned to placebo with a persuasive rationale but without deception, or to a control group with no treatment. Both groups received the same patient–provider relationship and contact time. Participants in the placebo-treated group had significantly higher global improvement scores.[10] In this study, the placebo effect occurred even though the participants were told they would be receiving an inert substance "like sugar pills." This may suggest that the placebo effect has multiple drivers, including expectancy, as participants were told that placebo "has been shown to produce significant improvement to [irritable bowel syndrome] symptoms," as well as the importance of the treatment rituals and therapeutic environment.

There is evidence that anxiety about the tolerability or efficacy of a treatment can be a driver of the nocebo effect. In a meta-analysis of placebo-treated participants in clinical trials of duloxetine versus placebo, treatment-emergent adverse events were reported more commonly in Phase II trials, then Phase III, and least in Phase IV.[11] This suggests that a nocebo response is more likely for a treatment that is more experimental and uncertain compared with one that is more established.

Choice of treatment and sense of control was found to influence both placebo and nocebo responses in an experiment where healthy participants (n = 61) were randomly assigned to choose between 2 equivalent β-blocker medications or be assigned to the medications. All study medications were actually placebos. There was an increased placebo response in the choice group and an increased nocebo response in the no-choice group.[12]

Neurobiological Findings

Numerous experiments have revealed insights into which regions of the brain are involved in the placebo response and which biochemical processes are occurring in association with placebo and nocebo events. Imaging studies have often used a placebo analgesia paradigm, as it is a reliable and convenient model.

Many variation of the analgesia paradigm exist. Placebos to replace psychotropic drugs are also a reliable and convenient paradigm, and a placebo antidepressant has been used for at least one imaging study. The placebo and nocebo phenomenon has been found in numerous medical conditions, across drug classes, and in non-pharmacologic contexts. It may be difficult to disentangle if a neurobiological response is applicable to the placebo and nocebo phenomena in general or only to a specific context or as treatment for a specific stimulus. The Figure summarizes brain regions, circuits, and neurotransmitters implicated in placebo and nocebo phenomena.

Neuroanatomic Regions

Studies using functional nuclear magnetic imaging (fMRI) and positron emission tomography (PET) have identified multiple brain regions involved in the placebo response. Several studies and a meta-analysis have identified the thalamus, primary and secondary somatosensory cortex, anterior cingulate cortex (ACC), amygdala, basal ganglia, and right lateral prefrontal cortex as brain regions; these were less activated when measured by fMRI, when placebo analgesia was used to modulate a response to a pain stimulus.[5] PET studies of placebo analgesia have identified the rostral ACC, prefrontal cortex, insula, thalamus, amygdala, nucleus accumbens and periaqueductal gray using a μ-opioid receptor radiotracers, and the basal ganglia using D2 and D3 receptor radiotracers as brain regions with neurotransmitter response to placebo analgesia.[13]

In a deceptive placebo analgesia paradigm fMRI study for visceral pain where participants are randomized to receive placebo and being told the substance is inert or placebo and being told that the substance is an analgesic, greater modulation by placebo analgesia of the posterior insula and dorsolateral prefrontal cortex was observed in women compared with men, although the efficacy of placebo analgesia in controlling expected or perceived pain did not differ between sexes.[14] A deceptive placebo analgesia paradigm fMRI study for noxious heat pain, where placebos were labeled as a popular branded original or a generic analgesic, original branded and generic labeled placebos were both associated with activation of the anterior insulae at baseline and activation of the dorsomedial prefrontal cortex after the interventions. Greater activation of the bilateral dorsolateral (as well as dorsomedial) prefrontal cortex (PFC) was observed for the placebo labeled as the original brand. The placebo labeled as the original brand was also associated with decreased pain intensity compared with the generic-labeled placebo.[15] A recent PET study using a μ-opioid receptor radiotracer, patients with major depressive disorder were treated with placebo in a crossover study in which one placebo was labeled "active" and the other "inactive," and told that the active treatment was a fast-acting antidepressant and the inactive treatment was a control. Active treatment was superior to inactive treatment for placebo-induced opioid release in brain regions subgenual ACC, nucleus accumbens, amygdala, thalamus, and hypothalamus.[16] Placebo activation of endogenous opioid neurotransmitters that bind to receptors in the pregenual and subgenual rostral ACC, the dorsolateral PFC, the insular cortex, and the nucleus accumbens, has also been observed in an analgesia paradigm using PET.[17] Substantial inter-individual variation has been reported for brain regions involved in placebo response to expectations of analgesia.[18]

An fMRI study of 24 healthy adults investigated neural activation in response to stimuli associated with different expectations. In 3 separate sessions (ie, training, conditioning, and scanning sessions) on different days, participants were subject to 12-second heat pain stimulus to their right forearm. At the conditioning and training sessions, participants skin was treated with an inert cream before the heat pain stimulus. One cream was labeled "lidocaine" (positive expectancy), one was labeled "neutral," and the third cream was labeled "capsaicin" (negative expectancy). Difference between positive and negative expectancy conditions were observed, either pre or post stimulus, in the dorsal ACC, right orbito-PFC, anterior insula, right dorsolateral PFC, left ventral striatum, orbitofrontal cortex, periaqueductal gray, and left operculum and putamen.[19] This experiment found that placebo and nocebo expectancies have effects on different brain networks in response to a pain stimulus.

There are limitations to using fMRI and PET to study models of the nocebo and placebo effects. Firstly, most experiments are conducted on health volunteers, so important drivers of the placebo response, such as hope and therapeutic alliance, are not included in the experimental construct. Secondly, study participants are inside a large piece of medical equipment, which is a specific experimental environment. Thirdly, the experimental environment limits the study design and duration.

Neurochemical Processes

The placebo response has been associated with the release of endorphins and dopamine, providing a neurochemical explanation of the efficacy of placebo analgesia.[13] Early evidence of the elevation of endogenous opioids in placebo analgesia was reported in 1978, when Levine et al[20] used placebo as an analgesic for dental postoperative pain and reversed the analgesic effects by administering the opiate antagonist naloxone. Endorphin and dopamine release and opioid and dopamine receptors are widely distributed, but are also clustered in specific brain regions that correspond with many of the regions identified by fMRI studies. There are 3 major types of opioid receptor, μ-opioid receptor, δ-opioid receptor, and κ-opioid receptor, which can be further divided into subtypes, and a fourth nociception or orphanin receptor.[21] These receptors are widely distributed through the brain and other organs, but with differences in expression and distribution.[21] Opioid receptors have a range of functions, including pain modulation and their association with analgesia, however, they are also associated with various functions, including mood regulation, homeostasis, cell proliferation, and neuroprotection.[21]

Much placebo neurobiological research has focused on analgesia, often investigating the μ-opioid receptor. Where major depressive disorder has been investigated[16] increased μ-opioid neurotransmission has been observed, similar to observations in analgesia research, which may suggest similarities to, or be a consequence of, using a similar research method. Inter-individual variation in μ-opioid neurotransmission has also been observed in a study of 50 healthy controls with and without placebo administration, where psychological trait scores measured with scales for altruism, straightforwardness, and angry hostility accounted for 25% of the variance in placebo analgesic response and also found that participants scoring above the median in a composite score of all 3 traits had increased μ-opioid neurotransmission in response to placebo administration.[22]

An experiment where hypertonic saline was injected into the masseter muscle of 20 healthy individuals to induce pain, with or without placebo analgesia, was investigated using PET to examine changes in dopamine and opioid neurotransmission. The study used [C^{11}]-labeled raclopride (selective for D_2 receptors) and carfentanil (selective for μ-opioid receptors). Participants were asked to rate the efficacy of the analgesic and describe adverse events. Effective placebo analgesia was associated with increased dopamine and opioid neurotransmission in multiple brain regions. A nocebo effect was identified in 5 participants who reported increased pain intensity during placebo administration. Nocebo responders showed decreased dopamine and opioid neurotransmission in the same brain regions where increased neurotransmission was observed in placebo responders.[23]

In a study where patients reporting mild perioperative pain were given saline solution and were told that the solution produced an increased pain (nocebo hyperanalgesia), pain was abolished when proglumide was added to the solution. Proglumide is a cholecystokinin antagonist, which blocks both the CCK_A and CCK_B receptor subtypes, suggesting that nocebo hyperanalgesia is mediated at least in part by cholecystokinin.[24]

PET studies have found that administration of a placebo to people with Parkinson's disease can induce dopamine release in the striatum.[25] Furthermore, in a study of 24 participants with Parkinson's disease undergoing deep brain stimulation, the firing rate of selected neurons was changed in participants who showed a clinical response to placebo, but not in nonresponders or partial responders to placebo. Mean firing frequency decreased in subthalamic and substantia nigra pars reticulata neurons and increased in ventral anterior and anterior ventral lateral thalamus neurons. The placebo effect had a duration of no more than 45 minutes. Other parts of the brain circuitry were not measured.[26] Another study found that placebo was enhanced with preconditioning by apomorphine exposure, with the greater number of exposures to apomorphine associated with a greater change in neuronal firing rates.[27]

Endocannabinoids have a role in placebo-induced analgesia, as reported in a study analogous to the 1978 naloxone experiment that reported on the role of endorphins.[20] Placebo was effective as an analgesic against tourniquet pain after preconditioning participants to analgesia with either the opioid morphine or the nonsteroidal anti-inflammatory drug ketorolac. In these preconditioned participants, the CB1 cannabinoid receptor antagonist rimonabant reversed placebo analgesia after preconditioning with ketorolac, but did not reverse placebo analgesia in participants preconditioned with morphine.[28]

Prostaglandin levels have also been found to change in response to placebo. In an experiment,

Exhibit A40-4

placebo was used to treat headache caused by high-altitude (3,500 m) hypobaric hypoxia, after preconditioning by treating headache with inhaled oxygen and later giving placebo (sham) oxygen, or by preconditioning with aspirin and later giving a placebo tablet. In both scenarios, the placebos were effective for reducing headache pain, but the analgesic effect of placebo oxygen was superior to placebo aspirin. Placebo oxygen was found to specifically reduce salivary prostaglandin E_2, mimicking the therapeutic pathway of oxygen therapy, whereas placebo aspirin had a more general effect on prostaglandin synthesis, mimicking the effect of cyclooxygenase inhibition.[29]

Interaction of Psychological and Physiological Factors

Placebo and nocebo responses occur within a psychological and physiological context. This context is critical for all aspects of the response, including the neurobiological elements. The context includes characteristics of the study or treatment in which the placebo or nocebo effect is observed and characteristics of the study participant or patient, as well as other characteristics, including the environment in which the study or treatment is being conducted. The doctor–patient relationship, for example, can include trust, where untrustworthiness has been associated with increased amygdala activity, and trustworthiness can be modulated by oxytocin.[30] Trust may be a characteristic not only of the active relationship, but is powerfully influenced by personality and developmental factors that set individuals levels of trust. Similarly, hope and hopelessness have been associated with serotonergic and noradrenergic systems,[30] showing the potential for variables relevant to placebo having a direct effect on neurotransmitter systems directly implicated in mood. Also relevant to the placebo response, admiration and compassion by a participant have been found through fMRI to result in a pattern of activation within the posteromedial cortice.[31] Learned helplessness has been found to effect serotonin regulation.[32] The relationship between pain and stress and anxiety with the hypothalamic–pituitary–adrenal axis and cortisol is well established.[33]

Negative and positive expectations, which are suggested to be major drivers of the placebo and nocebo responses, have been found to induce changes in reward circuitry in the nucleus accumbens, and similarly, conditioning may induce changes in learning mechanisms.[30]

DISCUSSION

The drivers of the placebo and nocebo phenomena may be a synergy of multiple biological and psychological variables, mediated by a further multitude of contextual and individual variables. There is clear evidence of physiological factors that underpin the phenomena, as well as a contribution by psychological factors. This is further complicated by considerable inter-individual differences. Although there is consistency in the literature in terms of which pathways are implicated in placebo and nocebo responses, neurotransmitter activation does not occur with all individuals experiencing the same stimulus. Factors such as conditioning, expectancy, hope and despair, wanting to please the experimenters, treatment setting, caring nature of the clinician, and personal beliefs about medications, all play a role.

Furthermore, while the placebo and nocebo effect has been observed for treatment for a broad range of medical conditions, it has only been carefully studied in experimental models of a narrow range of conditions, especially pain and analgesia. It is possible, or even likely, that the neural pathways involved in a placebo analgesia response are different, or only partly overlapping, from the neural pathways involved in a placebo response for a different treatment. The investigation of the biological and theoretical underpinning of the placebo and nocebo phenomena is at an early stage and much additional research is required.

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CONFLICTS OF INTEREST

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REVIEW ARTICLE

Nocebo Phenomena in Medicine

Their Relevance in Everyday Clinical Practice

Winfried Häuser, Ernil Hansen, Paul Enck

SUMMARY

Background: Nocebo phenomena are common in clinical practice and have recently become a popular topic of research and discussion among basic scientists, clinicians, and ethicists.

Methods: We selectively searched the PubMed database for articles published up to December 2011 that contained the key words "nocebo" or "nocebo effect."

Results: By definition, a nocebo effect is the induction of a symptom perceived as negative by sham treatment and/or by the suggestion of negative expectations. A nocebo response is a negative symptom induced by the patient's own negative expectations and/or by negative suggestions from clinical staff in the absence of any treatment. The underlying mechanisms include learning by Pavlovian conditioning and reaction to expectations induced by verbal information or suggestion. Nocebo responses may come about through unintentional negative suggestion on the part of physicians and nurses. Information about possible complications and negative expectations on the patient's part increases the likelihood of adverse effects. Adverse events under treatment with medications sometimes come about by a nocebo effect.

Conclusion: Physicians face an ethical dilemma, as they are required not just to inform patients of the potential complications of treatment, but also to minimize the likelihood of these complications, i.e., to avoid inducing them through the potential nocebo effect of thorough patient information. Possible ways out of the dilemma include emphasizing the fact that the proposed treatment is usually well tolerated, or else getting the patient's permission to inform less than fully about its possible side effects. Communication training in medical school, residency training, and continuing medical education would be desirable so that physicians can better exploit the power of words to patients' benefit, rather than their detriment.

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Words are the most powerful tool a doctor possesses, but words, like a two-edged sword, can maim as well as heal.", Bernard Lown (e1).

Doctor–patient communication and the patient's treatment expectations can have considerable consequences, both positive and negative, on the outcome of a course of medical therapy. The positive influence of doctor–patient communication, treatment expectations, and sham treatments, termed placebo effect, has been known for many years (e2) and extensively studied (1). The efficacy of placebo has been demonstrated for subjective symptoms such as pain and nausea (1). The Scientific Advisory Board of the German Medical Association published a statement on placebo in medicine in 2010 (2).

Method

The opposite of the placebo phenomenon, namely nocebo phenomena, have only recently received wider attention from basic scientists and clinicians. A search of the PubMed database on 5 October 2011 revealed 151 publications on the topic of "nocebo," compared with over 150 000 on "placebo." Stripping away from the latter all articles in which "only" placebo-controlled drug trials were reported left around 2200 studies investigating current knowledge of the placebo effect. In comparison, the data on the nocebo effect are sparse. Of the 151 publications, only just over 20% were empirical studies: the rest were letters to the editor, commentaries, editorials, and reviews (*Figure*).

Our intention here is to portray the neurobiological mechanisms of nocebo phenomena. Furthermore, in order to sensitize clinicians to the nocebo phenomena in their daily work we present studies on nocebo phenomena in randomized placebo-controlled trials and in clinical practice (medicinal treatment and surgery). Finally, we discuss the ethical problems that arise from nocebo phenomena which may be induced by explanation of the proposed treatment in the course of the patient briefing and describe possible solutions.

Definition of nocebo phenomena

The term "nocebo" was originally coined to give a name to the negative equivalent of placebo phenomena and distinguish between desirable and undesirable effects of placebos (sham medications or other sham interventions, for instance simulated surgery). "Nocebo" was used to describe an inactive substance or

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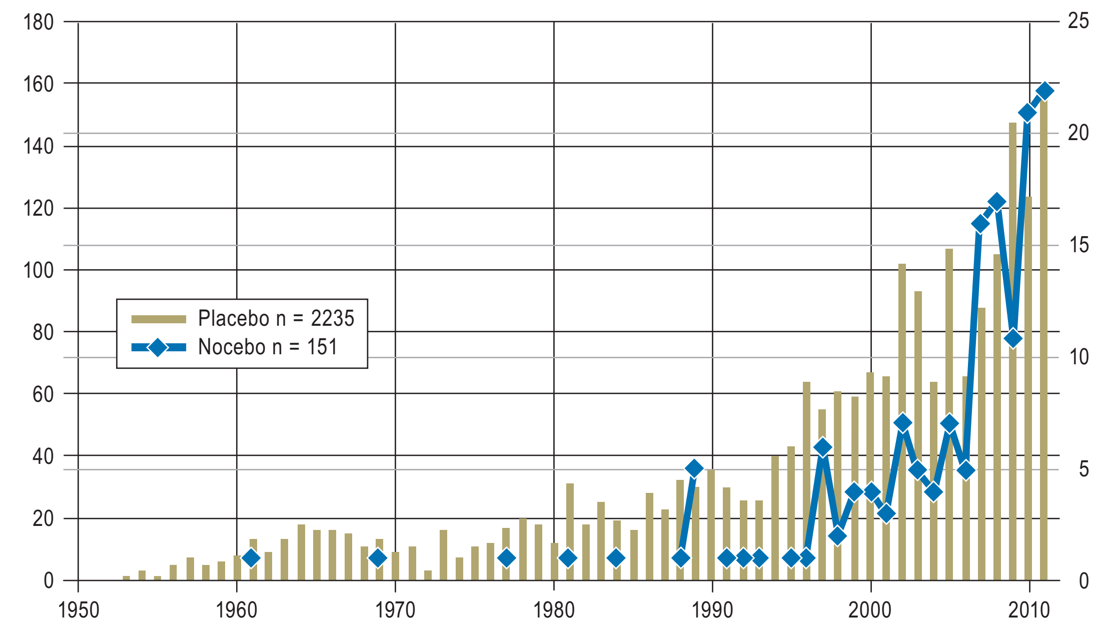
Number of studies on the placebo effect (olive-green bars, left ordinate) and the nocebo effect (blue diamonds, right ordinate) in PubMed between 1950 and 2011

FIGURE



ineffective procedure that was designed to arouse negative expectations (e.g., giving sham medication while verbally suggesting an increase in symptoms) (3).

"Placebo" and "nocebo" are meanwhile being used in another sense: The effects of every medical treatment, for example administration of drugs or psychotherapy, are divided into specific and non-specific. Specific effects are caused by the characteristic elements of the intervention. The non-specific effects of a treatment are called placebo effects when they are beneficial and nocebo effects when they are harmful.

Placebo and nocebo effects are seen as psychobiological phenomena that arise from the therapeutic context in its entirety, including sham treatments, the patients' treatment expectations and previous experience, verbal and non-verbal communications by the person administering the treatment, and the interaction between that person and the patient (4). The term "nocebo effect" covers new or worsening symptoms that occur during sham treatment e.g., in the placebo arm of a clinical trial or as a result of deliberate or unintended suggestion and/or negative expectations. "Nocebo response" is used to mean new and worsening symptoms that are caused only by negative expectations on the part of the patient and/or negative verbal and non-verbal communications on the part of the treating person, without any (sham) treatment (5).

Experimental nocebo research

Experimental nocebo research aims to answer three central questions:

- Are nocebo effects caused by the same psychological mechanisms as placebo effects, i.e., by learning (conditioning) and reaction to expectations?
- Are placebo and nocebo effects based on the same or different neurobiological events?
- Are the predictors of nocebo effects different from those of placebo effects?

Psychological mechanisms

The proven mechanisms of the placebo response include learning by Pavlovian conditioning and reaction to expectations aroused by verbal information or suggestion (6). Learning experiments with healthy probands have shown that worsening of symptoms of nausea (caused by spinning on a swivel chair) can be conditioned (7). Expectation-induced cutaneous hyperalgesia could be produced experimentally through verbal suggestion alone (8). Social learning by observation led to placebo analgesia on the same order as direct experience by conditioning (9).

Nocebo responses can also be demonstrated in patients. In an experimental study, 50 patients with chronic back pain were randomly divided into two groups before a leg flexion test: One group was informed that the test could lead to a slight increase in pain, while the other group was told that the test had no effect on pain level. The group with negative information reported stronger pain (pain intensity 48.1 [standard deviation (SD) 23.7] versus 30.2 [SD 19.6] on a 101-point scale) and performed fewer leg flexions (52.1 [SD 12.5] versus 59.7 [SD 5.9]) than the group with neutral instruction (10).

It can be concluded from these studies that both placebo and nocebo responses can be acquired via all kinds of learning. If such reactions occur in everyday clinical practice, one must assume that they arise from the patient's expectations or previous learning experiences (5).

Neurobiological correlates

A key part in the mediation of the placebo response is played by a number of central chemical messengers. Especially dopamine and endogenous opiates have been demonstrated to be central mediators of placebo analgesia. These two neurobiological substrates have also been shown to play a part in the nocebo response (hyperalgesia): While secretion of dopamine and endogenous opioids is increased in placebo analgesia, this reaction is decreased in hyperalgesia (11). Because worsening of symptoms e.g., increased sensitivity to pain is often associated with anxiety, other central processes play a part, e.g., the neurohormone cholecystokinin (CCK) in pain (12). To date, a genetic predisposition to placebo response has been demonstrated only for depression and social anxiety (e3); such a predisposition to nocebo response has so far not been shown (e4).

Interindividual variation

Sex is a proven predictor of the placebo response and also exerts some influence on the nocebo response. In the above-mentioned study on the aggravation of symptoms of nausea, women were more susceptible to conditioning and men to generated expectations (6).

Identification of predictors of nocebo responses is a central goal of ongoing investigations. The aim is to pinpoint groups at risk of nocebo responses, for example patients with high levels of anxiety, and optimize the therapeutic context accordingly (13).

Generation of nocebo responses by doctor–patient and nurse–patient communication

The verbal and non-verbal communications of physicians and nursing staff contain numerous unintentional negative suggestions that may trigger a nocebo response (14).

Patients are highly receptive to negative suggestion, particularly in situations perceived as existentially threatening, such as impending surgery, acute severe illness, or an accident. Persons in extreme situations are often in a natural trance state and thus highly suggestible (15, 16). This state of consciousness leaves those affected vulnerable to misunderstandings arising from literal interpretations, ambiguities, and negative suggestion *(Box)*.

In medical practice the assumption is that the patient's pain and anxiety are minimized when a painful manipulation is announced in advance and any expression of pain by the patient is met with sympathy. A study of patients receiving injections of radiographic substances showed that their anxiety and pain were heightened by the use of negative words such as "sting," "burn," "hurt," "bad," and "pain" when explaining the procedure or expressing sympathy (17). In another study, injection of local anesthetic preparatory to the induction of epidural anesthesia in women about to give birth was announced by saying either "We are going to give you a local anesthetic that will numb the area so that you will be comfortable during the procedure" or "You are going to feel a big bee sting; this is the worst part of the procedure." The perceived pain was significantly greater after the latter statement (median pain intensity 5 versus 3 on an 11-point scale) (18).

BOX

Unintended negative suggestion in everyday clinical practice (after 15, e5, e6)

- **Causing uncertainty**
  "This medication may help."
  "Let's try this drug."
  "Try to take your meds regularly."
- **Jargon**
  "We're wiring you up now." (connection to the monitoring device)
  "Then we'll cut you into lots of thin slices." (computed tomography)
  "Now we're hooking you up to the artificial nose." (attaching an oxygen mask)
  "We looked for metastases—the result was negative."
- **Ambiguity**
  "We'll just finish you off." (preparation for surgery)
  "We're putting you to sleep now, it'll soon be all over." (induction of anesthesia)
  "I'll just fetch something from the 'poison cabinet' (secure storage for anesthetics), then we can start."
- **Emphasizing the negative**
  "You are a high-risk patient."
  "That always hurts a lot."
  "You must strictly avoid lifting heavy objects—you don't want to end up paralyzed."
  "Your spinal canal is very narrow—the spinal cord is being compressed."
- **Focusing attention**
  "Are you feeling nauseous?" (recovery room)
  "Signal if you feel pain." (recovery room)
- **Ineffective negation and trivialization**
  "You don't need to worry."
  "It's just going to bleed a bit."

TABLE 1

Systematic reviews: discontinuation rates in placebo arms of randomized trials owing to adverse events

Reference	Verum	Number of studies	Discontinuation rate (%)
e9	Primary and secondary prevention of cardiovascular diseases: statins	20	4–26 *
e10	Multiple sclerosis: immune modulators	56	2.1 (95% CI: 1.6–2.7)
e10	Multiple sclerosis: symptomatic treatment	44	2.4 (95% CI: 1.5–3.3)
e11	Acute treatment of migraine	59	0.3 (95% CI: 0.2–0.5)
e11	Prevention of migraine	31	4.8 (95% CI: 3.3–6.5)
e11	Prevention of tension headache	4	5.4 (95% CI: 1.3–12.1)
22	Painful peripheral diabetic polyneuropathy	62	5.8 (95% CI: 5.1–6.6)
22	Fibromyalgia syndrome	58	9.5 (95% CI: 8.6–10.7)

CI = confidence interval; * no data on pooled discontinuation rates

The patient's expectations

Just as the announcement that a drug is going to be given can provoke its side effects even if it is not actually administered, telling headache patients that they are going to experience a mild electric current or an electromagnetic field (e.g., from cell phones) produces headaches (e7). The symptoms of Parkinson's disease patients undergoing deep brain stimulation are more pronounced if they know their brain pacemaker is going to be turned off than if they do not know (e8).

Nocebo phenomena in drug treatment

Researchers distinguish true placebo effects from perceived placebo effects. The true placebo effect is the whole effect in the placebo group minus non-specific factors such as natural disease course, regression to the mean, and unidentified parallel interventions. The true placebo effect can be quantified only by comparing a placebo group and an untreated group (19). The true nocebo effect in double-blind drug trials thus includes all negative effects in placebo groups minus non-specific factors such as symptoms from the treated disease or comorbid conditions and adverse events of accompanying medication (4). The nocebo effects in drug trials referred to below are perceived rather than "true" nocebo effects.

Adverse event profile and discontinuation rates in placebo groups of randomized trials

A systematic review showed that in randomized controlled trials (RCTs) of migraine (69 studies in total, 56 of them with triptans, 9 with anticonvulsants, and 8 with non-steroidal antirheumatic drugs), the side effect profile of placebo corresponded with that of the "true" drug being tested (20). A systematic review of RCTs of tricyclic antidepressants (TCAs; 21 studies) and selective serotonin reuptake inhibitors (SSRIs; 122 studies) revealed a significantly higher rate of adverse events in both the verum and placebo arms of the TCA trials compared to the verum and placebo arms of the SSRI trials. Patients given TCA placebos were significantly more likely to report dry mouth (19.2% versus 6.4%), vision problems (6.9% versus 1.2%), fatigue (17.3% versus 5.5%), and constipation (10.7% versus 4.2%) than patients taking SSRI placebos (21).

The side effects of medications therefore depend on what adverse events the patients and their treating physicians expect (20, 21). Rates of discontinuation owing to adverse effects of placebo in double-blind trials on patients with various diseases are presented in *Table 1*.

Problems in evaluating side effects of drugs

The methods used for recording adverse events influence the type and the frequency of effects reported: Patients specify more adverse events when checking off a standardized list of symptoms than when they report them spontaneously (21). In a large proportion of double-blind drug trials, the way in which subjective drug side effects were recorded is described inadequately or not at all (22). The robustness of the data on which summaries of product characteristics and package inserts are based must therefore be seen in a critical light.

The problems in evaluating side effects of drugs in RCTs also apply in everyday clinical practice. Is the symptom reported by the patient—nausea, for example—a side effect of medication, a symptom of the disease being treated, a symptom of another disease, or a (temporary) indisposition unconnected with either the drug or the disease?

Nocebo effects during drug treatment in everyday clinical practice

Nocebo effects have been described in *(Table 2)*:

- Drug exposure tests in the case of known drug allergy
- Perioperative administration of drugs
- Finasteride in benign prostate hyperplasia

TABLE 2

Nocebo effects in clinical studies

Reference	Diagnosis	Number of patients	Results
e12	Case series: exposure test in known drug allergy	600	27% reported adverse events (nausea, stomach pains, itching) on placebo
e13	Case series: exposure test in known drug allergy	435	32% reported adverse events (nausea, stomach pains, itching) on placebo
e14	Two RCTs: fatigue in advanced cancer	105	79% reported sleep problems, 53% loss of appetite, and 33% nausea on placebo*
e15	RCT: perioperative administration of drugs	360	Undesired effects were reported by 5–8% of patients in the sodium chloride group, 8% of patients in the midazolam-placebo group, and 3–8% of patients in the fentanyl-placebo group
e16	RCT: finasteride in benign prostate hyperplasia	107	Blinded administration of finasteride led to a significantly higher rate of sexual dysfunction (44%) in the group that was informed of this possible effect than in the group that was not informed (15%)
e17	RCT: 50 mg atenolol in coronary heart disease	96	Rates of sexual dysfunction: 3% in the group that received information on neither drug nor side effect, 16% in the group that was informed about the drug but not about the possibility of sexual dysfunction, 31% in the group that was told about both the drug and the possible sexual dysfunction
e18	RCT: 100 mg atenolol in coronary heart disease	114	Rates of sexual dysfunction: 8% in the group that received information on neither drug nor side effect, 13% in the group that was informed about the drug but not about the possibility of sexual dysfunction, 32% in the group that was told about both the drug and the possible sexual dysfunction
e19, e20	Acetylsalicylic acid versus sulfinpyrazone in unstable angina pectoris	555	Inclusion of gastrointestinal side effects in the patient briefing at two of the three study centers led to a six-fold rise in the rate of discontinuation owing to subjective gastrointestinal side effects. The study centers with and without briefing on gastrointestinal side effects showed no difference in the frequency of gastrointestinal bleeding or gastric or duodenal ulcers
23	Controlled study of lactose intolerance	126	44% of persons with known lactose intolerance and 26% of those without lactose intolerance complained of gastrointestinal symptoms after sham administration of lactose
e21	Case report from RCT of antidepressants	1	Severe hypotension requiring volume replacement after swallowing 26 placebo tablets with suicidal intent

*Worse ratings for sleep, appetite, and fatigue before the study were associated with a higher rate of reported adverse events; RCT = randomized controlled trial

- Beta-blocker treatment of cardiovascular diseases
- Symptomatic treatment of fatigue in cancer patients
- Lactose intolerance.

The lactose content of tablets varies between 0.03 g and 0.5 g. Small amounts of lactose (up to 10 g) are tolerated by almost all lactose-intolerant individuals. Therefore, complaints of gastrointestinal symptoms by lactose-intolerant patients who have been told by the physician or have found out for themselves that the tablets they are taking contain lactose may represent a nocebo effect (23).

In Germany, the *aut idem* ruling by which pharmacists may substitute a preparation with identical active ingredients for the product named on the prescription and discount agreements have led to complaints from patients and physicians of poor efficacy or increased adverse effects after switching to generic preparations. A cross-sectional survey conducted on behalf of the German Association of Pain Treatment (*Deutsche Gesellschaft für Schmerztherapie e.V.*) and the German Pain League (*Deutsche Schmerzliga e.V.*) questioned 600 patients who had been switched to an oxycodone-containing generic preparation. Ninety percent were less satisfied with the analgesic effect, and 61% reported increased pain intensity (German-language source: Überall M: *IQUISP Gutachten [Fokusgruppe Oxycodonhaltige WHOIII Opioide] Querschnittsbefragung zu den psychosozialen Folgen einer Umstellung von Originalpräparaten auf Generika bei chronisch schmerzkranken Menschen im Rahmen einer stabilen/zufriedenstellenden Behandlungssituation.* Überall M: IQUISP Expert Report [Focus Group Oxycodone-containing WHO III Opioids]: cross-sectional survey on the psychosocial consequences of substituting original preparations with generics for treatment of chronic pain in a stable/satisfactory treatment context [talk held on 8 March 2008 at a symposium sponsored by Mundipharma during the 19th German Interdisciplinary Pain Congress]).

A qualitative systematic review showed that patients with increased anxiety, depressivity, and somatization tendency are at greater risk of adverse events after switching to generic preparations (24). It must be discussed whether critical statements by medical opinion leaders (e22) and representatives of patients' self-help organizations (e23) on the substitution of powerful opioid preparations by generic equivalents might not be leading to nocebo effects. In the words of one such statement: "The consequences of substitution are always the same: more pain or more adverse events" (e23).

Expectations that a treatment will be poorly tolerated, whether based on experience or induced by information from the media or trusted third parties, may bring about nocebo effects. A systematic review and meta-analysis found a robust association between the expectation and the occurrence of nausea after chemotherapy (e24).

Ethical implications and the dilemma of the patient briefing

On one hand physicians are obliged to inform the patient about the possible adverse events of a proposed treatment so that he/she can make an informed decision (e25). On the other, it is the physician's duty to minimize the risks of a medical intervention for the patient, including those entailed by the briefing (25). However, the studies just cited show that the patient briefing can induce nocebo responses.

The following strategies are suggested to reduce this dilemma:

Focus on tolerability: Information about the frequency of possible adverse events can be formulated positively ("the great majority of patients tolerate this treatment very well") or negatively ("5% of patients report…") (4). A study on briefing in the context of influenza vaccination showed that fewer adverse events were reported after vaccination by the group told what proportion of persons tolerated the procedure well than by those informed what proportion experienced adverse events (e26).

Permitted non-information: Before the prescription of a drug, the patient is asked whether he/she agrees to receive no information about mild and/or transient side effects. The patient must, however, be briefed about severe and/or irreversible side effects (5). "A relatively small proportion of patients who take Drug X experience various side effects that they find bothersome but are not life threatening or severely impairing. Based on research, we know that patients who are told about these sorts of side effects are more likely to experience them than those who are not told. Do you want me to inform you about these side effects or not?" (5).

To respect patients' autonomy and preferences, they can be given a list of categories of possible adverse events for the medication/procedure in question. Each individual patient can then decide which categories of side effects he/she definitely wants to be briefed about and for which categories information can be dispensed with (e27).

Patient education: A systematic review (four studies, 400 patients) of patients with chronic pain showed that training from a pharmacist—e.g., general information on medicinal and non-medicinal pain treatment or on the recording of possible side effects of drugs and guidance in the case of their occurrence—reduced the number of side effects of medications from 4.6 to 1.6 (95% confidence interval of difference: 0.7–5.3) (e28).

Perspectives

Communication training with actor-patients or role-plays during medical studies or in curricula for psychosomatic basic care impart the ability to harness the "power" of the physician's utterances selectively for the patient's benefit (e29, e30). Skill in conveying positive suggestions and avoiding negative ones should also receive more attention in nurse training.

The German Medical Association's recommendations on patient briefing, published in 1990 (e25), urgently require updating. The points that need to be discussed include, for example, whether it is legitimate to express a right of the patient not to know about complications and side effects of medical procedures and whether this must be respected by the physician. Furthermore, it has to be debated whether some patients might not be left confused and uncertain by their inability to follow the legally mandatory comprehensive information on potential complications of medical treatments that is found, for example, on package inserts or multipage information and consent documents.

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KEY MESSAGES

- Every medical treatment (e.g., drug administration, psychotherapy) has specific and non-specific effects. Specific effects result from the characteristic elements of the intervention. The beneficial non-specific effects of a treatment are referred to as placebo effects, the harmful ones as nocebo effects.
- Placebo and nocebo effects are viewed as psychobiological phenomena that arise from the therapeutic context in its entirety (sham treatments, the patients' treatment expectations and previous experience, verbal and non-verbal communications by the person administering the treatment, and the interaction between that person and the patient).
- Nocebo responses may result from unintended negative suggestion by physicians or nurses.
- The frequency of adverse events is increased by briefing patients about the possible complications of treatment and by negative expectations on the part of the patient.
- Some of the subjective side effects of drugs can be attributed to nocebo effects.

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For eReferences please refer to:
www.aerzteblatt-international.de/ref2612

Exhibit A40-4

REVIEW ARTICLE

Nocebo Phenomena in Medicine

Their Relevance in Everyday Clinical Practice

Winfried Häuser, Ernil Hansen, Paul Enck

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A Systematic Review of Factors That Contribute to Nocebo Effects

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Objectives: Medication side effects are common, often leading to reduced quality of life, nonadherence, and financial costs for health services. Many side effects are the result of a psychologically mediated "nocebo effect." This review identifies the risk factors involved in the development of nocebo effects. ***Method:*** Web of Science, Scopus, MEDLINE, PsycINFO, Journals@Ovid full text, and Global Health were searched using the terms "nocebo" and "placebo effect." To be included, studies must have exposed people to an inert substance and have assessed 1 or more baseline or experimental factor(s) on its ability to predict symptom development in response to the inert exposure. ***Results:*** Eighty-nine studies were included; 70 used an experimental design and 19 used a prospective design, identifying 14 different categories of risk factor. The strongest predictors of nocebo effects were a higher perceived dose of exposure, explicit suggestions that the exposure triggers arousal or symptoms, observing people experiencing symptoms from the exposure, and higher expectations of symptoms. ***Conclusions:*** To reduce nocebo induced symptoms associated with medication or other interventions clinicians could reduce expectations of symptoms, limit suggestions of symptoms, correct unrealistic dose perceptions, and reduce exposure to people experiencing side effects. There is some evidence that we should do this especially for persons with at-risk personality types, though exactly which personality types these are requires further research. These suggestions have a downside in terms of consent and paternalism, but there is scope to develop innovative ways to reduce nocebo effects without withholding information.

Keywords: inert exposure, nocebo effect, predictors, review, symptoms

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Adverse drug reactions (ADRs) are common (Davies et al., 2009), and can have serious implications in terms of patient well-being and adherence (Ammassari et al., 2001) as well as significant financial costs for health services (NICE, 2009; Rodríguez-Monguió, Otero, & Rovira, 2003). However, ADRs are not always related to the physiological action of the medication (Faasse & Petrie, 2013). Only 10.9% of reported ADRs to commonly prescribed drugs are clearly attributable to the medication (de Frutos Hernansanz et al., 1994). It is thought a nocebo effect may play a role in the formation of other apparent side effects (Barsky, Saintfort, Rogers, & Borus, 2002). As well as medication side effects, nocebo effects have been implicated in symptoms attributed to technological exposures such as electro-magnetic fields (EMF) from mobile phones and Wi-Fi (Baliatsas et al., 2012; Rubin, Cleare, & Wessely, 2008). A nocebo effect is the experience of negative symptoms following exposure to an inert substance, which are triggered or exacerbated by psychological mechanisms such as expectations (Kennedy, 1961). The name "nocebo" was created to distinguish between the desirable ("placebo") and undesirable effects of an inert exposure (Häuser, Hansen, & Enck, 2012), although in practice the distinction between undesirable and desirable is not always clear cut. For example increased alertness may be beneficial in some contexts (e.g., prior to an examination) and detrimental in others (e.g., prior to sleep).

Current literature suggests there are three main mechanisms for a nocebo effect; misattribution, expectation, and learning. Misattribution theory suggests that people misattribute preexisting symptoms to the effects of a new exposure (although some authors believe that misattribution does not technically constitute a nocebo effect, see Colloca & Miller, 2011 and Enck, Bingel, Schedlowski, & Rief, 2013). Symptoms are common in everyday life (Petrie, Faasse, Crichton, & Grey, 2014), and although often harmless and short-lived, when people are subjected to a new exposure, symptoms that were present before or occur coincidentally are available to be mistakenly attributed to it (Petrie et al., 2005; Petrie, Moss-Morris, Grey, & Shaw, 2004). Therefore factors such as high baseline symptoms or high self-awareness may serve as risk factors for nocebo effects resulting from this mechanism. Negative expectations can also mediate nocebo effects (Hahn, 1997), and may in turn arise through explicit suggestions about the effects of an exposure (Jaén & Dalton, 2014; Myers, Cairns, & Singer, 1987), or predisposing factors such as pessimism (Geers, Helfer,

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Kosbab, Weiland, & Landry, 2005). These negative expectations can make the individual more likely to attend to new or current sensations, and attribute them to the exposure (Barsky et al., 2002). The response expectancy theory suggests that it is also possible for negative expectations to act more directly, with an expectation of, for example anxiety, being itself anxiety provoking thereby directly causing the negative effect that was expected (Kirsch, 1997a, 1997b). The last mechanism, learning, can elicit nocebo effects through association or social observation. For example, if an inert stimulus has been previously paired with a symptom-inducing stimulus (Barsky et al., 2002), which may occur through conscious or nonconscious mechanisms (Stewart-Williams, 2004), or through observing someone else experience symptoms to the same exposure (Vögtle, Barke, & Kroner-Herwig, 2013).

Given the significant costs nocebo effects can have on patient quality of life and health services it is important to develop interventions to minimize these effects from occurring. Many risk factors have been implicated, but no study has systematically reviewed these to identify those which are the strongest predictors of nocebo effects; something that would assist in the development of such interventions. Instead, previous systematic reviews have focused on the magnitude of nocebo effects for a specific symptom, for example, Petersen et al. (2014) or in clinical trials of experimental medical treatments (Häuser, Bartram, Bartram-Wunn, & Tolle, 2012). One review (Symon, Williams, Adelasoye, & Cheyne, 2015) has provided a preliminary assessment of some of the risk factors involved in nocebo effects. However this “scoping review” identified only 17 papers—a limited subset of the available literature. To address this gap our systematic review aimed to identify the risk factors involved in the reporting of any symptom in response to an inert exposure. This will allow the identification of factors which appear to be consistent predictors of nocebo effects and aid in the development of evidenced-based interventions to prevent them from occurring in the future.

Method

Identification of Studies

Searches were carried out on December 11, 2014, using the following databases: Web of Science, Scopus, MEDLINE, PsycINFO, Ovid, and Global Health. The search terms consisted of “nocebo” or “placebo effect,” and where available, searches were limited to studies with a human sample, with review articles restricted. The reference sections of included studies were also examined as well as papers suggested through personal contacts. No gray literature was searched and no temporal constraints were used. The review followed a previously designed, unpublished protocol.

Selection Criteria

Studies were eligible for inclusion if they met the following criteria:

- Studied a human population (healthy volunteers, patients or children were allowed).
- Used an experimental or prospective design.
- Used an inert exposure, that is, containing no pharmacological or physiological active ingredient.
- Assessed factors on their ability to predict symptom reporting, and these factors could be baseline characteristics or experimentally induced.
- Included an outcome of symptom reporting after participants received an inert exposure. Reported symptoms must not have been attributable to an active exposure (e.g., studies where an inert exposure was applied after an active exposure such as heat stimulation were excluded, as in this case the symptoms would have resulted from the heat stimulation).
- Measured symptoms via self-report or inferred through objective measures (e.g., scratching behavior). Such symptoms could be somatic, a measure of arousal or mood. Because of the difficulty in defining when an outcome is aversive or beneficial we took an inclusive approach. For example measures of alertness (where an increase could be aversive in some instances) or contentedness (where decreases might be possible) were both included.
- Published in any language.

Data Extraction

For each study included in the review, details relating to 20 issues were extracted. In summary these related to: sample characteristics, methodological design, type of exposure, experimental conditions and/or baseline risk factors, symptom measurement, statistical analysis, and results. Any non-English articles were translated. We differentiated between studies that used an experimental or a prospective design to easily identify factors implicated in nocebo effects that can be manipulated and those that naturally occur at baseline. For a copy of the data extraction sheet used, see Appendix 1 in the supplemental materials.

Quality Assessment

Eligible studies using an experimental design were assessed using the Cochrane Collaboration’s Risk of Bias tool (Higgins et al., 2011). For prospective studies, the CASPin International (1998) critical appraisal tool was used and adapted to give a “high,” “unclear,” or “low” risk of bias score, which were color coded red, orange, and green, respectively. Originally the CASP is scored with yes/no answers but this was rescored to low risk (yes) and high risk (no) as well as including an unclear risk response for when enough information was not provided, similar to the Cochrane Risk of Bias tool. As these tools had no criteria assessing sample size we looked at this separately.

Review Process

Rebecca K. Webster conducted the database searches and screened the titles and abstracts of articles to assess their potential relevance. Guidance was obtained from G. James Rubin if there was any uncertainty as to including an article for full text review. Rebecca K. Webster obtained the full articles for those citations that appeared potentially relevant and checked them against the inclusion criteria. If it was unclear whether an article met the inclusion criteria, consensus was sought from G. James Rubin and John Weinman, Rebecca K. Webster then independently extracted data for each included study and carried out the quality assessment with guidance from G. James Rubin Because of the expected heterogeneity in the studies we did not plan for any meta-analyses and instead we used a narrative synthesis. There is no general consensus on the best way to carry out a narrative synthesis for systematic reviews (Popay et al., 2006). As such we decided to use a weight of evidence approach. To do this, we identified the strength of evidence for each risk factor based on the number of studies investigating each risk factors and their respective quality.

Results

Search Results

The database search retrieved 12,582 citations. After removing duplicates 6,585 citations remained. After screening titles and abstracts, we reviewed the full text of 88 articles relating to 96 studies. Of these, 13 studies were excluded for not investigating any risk factors for the development of symptoms, nine were excluded for using an active exposure and seven were excluded for not measuring symptoms. Sixty-six articles met the inclusion criteria. Twenty-one additional articles were identified by reference checks of included articles and through personal contacts; resulting in a total of 87 articles. Two articles reported results on two separate studies each (Walach & Schneider, 2009; Winters et al., 2001) and are referred to as “Exp 1” or “Exp 2” where necessary, leaving 87 articles reporting on 89 studies. Of these, 70 were experimental (see Table 1) and 19 prospective (see Table 2). Figure 1 provides a flow diagram of the study selection according to the Preferred Reporting for Systematic Reviews and Meta-analyses statement (Moher, Liberati, Tetzlaff, & Altman, 2009).

Quality Assessment

Experimental studies. The quality of experimental studies was poor (see Figure 2), with the main problem being a lack of clear reporting. Thirty-six studies neglected to mention how they carried out randomization, whereas 22 studies were at high risk of bias for failing to mention whether participants were randomized or for not using randomization at all. Because of the unclear reporting of random sequence generation, the risk for allocation concealment bias followed a similar pattern. For blinding of participants and personnel, studies often failed to state whether the experimenters were blind to the manipulation that accompanied the exposure, leaving the risk of bias unclear. Only six studies used adequate blinding procedures, with 12 not using blinding at all. Sixty-five studies used self-report measures, as such blinding of the outcome assessment was judged to be unlikely to influence these results. For 52 studies, drop outs were not addressed, or if they were, they typically failed to explain how this affected the results, leaving the risk of bias unclear. Only one study had lodged a protocol in a publically accessible registry before the start of recruitment, leaving us unable to assess the risk for selective reporting for the remaining studies. As well as this we looked for justification of sample size to assess if each study was adequately powered. Again this was poorly addressed, with only 9 of the 70 studies mentioning that they carried out an a priori sample size calculation.

Prospective studies. The prospective studies performed well against the quality check (see Figure 2). All studies addressed a clearly focused issue with a standardized exposure across all participants. Studies often lacked information about how participants were recruited. However, self-report measures were widely used to minimize bias from experimenters. The identification and control of confounding factors was only deemed an issue for six studies that neglected to control for demographic factors such as gender or age and past symptom reporting. The follow-up of participants was judged to be appropriate in 16 studies. Regarding the generalizability of the findings, it was often difficult to know whether the results could be applied to the population being studied because of the insufficient information about how participants were recruited. In addition, similarly to the experimental studies, justification for sample size was limited with only one study providing an a priori sample size calculation.

Experimentally Induced Risk Factors Categories

Seventy experimental studies were included that investigated risk factors which fell into 9 different categories as discussed below (further details in supplementary Tables 3–11).

Learning. Twenty-three studies manipulated different types of learning on symptom reporting finding some evidence for its role in nocebo effects. Four of these investigated prior experience of which two lower quality studies found no significant effects (Bayer, Coverdale, Chiang, & Bangs, 1998; Dinnerstein & Halm, 1970). However, André-Obadia, Magnin, and Garcia-Larrea (2011) showed that sham rTMS tended to worsen patients’ pain when following an active yet unsuccessful rTMS treatment (however caution is required as no statistical test accompanied this finding), and a high-quality study by Stegen et al. (1998) found that participants reported significantly more arousal and respiratory symptoms when completing a breathing trial with room air before a breathing trial with carbon dioxide rather than afterward. As such there is some evidence that prior experience is involved in the development of nocebo effects. Two studies of mixed quality explored the impact of implicit association supporting its role in the nocebo effect, finding that drinking sham caffeine in a coffee solution resulted in significantly more alertness, contentedness, and arousal, than drinking sham caffeine in an orange juice solution (Flaten & Blumenthal, 1999; Mikalsen, Bertelsen, & Flaten, 2001). Three studies of high quality investigated learning through the manipulation of social observation, with two finding a significant effect, broadly supporting its role in the nocebo effect. Lorber, Mazzoni, and Kirsch (2007) failed to show any main effects of observing a confederate display symptom behaviors after inhaling a sham environmental toxin which they were also exposed to. However, in a similar study, participants who observed a confederate display symptoms had significantly higher symptom ratings after inhalation than participants who did not (Mazzoni, Foan, Hyland, & Kirsch, 2010). Similarly, patients who watched a video of people scratching compared to those who saw a video of people sitting idle had higher itch and scratching behavior rating after administration of sham histamine (Papoiu, Wang, Coghill, Chan, & Yosipovitch, 2011), no results were reported for the healthy volunteers in this study.

Of the remaining 14 studies, 13 investigated learning by using classical conditioning to pair inert exposures such as odors with CO_2 inhalation before presenting the inert exposures on their own (De Peuter et al., 2005; Devriese, De Peuter, Van Diest, Van de

Table 1
Summary of the Methods Used in Experimental Studies

Reference and quality	Study design	Population (*N*, mean age, %male)	Inert exposure	Experimental risk factor(s) and conditions (*n*)	Baseline risk factors
André-Obadia et al. (2011)[b,d]	RCT (B)	Chronic neuropathic pain patients (45, 55.0, 37.8)	Sham rTMS	1. Prior experience: a. Sham rTMS before active rTMS (20); b. Sham rTMS after successful active rTMS (12); c. Sham rTMS after ineffective active rTMS (13)	Pain
Angelucci and Pena (1997)[d]	RCT (B)	Student caffeine consumers (148, U/K, 23.0)	Sham coffee	1. Arousal suggestions: a. Given coffee with no expectations (37); b. Given coffee with low arousal expectations (37); c. Given coffee with high arousal expectations (37); d. no coffee and no expectations (37)	State and trait anxiety, Suggestibility, Expectations, Gender
Bayer et al. (1991)[d]	RCT (B + W)	Unemployed Men (100, U/K, 100.0)	Sham electrical shock	1. Symptom suggestions: a. Told they would receive a safe but often painful undetectable current (60); b. Were assured there would be no shocks (40) 2. Perceived dose: a. Within each group the stimulator setting increased from 0 to 80 mA	None
Bayer et al. (1998)[a,d]	RCT (B + W)	Job seekers (62, U/K, 82.0)	Sham electrical shock	1. Prior experience: a. Exposed to two physical pain induction procedures prior to sham stimulation (32); b. Warned of pain and received sham stimulation. They were not exposed to any prior pain induction (30) 2. Perceived dose: a. Within each group the stimulator setting increased in steps of 10 every 5 minutes till it reached 50	Expectations
Benedetti et al. (1997)[d]	RCT (B)	Video assisted thoracoscopy patients (36, 53.7, 66.1)	Sham treatment	1. Symptom suggestions: a. Open injection that it would increase pain (18); b. Hidden injection (18)	None
Brodeur (1965)[d]	RCT (B)	Healthy senior students (45, U/K, 91.1)	Sham arousal capsule	1. Arousal suggestions: a. Told it was a stimulant (15); b. Told it was a tranquilizer (15); c. No suggestion (15)	None
Colagiuri et al. (2012)[d]	RCT (B)	Students experiencing sleep difficulty (82, 20.2, 22.0)	Sham sleeping pill	1. Symptom suggestions: a. Treatment might cause one side effect (29); b. Treatment might cause four side effects (23); c. No warning about side effects (30)	None
Crichton et al. (2014)[d]	RCT (B)	Students (54, U/K, 37.0)	Sham infrasound	1. Symptom suggestions: a. TV footage detailing symptomatic experiences attributed to wind farms *(27)*; b. TV footage with experts stating wind farms would not cause symptoms *(27)*	None
Dalton (1999)[d]	RCT (B)	Healthy volunteers (180, 31.7, 49.4)	Odors	1. Odors: a. Pleasant smelling methyl salicylate (60); b. neutral smelling isobornyl acetate (60); c. Foul smelling butanol (60) 2. Symptom suggestions: a. Told they would have relaxing effects (60); b. Told they were industrial solvents (60); c. Told they were approved for olfactory research (60)	Odor reactivity, Olfactory sensitivity
De Peuter et al. (2005)[d]	RCT (W)	Asthma patients and healthy controls (40, *23.9*, 52.5)	Sham inhaler	1. Conditioning: a. one sham inhaler paired with CO2 challenge; b. one sham inhaler paired with O2	Expectations, Negative affect, Clinical condition
Devriese et al. (2000)[a,d]	Non RCT (B + W)	Healthy students (56, U/K, 41.1)	Odors	1. Odor: a. Foul smelling ammonia; b. Pleasant smelling niaouli 2. Conditioning: a. Ammonia paired with CO2 breathing task, Niaouli paired with room air breathing task (28); b. Ammonia paired with room air breathing task, Niaouli paired with CO2 breathing task (28) 3. Timing: a. Test phase immediately after conditioning trials (28); b. Test phase one week after conditioning trials (28) 4. Generalization: a. New foul smelling odor butyric acid; b. New foul smelling odor acetic acid; c. New pleasant smelling odor citric aroma	Negative affect

(*table continues*)

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Table 1 (*continued*)

Reference and quality	Study design	Population (*N*, mean age, %male)	Inert exposure	Experimental risk factor(s) and conditions (*n*)	Baseline risk factors
Devriese et al. (2004)[a,d]	Non RCT (B + W)	Healthy students (53, U/K, U/K)	Odors	1. Odor: a. Foul smelling ammonia; b. Foul smelling butyric acid 2. Conditioning: a. Ammonia paired with CO2 breathing task, butyric acid paired with room air breathing task (28); b. Ammonia paired with room air breathing task, butyric acid paired with CO2 breathing task (25) 3. Symptom suggestions: a. Given information about possible health damaging effects of chemical pollution (U/K); b. No information (U/K)	Negative affect, Perceived cue odor
Devriese et al. (2006)	RCT (B + W)	Psychology students (40, U/K, .0)	Odors	1. Odor: a. Foul smelling ammonia; b. Foul smelling acetic acid 2. Conditioning: a. Ammonia paired with CO2 breathing task, acetic acid paired with room air breathing task (20); b. Ammonia paired with room air breathing task, acetic acid paired with CO2 breathing task (20) 3. Symptom suggestions: a. Given information about possible health damaging effects of chemical pollution (20); b. No information (20)	None
Dinnerstein and Halm (1970)[c,d]	RCT (B)	Male students (80, U/K, 100.0)	Sham arousal liquid	1. Arousal suggestions: a. Told it was an energizer (40); b. Told it was a tranquilizer (40) 2. Prior experience: a. Received aspirin prior to sham (40); b. Received lactose prior to sham (40)	None
Faasse et al. (2013)[b,c,d]	RCT (B)	Healthy students (60, 19.4, 43.5)	Sham anti-anxiety tablet	1. Brand suggestions: a. Branded reformulation change (20); b. Generic reformulation change (20); c. No change (20)	None
Flaten (1998)[d]	RCT (B)	Healthy students (48, U/K, 35.4)	Sham arousal drink	1. Arousal suggestions: a. Told you will feel relaxed and sleepy (16); b. Told you will feel alert and a little stress (16); c. Told you will take an inactive drug (16)	None
Flaten and Blumenthal (1999)[d]	RCT (W)	Healthy coffee drinkers (21, 24.8, 61.9)	Decaffeinated solution	1. Association: a. Orange juice; b. Decaffeinated coffee	None
Flaten et al. (1999)[d]	RCT (B)	Healthy volunteers in non-health professions (34, U/K, 54.5)	Sham arousal capsule	1. Arousal suggestions: a. The drug will make you feel relaxed (11); b. The drug will make you feel alert (12); c. You will receive capsules that contain a prescription drug (11)	None
Flaten et al. (2003)[a,b,d]	W	Coffee drinkers (20, U/K, 50.0)	Sham coffee	1. Perceived dose: a. Participants were first given one cup and then a second	Symptoms, Expectations
Gavrylyuk et al. (2010)[d]	RCT (B)	Healthy volunteers (30, 24.9, 32.0)	Saline eye drops	1. Symptom suggestions: a. Informed of pupil dilation effects (10); b. Informed of pupil constriction effects (10); c. Informed of saline eye drops (10)	None
Geers et al. (2006)[d]	RCT (B)	Healthy students (54, U/K, 31.5)	Sham over-the-counter pill	1. Likelihood suggestions: a. Told the pill had unpleasant side effects (18); b. Told they may or may not receive the active drug (19); c. Told they would ingest an inactive drug (17) 2. Self-awareness: a. Told to closely monitor feelings/bodily sensations (27); b. Not given any such instructions (27)	None
Geers et al. (2011)[d]	RCT (B)	Healthy students (102, 20.5, 21.6)	Sham caffeine capsule	1. Likelihood suggestions: a. Told it contained 250mg of caffeine (34); b. Told they may or may not be ingesting 250mg of caffeine (34); c. Not given the capsule and received no caffeine expectation (34)	Gender, Age, Caffeine consumption

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Table 1 (*continued*)

Reference and quality	Study design	Population (*N*, mean age, %male)	Inert exposure	Experimental risk factor(s) and conditions (*n*)	Baseline risk factors
Geers, Helfer, et al. (2005)[d]	RCT (B)	Healthy students (54, 21.0, 29.6)	Sham over-the-counter pill	1. Likelihood suggestions: a. Told the pill had unpleasant side effects *(18)*; b. Told the pill would make them feel either unpleasant or was an inactive substance *(18)*; c. Told they would ingest an inactive pill *(18)* 2. Self-awareness: a. Told to attend to any symptoms experienced (27); b. Not given any such instructions (27)	Age, Gender, Optimism
Geers, Weiland, et al. (2005)[d]	RCT (B)	Healthy students (57, U/K, 35.1)	Sham caffeine pill	1. Arousal suggestions: a. Told they were given caffeine (U/K); b. No mention of caffeine (U/K) 2. Cooperation prime: a. Given a scrambled sentence test with a cooperation prime (U/K); b. Given a scrambled sentence test with a neutral prime (U/K)	Caffeine consumption
Gibbons et al. (1979)[a,d]	RCT (B)	Female students (38, U/K, .0)	Sham drug	1. Symptom suggestions: a. Told they were taking Cavanol which would produce some noticeable side effects (19); b. Told they were taking baking soda (19) 2. Self-awareness: a. Mirror was facing participants (19); b. Mirror was not facing participants (19)	None
Goldman et al. (1965)[a,b,d]	Non RCT (B)	Male veterans with schizophrenia (64, 44.0, 100.0)	Sham arousal treatment	1. Type of administration: a. Received sugar pill (32); b. Received saline injection (32) 2. Arousal suggestions: a. Told it would heighten their ward activity (32); b. Told it would lower their ward activity (32)	Attitudes towards medication
Harrell and Juliano (2009)[c]	RCT (B)	Adult non-smoking coffee consumers *(30, 22.6, 22.0)*	Sham coffee	1. Performance suggestions: a. Told caffeine enhances performance *(15)*; b. Told caffeine impairs performance *(15)*	None
Harrell and Juliano (2012)[c,d]	RCT (B)	Adult smokers (43, 28.7, 67.4)	Sham cigarette	1. Performance suggestions: a. Told cigarette enhances performance (20); b. Told cigarette impairs performance (23)	Gender
Heatherton et al. (1989)[d]	RCT (B)	Female students (59, U/K, .0)	Sham vitamin pill	1. Symptom suggestions: a. Told vitamin has been reported to make people feel hungry (19); b. Told vitamin has been reported to make people feel full (20); c. Told no further information (20)	Participant restraint
Higuchi et al. (2002)[d]	RCT (B)	Healthy volunteers (30, 21.2, 40.0)	Fragrance (Jasmine or Lavendar)	1. Arousal suggestions: a. Told it was relaxing (10); b. Told it was stimulating (10); c. No information given (10)	None
Jaén and Dalton (2014)[a,b,d]	Non RCT (B)	Asthmatics (17, 38.5, 52.9)	Sham active odor	1. Symptom suggestions: a. Labelled the odor as therapeutic (9); b. Labelled the odor as asthmogenic (8)	None
Jensen and Karoly (1991)[d]	RCT (B + W)	Students (86, U/K, 45.3)	Sham sedative pill	1. Social desirability: a. Type B personality is more positive then type A. Type B have been shown to respond more to pills *(43)*: b. Relationship between type A and B personality and response to pills is very weak *(43)* 2. Perceived dose: a. Suggestions of a high dose or low dose were counterbalanced across each group	Gender
Kaptchuk et al. (2006)	RCT (B)	Adults with distal pain in the arms (266, 36.7, 45.9)	Sham treatment	1. Type of administration: a. Received sham acupuncture (133); b. Received placebo pill (133)	None
Kirsch and Weixel (1988)[d]	RCT (B)	Student coffee drinkers (U/K, *19.3, 31.0*)	Sham coffee	1. Likelihood suggestions: a. Told they would receive coffee (U/K); b. Told they may or may not receive caffeinated coffee (U/K); c. No beverage, waited for 20 minutes (U/K) 2. Perceived dose: a. 1 tsp (U/K); b. 2 tsps (U/K); c. 3 tsps (U/K); d. 5 tsps (U/K); e. 8 tsps (U/K)	None
Kuenzel et al. (2012)[d]	RCT (B)	English speaking students (148, 21.7, 18.2)	Herbal infusion tea	1. Arousal suggestions: a. Told it would make them feel relaxed (45); b. Told it would make them feel active (53); c. No information given (50)	None

(*table continues*)

Exhibit A40-4

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Table 1 (*continued*)

Reference and quality	Study design	Population (*N*, mean age, %male)	Inert exposure	Experimental risk factor(s) and conditions (*n*)	Baseline risk factors
Lorber et al. (2007)[d]	RCT (B)	Students without upper respiratory conditions (86, U/K, 40.7)	Sham environmental toxin	1. Social observation: a. Told inhaled substance has been reported to produce symptoms and observed a female confederate inhale and display symptoms (U/K); b. As above but no observation of confederate (U/K); c. Did not inhale the substance and observed a female confederate inhale and display symptoms (U/K); d. As above but no observation of confederate (U/K)	Gender
Lotshaw et al. (1996)[d]	RCT (B)	Male student coffee drinkers (*50*, U/K, 100.0)	Sham coffee	1. Arousal suggestions: a. Told coffee received decaffeinated *(25)*; b. Told decaffeinated received decaffeinated *(25)*	None
Mazzoni et al. (2010)[d]	RCT (B)	Healthy students (120, 20.7, 50.0)	Sham environmental toxin	1. Social observation: a. Observed a male/female confederate inhale the substance and display symptoms *(60)*; b. Did not observe a male or female confederate inhale the substance and display symptoms *(60)*	Personality, Gender, Gender of model
Meulders et al. (2010)[a,d]	Non RCT (B + W)	Healthy adults (58, 22.0, 48.3)	Odors	1. Odor: a. Foul smelling ammonia; b. Foul smelling butyric acid 2. Conditioning: a. Ammonia paired with CO2 breathing task, butyric acid paired with room air breathing task (29); b. Ammonia paired with room air breathing task, butyric acid paired with CO2 breathing task (29)	Ability to predict which odor produced the most symptoms
Mikalsen et al. (2001)[d]	RCT (W)	Student coffee drinkers (21, 25.9, 66.7)	Sham coffee	1. Arousal suggestions: a. Told it was caffeine; b. Told it was not caffeine 2. Association: a. Given in a juice solution; b. Given in a coffee solution	None
Mrňa and Skiřvánek (1985)[a,b,d]	W	Healthy volunteers (21, 17.0, 47.6)	Sham arousal drug	1. Arousal suggestions: a. Told it was a new doping drug undetectable by anti-doping tests; b. Told it was to relax pre-restart states	Prior placebo response
Neukirch and Colagiuri (2014)[a,d]	RCT (B)	Students with sleep difficulty (91, 21.3, 33.0)	Sham sleep medication	1. Symptom suggestions: a. Warned about an increase/decrease in appetite and received placebo treatment (24); b. Warned about the side effect but received no treatment (23); c. Not warned about the side effects and received placebo treatment (22); d. Not warned about the side effects and received no treatment (22)	None
Nevelsteen et al. (2007)[d]	RCT (B)	Healthy males (59, 48.4, 100.0)	Sham magnetic field	1. Performance suggestions: a. Told magnetic fields enhance cognitive performance (15); b. Told magnetic fields impair cognitive performance (15); c. Told magnetic fields have no effect on cognitive performance (14); d. Not exposed to sham magnetic field and received no information (15)	State-trait anxiety, Depression, Positive and Negative affect, Sensitivity to anxiety, Vigilance, Comfort under helmet
Ossege et al. (2005)	RCT (B)	Healthy volunteers (60, *27.6*, 40.0)	Sham drug	1. Likelihood suggestions: a. Misleading information that is was an active medication (30); b. 50% chance that it was a placebo or active medication (30)	None
Papoiu et al. (2011)[d]	RCT (W)	Healthy volunteers and patients with atopic dermatitis (25, U/K, 44.0)	Sham histamine	1. Social observation: a. Watched a 5 minute video of people scratching their left forearm; b. Watched a 5 minute video of the same persons in the scratching video but sitting idle.	Gender
Penick and Fisher (1965)[a,b,c,d]	W	Healthy medical students (14, U/K, U/K)	Sham arousal drug	1. Arousal suggestions: a. Told they would receive a stimulant drug; b. Told they would receive a sedative drug	None

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Table 1 (*continued*)

Reference and quality	Study design	Population (*N*, mean age, %male)	Inert exposure	Experimental risk factor(s) and conditions (*n*)	Baseline risk factors
Pennebaker and Skelton (1981)[d]	RCT (B)	Students (38, U/K, 31.6)	Ultrasonic noise	1. Symptom suggestions: a. Told it would increase skin temperature (13); b. Told it would decrease skin temperature (12); c. Told it would have no effect on skin temperature (13)	None
Put et al. (2004)[a,b,c,d]	W	Asthma patients (32, 40.0, 50.0)	Sham inhaler	1. Symptom suggestions: a. Told it would have no effect on breathing; b. Told it was a bronchoconstrictor; c. Told it was a bronchodilator	Negative affect, Social desirability
Read and Bohr (2014)[a,b,c,d]	Non RCT (B)	Volunteers without photosensitive epilepsy (177, 25.3, U/K)	Sham 3D TV	1. Symptom suggestions: a. Told it was 3D and wore passive 3D glasses (22); b. Told it was 3D and wore active no shuttering 3D glasses (33); c. Told it was 2D and did not wear glasses (122)	Gender
Schneider et al. (2006)[c,d]	RCT (B)	Healthy Adults (45, 31.0, 22.2)	Sham coffee	1. Arousal suggestions: a. Told they were to consume decaffeinated coffee (15); b. Told they were to consume regular coffee (15); c. Informed they would receive no beverage and no instructions (15)	None
Schweiger and Parducci (1981)[d]	RCT (B)	Students (34, U/K, 52.9)	Sham electric current	1. Symptom suggestions: a. Told a low current would be delivered, too mild to be felt but had produced mild headaches in the past (17); b. Told current would be too weak to be felt, but some people develop mild headaches as a side effect (17)	None
Slánská et al. (1974)[a,d]	Non RCT (B)	Medical students (33, U/K, U/K)	Salt solution	1. Arousal suggestions: a. Told it was a stimulant (17); b. Told it was a sedative (16)	Stability – instability, Activity – passivity, Submissive-dominance, Rationality-sensuousness, Introversion-extraversion
Stegen et al. (1998)[d]	RCT (W)	Healthy psychology students (72, U/K, 48.6)	Breathing trial with room air	1. Conditioning: a. Room air breathing trial before 7.5% CO2 challenge; b. Room air breathing trial after 7.5% CO2 challenge	Negative affect
Szemerszky et al. (2010)[a,b,c,d]	W	Healthy students (40, 22.8, 27.5)	Sham EMF	1. Perceived dose: a. Told it would be weak; b. Told it would be strong	Gender, Expectations, IEI-EMF scores, State anxiety, Dispositional optimism, Somatization, Somatosensory amplification, Motivation
Tippens et al. (2014)[d]	RCT (B)	Obese adults (79, 49.4, 10.4)	Sham weight loss supplement	1. Likelihood suggestions: a. Told they would be given an active weight loss supplement (27); b. Told they would be randomly assigned to either the active or placebo supplement (28); c. Only received lifestyle education (24)	None

(*table continues*)

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Table 1 (*continued*)

Reference and quality	Study design	Population (*N*, mean age, %male)	Inert exposure	Experimental risk factor(s) and conditions (*n*)	Baseline risk factors
Van den Bergh et al. (1999)[a,d]	Non RCT (B + W)	Healthy students (64, U/K, 25.0)	Odors	1. Odor: a. Foul smelling ammonia; b. Foul smelling butyric acid 2. Conditioning: a. Ammonia paired with CO2 breathing task, butyric acid paired with room air breathing task (32); b. Ammonia paired with room air breathing task, butyric acid paired with CO2 breathing task (32)	None
Van den Bergh et al. (1995)[a,d]	Non RCT (B + W)	Healthy students (28, U/K, 50.0)	Odors	1. Odor: a. Foul smelling ammonia; b. Pleasant smelling niaouli 2. Conditioning: a. Ammonia paired with CO2 breathing task, Niaouli paired with room air breathing task (14); b. Ammonia paired with room air breathing task, Niaouli paired with CO2 breathing task (14)	Negative affect
Van den Bergh et al. (1997)[a,d]	Non RCT (B + W)	Psychosomatic patients (28, 36.0, 50.0)	Odors	1. Odor: a. Foul smelling ammonia; b. Pleasant smelling niaouli 2. Conditioning: a. Ammonia paired with CO2 breathing task, Niaouli paired with room air breathing task (14); b. Ammonia paired with room air breathing task, Niaouli paired with CO2 breathing task (14) 3. Generalization: a. New foul smelling odor Ichytol; b. New pleasant smelling odor Rose	Gender, State and trait anxiety, Blunting behavior
Van den Bergh et al. (1998)[d]	RCT (B + W)	Healthy adults (56, 42.5, 50.0)	Odors	1. Odor: a. Foul smelling ammonia; b. Pleasant smelling niaouli 2. Self-awareness: a. Told to count lower tones and disregard higher tones (28); b. Told to ignore tones (28) 3. Conditioning: a. Ammonia paired with CO2 breathing task, Niaouli paired with room air breathing task (28); b. Ammonia paired with room air breathing task, Niaouli paired with CO2 breathing task (28) 4. Generalization: a. New foul smelling odor Ichytol; b. New pleasant smelling odor Rose	Gender
Van Diest et al. (2006)[d]	RCT (B + W)	Students (28, U/K, 21.4)	Odors	1. Odor: a. Foul smelling ammonia; b. Foul smelling acetic acid 2. Conditioning: a. Ammonia paired with hypocapnic over breathing trial, acetic acid paired with normocapnic over breathing trial (13); b. Ammonia paired with normocapnic over breathing tria, acetic acid paired with hypocapnic over breathing trial (15) 3. Type of breathing: a. Test odors given with normocapnic breathing trial (U/K); b. Test odors given with spontaneous breathing (U/K)	None
Walach and Schneider (2009) Exp 1	RCT (B)	Healthy adult coffee drinkers (60, 32.3, 23.3)	Sham coffee	1. Likelihood suggestions: a. Told it was caffeine (15); b. Told it could be placebo or caffeine (15); c. Told it could be placebo or caffeine (15); d. Received no beverage (15)	Expectations
Walach and Schneider (2009) Exp 2	RCT (B)	Healthy adult coffee drinkers (*30, 29.9, 33.3*)	Sham coffee	1. Arousal suggestions: a. Told it was caffeine *(15)*; b. Received no beverage *(15)*	Expectations
Walach et al. (2001)	RCT (B)	Coffee drinkers (157, 28.1, 34.0)	Sham coffee	1. Likelihood suggestions: a. Told they would receive a placebo (41); b. Told they would receive coffee (39); c. Told they may receive real coffee or decaffeinated coffee (39); d. No substance or instruction given (38) 2. Experimenter expectations: a. Experimenter told the physiological effects from a caffeine placebo are real (proplacebo) (U/K); b. Experimenter told the effects of caffeine placebos are just due to artifacts (antiplacebo) (U/K)	Expectations

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Table 1 (*continued*)

Reference and quality	Study design	Population (*N*, mean age, %male)	Inert exposure	Experimental risk factor(s) and conditions (*n*)	Baseline risk factors
Walach et al. (2002)	RCT (B)	Coffee drinkers (159, 25.5, 58.0)	Sham coffee	1. Symptom suggestions: a. Received an information leaflet describing the pharmacological effects of caffeine (U/K); b. Received no further information (U/K) 2. Likelihood suggestions: a. Told they would receive a placebo (39); b. Told they would receive coffee (40); c. Told they may receive real coffee or decaffeinated coffee (40); d. No substance or instruction given (40)	None
Winters et al. (2001) Exp 1[a,d]	Non RCT (B)	Psychology students (50, U/K,U/K)	Ammonia	1. Conditioning: a. Odor + CO2 trials and room air trials (10); b. Odor trials and CO2 trials (10); c. Odor trials, CO2 trials, odor + CO2 trials, room air trials (10); d. odor trials, room air trials (10); e. CO2 trials, room air trials (10)	None
Winters et al. (2001) Exp 2[a,d]	Non RCT (B)	18–30 year olds (40, U/K,U/K)	Odors	1. Odor: a. Foul smelling ammonia (20); b. Pleasant smelling niaouli (20) 2. Conditioning: a. Odor + CO2 trials and room air trials (20); b. Odor trials and CO2 trials (20)	None
Winters et al. (2003)[d]	Non RCT (B + W)	18–30 year olds (32, U/K,15.6)	Odors	1. Odor: a. Foul smelling ammonia; b. Pleasant smelling niaouli 2. Conditioning: a. Ammonia paired with CO2 breathing task, Niaouli paired with room air breathing task (16); b. Ammonia paired with room air breathing task, Niaouli paired with CO2 breathing task (16) 3. Verbal suggestions of symptoms: a. Given leaflet describing widespread chemical pollution of the environment is a potential cause of multiple chemical sensitivity (16); b. No information given (16)	None
Wise et al. (2009)[c]	RCT (B)	Patients with poor asthma control (241, 39.0, *29.5*)	Sham asthma drug	1. Symptom suggestions: a. Emphasized benefit of treatment and described potential side effects (121); b. Expressed uncertainty about improvement following treatment and did not describe potential side effects (120)	None
Witthöft and Rubin (2013)	RCT (B)	Adult English speakers (147, 29.8, 32.7)	Sham EMF	1. Symptom suggestions: a. Watched a documentary concerning the potential adverse health effects of Wi-Fi (76); b. Watched a BBC News report concerning the security of the internet and mobile phone data (71)	State anxiety, Age, Gender, Level of education, Personality
Zimmermann-Viehoff et al. (2013)[b,d]	RCT (B)	Healthy Caucasians (92, 24.5, 41.3)	Sham arousal oral spray	1. Symptom suggestions: a. Told it contained a drug to increase blood pressure (33); b. Told it contained a drug to decrease blood pressure (29); c. Told it was a placebo (30)	None

Note. RCT = randomized controlled trial; Non RCT = nonrandomized controlled trial; B = between subjects design; W = within subjects design; U/K = unknown; *italicized* = not directly given but has been extrapolated from the available data; rTMS = repetitive transcranial magnetic stimulation; EMF = electromagnetic field; tsp = teaspoon; IEI-EMF = idiopathic environmental intolerance attributed to electromagnetic fields; CO2 = carbon dioxide; O2 = oxygen.
[a] High-risk random sequence generation bias. [b] High-risk allocation concealment bias. [c] High-risk blinding of participants and personnel bias. [d] Did not mention an a priori sample size calculation.

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Table 2
Summary of the Methods Used in Prospective Studies

Reference and quality	Study design	Population (*N*, mean age, %male)	Inert exposure	Baseline risk factor(s)
Bogaerts et al. (2010)[e]	P	Female patients with medically unexplained dyspnea and healthy controls (58, U/K, .0)	Breathing trial with room air	State anxiety, Negative affect, Clinical condition
Casper et al. (2001)[e]	P	Nonpsychotic major depressive patients (876, U/K, 42.8)	Sham fluoxetine treatment	Gender, Depression severity
Danker-Hopfe et al. (2010)	P	Villages in Germany with weak RF-EMF sources (397, U/K, 49.1)	Sham EMF	Bad sleep quality, General fear/anxiety towards risks of RF-EMF, Fear/anxiety towards base station, Preoccupation with EMF, Visibility of the base station
Davis et al. (1995)[a,d,e]	P	Healthy adults (27, U/K, 55.6)	Sham anti-depressant pill	Neuroticism, Somatosensory amplification
de la Cruz et al. (2010)[e]	P	Patients with cancer related fatigue (105, U/K, 40.0)	Sham treatment	Anxiety, Nausea, Sleep, General health, Well-being, Cognitive status, Age, Education level
De Peuter et al. (2007)[e]	P	Asthma patients (30, 38.0, 26.7)	Sham histamine inhalation	Negative affect
Drici et al. (1995)[b,e]	P	Healthy volunteers (52, 23.5, 50.0)	Sham paracetamol eye drop	Employment, Type A Personality, Type B Personality
Fillmore and Vogel-Sprott (1992)[e]	P	Male students (56, U/K, 100.0)	Sham coffee	Symptom expectations
Goetz et al. (2008)[e]	P	Parkinson's patients with dyskinesia (484, U/K, U/K)	Sham medication	Age, Gender, Dyskinesia severity, UPDRS motor score, Daily L-dopa dose, Dyskinesia duration, Adverse events, Severity of adverse events, Geographical site of enrolment, Study (1 or 2)
Köteles and Babulka (2014)[a,d,e]	P	Adult volunteers (33, 37.7,15.2)	3 types of Essential oils (Randomized to 1)	Expectations, Pleasantness of odor
Liccardi et al. (2004)[b,e]	P	Patients with ADRs (600, 42.0, 30.3)	Sham allergen pill	Gender, Hospital centre
Link et al. (2006)[a,b,c,d,e]	P	Students (36, 22.7, 44.0)	Sham herbal supplement	Expectations, State anxiety, Social desirability
Lombardi et al. (2008)[a,d,e]	P	Patients with ADRs (435, 39.7, 32.0)	Sham allergen pill	Gender, Age, Atopic status, Severity of previous reaction, Type of previous reaction
Molcăn, Heretik, Novotrý, Vajidičková, and Zucha (1982)[b,e]	P	Medical students (48, U/K, 52.1)	Sham arousal pill	Expectations, State anxiety, Trait anxiety
Stegen et al. (2000)[a,b,d,e]	P	Healthy psychology students (44, U/K, 27.3)	Breathing trial with room air	Negative affect, Social desirability
Strohle (2000)[e]	P	Healthy adults and patients with panic disorder (U/K, *33.5, 56.6*)	Sham panic disorder trigger	Gender, Clinical condition
Sullivan et al. (2008)[c,e]	P	Patients with neuropathic pain (24, 54.7, 62.5)	Sham cream treatment	Pain catastrophizing
Vase et al. (2013)[e]	P	Patient with pain due to tooth removal (U/K, *25.5, 47.5*)	Sham acupuncture	Expectations
Wendt et al. (2014)[e]	P	Healthy males (24, 25.0, 100.0)	Sham immunosuppressive capsule	Genes

Note. P = prospective design; U/K = unknown; *italicized* = not directly given but has been extrapolated from the available data; ns = nonsignificant; UPDRS = unified Parkinson's disease rating scale; RF-EMF = radio frequency electromagnetic fields; EMF = electromagnetic fields; ADRs = Adverse drug reactions.
[a] High-risk for selection bias. [b] High-risk for confounding factors. [c] High-risk for insufficient follow-up. [d] High-risk for low generalizability. [e] Did not mention an a priori sample size calculation.

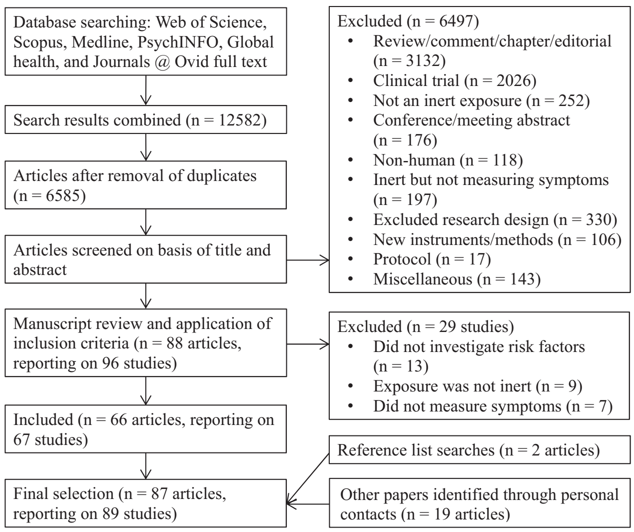

Figure 1. Flow diagram of the selection process of studies including the number of events and reasons for exclusion.

Woestijne, & Van den Bergh, 2006; Devriese et al., 2000; 2004; Meulders et al., 2010; Van den Bergh et al., 1999; Van den Bergh, Kempynck, van de Woestijne, Baeyens, & Eelen, 1995; Van den Bergh, Stegen, & Van de Woestijne, 1997, 1998; Van Diest et al., 2006; Winters et al., 2001 Exp 1 and 2; Winters et al., 2003). Six studies of mixed quality found significant effects of classical conditioning and although seven found no main effect of conditioning on symptom reporting, six of these were of lower quality. As such there is some evidence for the role of classical conditioning in nocebo effects, and that this learning effect can be generalized to new odors (Devriese et al., 2000; Van den Bergh et al., 1997, 1998). However, odor type alone without classical conditioning is not enough to elicit symptoms as demonstrated in this group of studies and the remaining study in this category (Dalton, 1999).

Perceived dose. Six studies manipulated participant perceptions of the dose of the exposure that they received. Four of these found significant effects with three being of higher quality, broadly supporting a link between higher perceived dose and nocebo effects. Only two studies found no significant effects of dose related to decaffeinated coffee consumption (Flaten, Aasli, & Blumenthal, 2003) or taking a sham sedative pill (Jensen & Karoly, 1991). The remaining four all demonstrated significant main effects: Increasing the setting on a sham shock generator increased pain intensity ratings in two studies (Bayer, Baer, & Early, 1991; Bayer et al., 1998), tension scores increased as a function of perceived dose following decaffeinated coffee consumption in one study (Kirsch & Weixel, 1988), and in a final study being told that a sham EMF exposure would be strong resulted in a higher overall symptom scores compared to being told the exposure would be weak (Szemerszky, Köteles, Lihi, & Bardos, 2010).

Self-awareness. Four studies manipulated self-awareness during exposure. Three higher quality studies found no significant effects with only one lower quality study reporting an effect. As such there is little evidence that self-awareness increases the likelihood of a nocebo effect. Both Geers, Helfer, et al. (2005) and Geers, Helfer, Weiland, and Kosbab (2006) showed no significant main effects of instructing participants to attend to any symptoms or sensations they experienced. Using a distraction task also did not have a significant effect on symptom reporting (Van den Bergh et al., 1998). Gibbons, Carver, Scheier, and Hormuth (1979), however, did find a significant main effect, with participants facing a mirror reporting less perceived arousal than participants not facing a mirror following ingestion of a sham drug.

Type of administration. Two studies of mixed quality tested whether type of administration affects symptom reporting, finding no evidence for a link with nocebo effects. There was no difference in symptom reporting between a sham pill and either a saline injection (Goldman, Witton, & Scherer, 1965) or sham acupuncture (Kaptchuk et al., 2006).

Verbal suggestions on performance. Three studies manipulated verbal suggestions about the effect an inert exposure would have on performance. Two higher quality studies found no significant effects with only one lower quality study reporting an effect. As such there is little evidence that suggesting an exposure impairs performance increases the likelihood of a nocebo effect. Both Harrell and Juliano (2009) and Nevelsteen, Legros, and Crasson (2007) found no significant main effects of suggesting sham coffee or sham EMF would enhance or impair performance on a task on any of their symptom measures, respectively. However, smokers told that a sham cigarette would impair performance had significantly more craving symptoms than those who were told it would enhance performance (Harrell & Juliano, 2012).

Verbal suggestions of likelihood of exposure. Nine studies manipulated suggestions about the likelihood that an exposure would occur. All studies were of higher quality with four finding

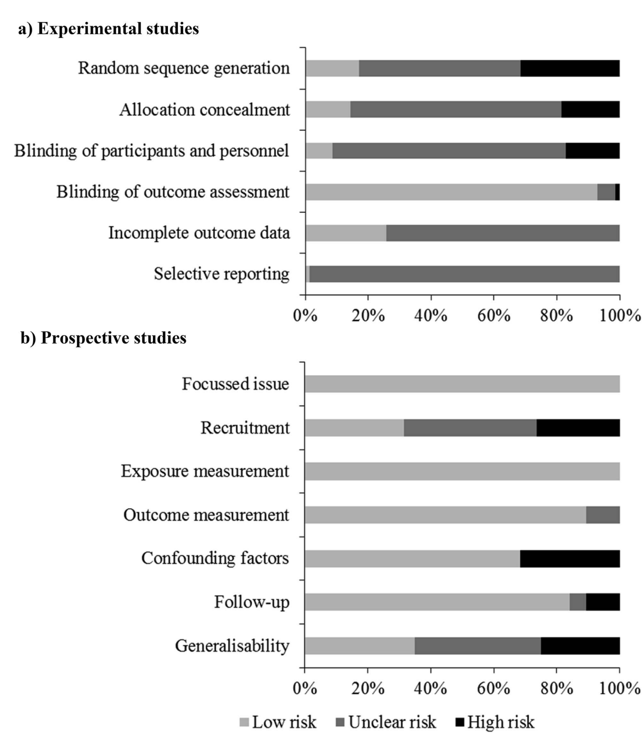

Figure 2. Quality assessment of experimental and prospective studies.

significant effects and five finding nonsignificant effects. In other words, there was mixed evidence for the role of likelihood suggestions in nocebo effects. The studies used a mixture of conditions in which participants were either told they would receive an active exposure (deception), might receive an active or inactive exposure (double-blind), would receive an inactive exposure (open) or nothing (control). Five of the studies found no significant main effects (Geers, Helfer, et al., 2005; Geers et al., 2006; Ossege et al., 2005; Walach, Schmidt, Dirhold, & Nosch, 2002; Walach & Schneider, 2009 Exp 1). Geers, Wellman, Fowler, Rasinski, and Helfer (2011), however, found that participants reported significantly more side effects in response to a sham pill when given deceptive information, compared with double-blind or control information. In addition, participants given deceptive or double-blind suggestions had a significantly higher increase in alertness following ingestion of sham coffee (Kirsch & Weixel, 1988) and a significantly higher number of adverse events following a sham weight loss supplement (Tippens et al., 2014) than participants in the control condition. For Walach, Schmidt, Bihr, and Wiesch (2001) participants told they would receive an inactive exposure scored higher on general wellbeing than those who received no substance or instruction.

Verbal suggestions of arousal. Sixteen studies manipulated suggestions about the effect an inert exposure would have on arousal. Thirteen studies showed a significant effect, with 10 of these being of higher quality. This strongly supports a link with nocebo effects. Only three studies revealed no main effects (Brodeur, 1965; Kuenzel, Blanchette, Zandstra, Thomas, & El-Deredy, 2012; Penick & Fisher, 1965). The remaining 13 all demonstrated significant effects. Participants given stimulant suggestions compared to sedative suggestions had higher tension scores and were more lively after administration of a sham drug (Flaten, Simonsen, & Olsen, 1999; Mrna & Skrivanek, 1985), and had higher scores of stress, arousal, alertness, friendliness and aggressiveness, and lower fatigue scores after ingestion of an inert drink (Dinnerstein & Halm, 1970; Flaten, 1998; Slánská, Tikal, Hvizdosova, & Benesova, 1974). Higuchi, Shoji, and Hatayama (2002) demonstrated lower stress and stimulant symptoms for participants given relaxing suggestions compared to no information for lavender and jasmine fragrances respectively. Goldman et al. (1965) found that more patients reported suggested drug effects in a sedative condition than in a stimulant condition. The remaining studies found a significant increase in caffeine related symptoms (Geers, Weiland, Kosbab, Landry, & Helfer, 2005; Lotshaw, Bradley, & Brooks, 1996), and alertness (Schneider et al., 2006; Walach & Schneider, 2009 Exp 2) and a significant decrease in calmness (Mikalsen et al., 2001) for participants told they would receive caffeine compared to participants who were told they would not receive caffeine or who received no beverage. Finally, Angelucci and Pena (1997) found that participants given coffee with low arousal expectations had significantly lower alertness compared to participants given coffee with no expectations, high arousal expectations, or no coffee at all.

Verbal suggestions of symptoms. Twenty-one studies manipulated suggestions about what symptoms to expect from an inert exposure. Thirteen found a significant effect, with 11 of these being of higher quality, broadly supporting a link with nocebo effects. Of the 21 studies, eight reported no significant main effects (Devriese et al., 2004, 2006; Heatherton, Polivy, & Herman, 1989; Jaén & Dalton, 2014; Schweiger & Parducci, 1981; Walach et al., 2002; Winters et al., 2003; Witthöft & Rubin, 2013). For the remaining 13 studies, Benedetti, Amanzio, Casadio, Oliaro, and Maggi (1997); Crichton, Dodd, Schmid, Gamble, and Petrie (2014); Wise et al. (2009) and Pennebaker and Skelton (1981) found significantly higher symptoms scores for those warned about side effects compared to those not warned after administration of sham treatment, infrasound, and ultrasonic noise, respectively. Dalton (1999), Neukirch and Colagiuri (2015), and Put et al. (2004) found that participants' symptoms were significantly consistent with the warning they received about an odor, sham sleep medication, and sham inhaler, respectively. Three studies demonstrated that participants experienced significantly more symptoms when informed about side effects to a sham drug (Gibbons et al., 1979; Zimmermann-Viehoff et al., 2013) or saline eye drops (Gavrylyuk, Ehrt, & Meissner, 2010) compared with being informed it was a placebo. Similarly both Bayer et al. (1991) and Read and Bohr (2014) established significantly higher symptoms scores for those informed they would receive an active compared to an inactive exposure. Colagiuri, McGuinness, Boakes, and Butow (2012), however, found the opposite; participants not warned about the side effects experienced more and a greater severity of side effects than those warned about one or four side effects.

Miscellaneous. Six studies looked at factors that did not fit into the above categories. There was no significant effect of manipulating participants to cooperate (Geers, Weiland, et al., 2005) or the experimenters' expectations of participants' symptoms (Walach et al., 2001). However, Faasse, Cundy, Gamble, and Petrie (2013) found that manipulating tablet brand to make participants think they had changed to a generic version resulted in a significantly higher number of symptoms compared with participants told that they were still taking the original branded tablet, although this study was of lower quality than the others in this group. Jensen and Karoly (1991) have shown that manipulating social desirability so that participants think responding to the pill is more socially desirable results in significantly higher symptom scores. Type of breathing has also been shown to affect symptom reporting with normocapnic overbreathing resulting in higher respiratory symptoms compared with spontaneous breathing (Van Diest et al., 2006). Lastly, a conditioned odor results in more symptoms if the odor is presented immediately rather than a week after conditioning trials (Devriese et al., 2000).

Baseline Risk Factors Categories

Nineteen prospective studies and also 33 experimental studies which assessed baseline risk factors were included which fell into six different categories as discussed below (further details in supplementary Tables 12–17).

Demographics. Twenty studies looked at the risk of demographic characteristics, finding no demonstrable evidence for their role in nocebo effects. Five of these investigated age and found it did not predict any symptom outcomes (de la Cruz, Hui, Parsons, & Bruera, 2010; Geers, Helfer, et al., 2005; Goetz et al., 2008; Lombardi, Gargioni, Canonica, & Passalacqua, 2008; Witthöft & Rubin, 2013). As four of these studies were of higher quality, this is good evidence that age is not linked with the development of nocebo effects. Eighteen studies (Angelucci & Pena, 1997; Casper, Tollefson, & Nilsson, 2001; Geers, Helfer, et al., 2005; Geers et al., 2011; Goetz et al., 2008; Harrell & Juliano, 2012; Jensen & Karoly, 1991; Liccardi et al., 2004; Lombardi et al., 2008; Lorber et al., 2007; Mazzoni et al., 2010; Papoiu et al., 2011; Read & Bohr, 2014; Strohle, 2000; Van den Bergh et al., 1997, 1998; Witthöft & Rubin, 2013) looked at gender and only four reported significant results suggesting women are more susceptible to nocebo effects than men (Casper et al., 2001; Liccardi et al., 2004; Strohle, 2000; Szemerszky et al., 2010). Of the remaining 14 showing nonsignificant effects, 12 were of high quality, suggesting there is very little evidence for the role of gender in nocebo effects. The effects of level of education (de la Cruz et al., 2010; Witthöft & Rubin, 2013) were equivocal in two high quality studies, whereas employment (Drici, Raybaud, Delunardo, Iacono, & Gustovic, 1995) was not a significant predictor.

Clinical characteristics. Fourteen studies investigated clinical characteristics, finding mixed evidence for a link with nocebo effects. Six studies of high quality looked at the effect of baseline symptom scores, finding mixed evidence for a link with nocebo effects. Two found no significant effects (André-Obadia et al., 2011; Casper et al., 2001). For the other four, results were mixed. Danker-Hopfe, Dorn, Bornkessel, and Sauter (2010) and de la Cruz et al. (2010) found that higher symptom scores at baseline predicted higher symptom scores after exposure to sham EMF and treatment respectively, whereas Flaten et al. (2003) and Goetz et al. (2008) found the opposite after drinking decaffeinated coffee and taking sham medication for Parkinson's respectively. Six studies of high quality looked at the effect of type of clinical condition, with five finding a significant effect. They showed that suffering from a condition that is exacerbated by the suggested sham exposure significantly increased symptom reporting compared to healthy volunteers, strongly supporting a link with nocebo effects. Nevelsteen et al. (2007) found that depression did not predict symptoms in response to a sham magnetic field. However, De Peuter et al. (2005); Papoiu et al. (2011); Strohle (2000) and Bogaerts et al. (2010) showed that suffering from atopic dermatitis, panic disorder, asthma, or medically unexplained dyspnea resulted in significantly more symptoms in response to sham histamine, sham panic disorder trigger, sham inhaler, and breathing trials with room air, respectively, compared with healthy volunteers. In addition, Szemerszky et al. (2010) found that the level of perceived sensitivity to EMFs was positively correlated with symptom scores after sham EMF exposure. The remaining two studies looked at previous drug reactions finding weak evidence for a link with nocebo effects. Lombardi et al. (2008) found no significant effects of type or severity of previous drug reaction on symptoms in response to a sham allergen pill. However, a higher quality study by Mrňa and Skiřvánek (1985) found the reaction to another sham drug was significantly correlated with perceived drug effect.

Expectations. Thirteen studies looked at the effect of participant expectations on symptom reporting, broadly supporting a link with nocebo effects. Eleven of these studies looked at participants' symptom expectations, of which five higher quality studies revealed no significant effects (Angelucci & Pena, 1997; Molčăn et al., 1982; Walach et al., 2001; Walach & Schneider, 2009 Exp 1 and 2). The remaining six studies demonstrated that expectations of symptoms significantly predicted (Fillmore & Vogel-Sprott, 1992; Köteles & Babulka, 2014; Vase et al., 2013) or correlated (De Peuter et al., 2005; Flaten et al., 2003; Szemerszky et al., 2010) with symptom reporting. Five of these studies were of higher quality therefore broadly supporting a link with nocebo effects. Three studies also looked at expectations in terms of the substance taken finding weak evidence for its role in nocebo effects. Link, Haggard, Kelly, and Forrer (2006) found that participants who believed they had taken an active pill reported more symptoms than those who thought they had a taken a sham pill, however this was a low quality study. Higher quality studies by Bayer et al. (1998) and Walach et al. (2001) also investigated this but found no significant effects.

Anxiety. Nine studies looked at the influence of anxiety on symptom reporting, finding weak evidence for a link with nocebo effects. Six studies of mixed quality looked at state anxiety (Bogaerts et al., 2010; Link et al., 2006; Molčăn et al., 1982; Nevelsteen et al., 2007; Szemerszky et al., 2010; Witthöft & Rubin, 2013) but only Nevelsteen et al. (2007) found a significant effect, with state anxiety predicting physical symptom scores. Molčăn et al. (1982) and Nevelsteen et al. (2007) found no significant effects of trait anxiety. Angelucci and Pena (1997) found combined state and trait anxiety scores significantly predicted anxiety, but did not report results for state and trait anxiety separately. However, no such effect of combined state and trait anxiety was found on symptom reporting to an odor (Van den Bergh et al., 1997), although this was a lower quality study. Finally, a high quality study by Danker-Hopfe et al. (2010) found that anxiety toward a local base station predicted subjective sleep quality after sham EMF exposure.

Personality. Twenty-two studies looked at different aspects of personality as predictors of symptoms. Twelve studies showed significant effects of personality of which only three were of low quality as such finding evidence broadly supporting a link with nocebo effects. There were no significant effects of suggestibility (Angelucci & Pena, 1997), sensitivity to anxiety (Nevelsteen et al., 2007), restraint (Heatherton et al., 1989), or social desirability (Link et al., 2006; Put et al., 2004; Stegen, Van Diest, Van de Woestijne, & Van den Bergh, 2000). However, studies did show significant effects of the following on at least one symptom outcome: Type A personalities reported more side effects than Type B (Drici et al., 1995); pain catastrophizing positively correlated with side effect reports (Sullivan, Lynch, Clark, Mankovsky, & Sawynok, 2008); blunting behavior predicted symptom reporting (Van den Bergh et al., 1997); positive affect and vigilance predicted symptom scores (Nevelsteen et al., 2007); "frail and submissive" personality correlated with the exposures perceived effect (Slánská et al., 1974); somatization and motivation predicted symptom score (Szemerszky et al., 2010); and modern health worries and somatosensory amplification predicted symptom scores (Witthöft & Rubin, 2013). There was mixed evidence for the role of negative affect (Bogaerts et al., 2010; De Peuter et al., 2005, 2007; Devriese et al., 2000, 2004; Nevelsteen et al., 2007; Put et al., 2004; Stegen et al., 1998, 2000; Van den Bergh et al., 1995), neuroticism (Davis, Ralevski, Kennedy, & Neitzert, 1995; Mazzoni et al., 2010), and pessimism (Geers, Helfer, et al., 2005; Szemerszky et al., 2010).

Miscellaneous. Thirteen studies looked at baseline factors which did not fit into the above categories. These included caffeine consumption (Geers, Weiland, et al., 2005; Geers et al., 2011), olfactory sensitivity (Dalton, 1999), perceived cue odor (Devriese et al., 2004), visibility of a mobile phone base station and preoccupation with EMF (Danker-Hopfe et al., 2010), geographical site of enrolment (Goetz et al., 2008), hospital center (Liccardi et al., 2004), stress experienced while wearing a helmet delivering sham EMF (Nevelsteen et al., 2007), ability to predict which odor produced the most symptoms (Meulders et al., 2010), and risk perception (Nevelsteen et al., 2007), which had no significant effects. Köteles and Babulka (2014), however, found that odor pleasantness predicted perceived change in alertness for eucalyptus oil. In addition, odor reactivity predicted symptom responding to odors (Dalton, 1999) and high regard for medications positively correlated with perceived drug effect (Goldman et al., 1965). Mazzoni et al. (2010) found that if the gender of the model matched the participant this predicted symptom development in social observation studies. Nevelsteen et al. (2007) found that less comfort under the helmet delivering the sham EMF predicted symptoms. Finally, Wendt et al. (2014) reported that significantly more symptoms were reported in val/val homozygous carriers compared to val 158/Met 18 and Met/Met 158 homozygous carriers after sham treatment.

Interactions Between Risk Factor Categories

As well as investigating the main effects of each risk factor, some studies assessed the interactions between risk factors, as displayed in the last column of Tables 3 through 17. Those risk factors which were implicated often in these interactions were factors such as "likelihood suggestion" which interacted with: "pessimism"—participants given deceptive suggestions report more symptoms compared to those told it was an inactive pill, if they were pessimists (Geers, Helfer, et al., 2005); "self-awareness"—participants given deceptive suggestions reported more symptoms when asked to monitor their bodily sensations (Geers et al., 2006); and "perceived dose"—tension increased with increasing coffee dose for those given deceptive suggestions, but decreased with increasing coffee dose when given double-blind suggestions (Kirsch & Weixel, 1988).

In addition, "classical conditioning" showed interactions with "odor"; pairing an odor with CO2 elicited symptoms to the odor alone, only if the odor was foul smelling (Devriese et al., 2000; Van den Bergh et al., 1995, 1997; Winters et al., 2003). This interaction between "classical conditioning" and "odor" was also found to more likely occur among people with high "negative affect" (Devriese et al., 2000) and those manipulated to have higher "self-awareness" (Van den Bergh et al., 1998). Negative affect also interacted with "symptom suggestions," with higher obstruction and dyspnea symptom scores after suggestions of bronchoconstriction compared to bronchodilation for a sham inhaler if participants had high negative affect (Put et al., 2004). An interaction was also found with "prior experience," with high negative affect participants reporting more arousal and symptoms on the whole to a room-air breathing trial when this preceded rather than followed a CO2 breathing trial (Stegen et al., 1998).

As well as interacting with negative affect, symptom suggestions interacted with other factors. These included the following: "self-awareness," participants reported more symptoms when told they were taking an active drug with side effects if they were not facing a mirror (Gibbons et al., 1979); "odors," more symptom reports following suggestion of symptoms if the odor was unpleasant (Dalton, 1999); "classical conditioning," higher total, respiratory, cardiac, and unclassified symptom scores following exposure to an odor previously paired with CO2 if participants received symptom suggestions (Winters et al., 2003); and "state anxiety," higher total and head/concentration symptoms following symptom suggestions if participants had high anxiety (Witthöft & Rubin, 2013).

Discussion

Summary of Main Results

From the 89 studies that met our inclusion criteria, 14 categories of risk factor for a nocebo effect were identified, including nine experimentally induced risk factor categories and six baseline risk factor categories (miscellaneous categories were present for both experimental and prospective studies). Of these categories, "learning/social observation," "perceived dose," "verbal suggestions of arousal and symptoms," and "baseline symptom expectations" appeared to be the strongest predictors of nocebo effects. There was some evidence for the role of "personality" in nocebo effects; however which facets of personality are more strongly linked with nocebo effects needs further research. In addition, although not strong predictors on their own, learning/classical conditioning, likelihood suggestion, self-awareness, and negative affect consistently interacted with other risk factors.

Given the proposed psychological mechanisms behind nocebo effects it is perhaps unsurprising that these factors have been consistently identified in the literature. Specifically looking at the expectation mechanism, it is intuitive that verbal suggestions of symptoms can generate expectations of these effects leading to symptom reporting. In support of this, participants' own baseline expectations can trigger symptoms, while perceived dose presumably affects symptom reports through a mediating effect of expectations, with a higher dose associated in a participant's mind with a stronger effect. This could also explain the significance of medication brand, with branded medication being generally expected by the public to be better quality than generic unbranded medication and therefore less likely to cause side effects (Faasse et al., 2013). Expectations could also explain why four studies which measured symptom reports both for prewarned and nonwarned symptoms found stronger effects for symptoms that had previously been suggested (Faasse et al., 2013; Gibbons et al., 1979; Lorber et al., 2007; Mazzoni et al., 2010). It also explains why no effect was found for performance suggestions, as this should not directly influence expectations of symptoms from the exposure.

It is important not to overemphasize the nature of our results with respect to expectation, however. In particular, it was striking that type of administration and verbal suggestions of the likelihood of exposure did not appear to be relevant despite both supposedly raising expectations of symptoms. Possibly, the influence of these factors on expectations is weaker than might be thought. Alternatively, methodological factors may account for the lack of effect. For example, both studies assessing type of administration used patient samples (Goldman et al., 1965; Kaptchuk et al., 2006). Given their greater experience with medical procedures, merely changing an intervention from a pill to an injection may not have triggered a substantial change in expectations. For three of the likelihood suggestion studies (Walach et al., 2001, 2002; Walach

& Schneider, 2009 Exp 1) it was suggested that the absence of an effect could have been because of cultural differences, with the caffeine effect stereotype not as strong in Germany as it is in the U.S.A.

The overall support for the role of expectations identified in our review still allows for at least two "submechanisms" to exist. The first is a role for attentional bias and symptom detection (Hahn, 1997). The second is a more direct effect, where-by expectations affect emotional state (Kirsch, 1997b; Stewart-Williams, 2004). For example, Kirsch (1997b) pointed out that the expectation of anxiety is likely to be anxiety provoking, thereby directly causing the outcome. This could explain the strong results seen for manipulating verbal suggestions of arousal on symptom reporting, as the expectation of arousal or relaxation is itself likely to be arousing or relaxing. However, there does need to be a degree of caution in interpreting these results on arousal as they could be interpreted as part of the placebo response.

With regard to misattribution as a mechanism, the evidence from the studies that investigated self-awareness as a risk factor did not support this, with the two most directly relevant studies that instructed participants to monitor for any sensations failing to find an effect. Equally, for the six studies investigating the effect of baseline symptoms on symptom reporting the results were mixed providing inconclusive support for misattribution. However, five studies (Bogaerts et al., 2010; De Peuter et al., 2005; Papoiu et al., 2011; Strohle, 2000; Szemerszky et al., 2010), showed that suffering from a condition with symptoms similar to those being induced was a predictor of symptom reporting. As such, although the mechanism remains plausible, further evidence is required to clarify its importance.

For the learning mechanism support was found from studies investigating the risk factor "association," with the taste of decaffeinated coffee being enough to elicit caffeine related symptoms (Flaten & Blumenthal, 1999; Mikalsen et al., 2001). For prior experience, the results were weak but this could have been attributable to a lack of experience as this manipulation was typically a one off event. However, there was evidence for the role of social observation, with two of three studies showing a significant effect. In addition, support for learning was seen in the studies using classical conditioning, which involved a number of trials. Almost half of the studies showed that conditioning CO_2 inhalation with any odor is enough to elicit symptoms to the odor itself, and a reliable finding among the studies was that this was especially the case if the odor was unpleasant.

For baseline risk factors, we found no evidence of any effects of gender. However, since conducting the literature search, one additional study that would have met the inclusion criteria has become apparent and which is relevant here. This study by Faasse, Grey, Jordan, Garland, and Petrie (2015) investigated the risk factor of observing a female confederate display symptoms, demonstrating a significant effect on symptom reporting in females. It is interesting to note that Lorber et al. (2007), who also studied social observation, also only found a significant effect in females. One possibility is that it may be something inherent to social observation that makes females more vulnerable to nocebo effects. Other demographic factors such as age, employment status or level of education were also not risk factors. Interestingly, anxiety did not come out as a strong predictor despite the role it could play through misattribution (generating physical symptoms that are available to be misattributed) and expectations (apprehension of symptoms). One possible explanation for this advanced by Szemerszky et al. (2010) is that scores of anxiety could reach a ceiling effect due to advance information about the risks of taking part in the study. For other baseline risk factors, many different types of personality were implicated such as: Type A personality (Drici et al., 1995), lower positive affect, vigilance (Nevelsteen et al., 2007), pessimism, motivation to cooperate, somatization, somatosensory amplification, modern health worries (Szemerszky et al., 2010; Witthöft & Rubin, 2013), and neuroticism (Davis et al., 1995). A lack of consistency in the personality traits studied makes it difficult to interpret these findings, but many would seem to fit with expectation and/or misattribution mechanisms.

Nocebo effects have occasionally been referred to as the 'evil twin' of placebo effects. If true, one would expect the risk factors for a nocebo effect to be the inverse of the risk factors for a placebo effect. At a first look the mechanisms supported in our review do appear to be similar to those previously identified for placebo effects, albeit acting in the opposite direction. For example, the expectancy mechanism has been implicated for placebos through factors such as verbal suggestions, and participants' own baseline expectations which lead to positive expectations for pain or symptom relief (Benedetti et al., 2003; Kam-Hansen et al., 2014; Price et al., 1999; Vits et al., 2013). In addition, learning mechanisms such as prior experience of pain relief, social observation, or conditioning people to experience pain relief results in subsequent placebo responses (Colloca & Benedetti, 2006, 2009; Suchman & Ader, 1992). It also seems that opposite personality characteristics also predict placebo responding for example, optimism (Geers, Kosbab, Helfer, Weiland, & Wellman, 2007) as opposed to pessimism. One notable exception, however, would be the misattribution of preexisting symptoms, as logically this can only be relevant for nocebo: one cannot misattribute the absence of preexisting symptoms to an exposure. However, it is possible one could misattribute and fixate on a coincidental decline in symptoms after taking a sham tablet, and misattribute their improved wellbeing to the tablet.

Quality of Original Research

It is possible that some of our conclusions may be attributable to differences in quality between those studies that found an effect and those that did not. We did not observe any clear trend for lower quality studies to report more or fewer significant results than higher quality studies. However, on the whole the quality of the studies included in this review was limited because of poor reporting of key issues in experimental research such as randomization, allocation concealment, blinding, and not registering a study protocol before initiating recruitment. Prospective studies had fewer quality concerns, however given that experimental studies allow the control of more variables the results of these have more weighting than those from the prospective studies. It is also worth noting that almost half of studies did not mention receiving ethical approval. In an area of research requiring deception, or at least withholding information to deliberately cause symptoms, this is surprising. There is scope for future researchers to improve the methodological rigor of this field. Another surprising limitation of many of the studies included in this review was the lack of a priori sample size calculations. Only 10 of 89 studies included in this review mentioned carrying out a sample size calculation in order to make sure the sample was adequately powered to test their research question(s). As such, we could not assess the quality of studies based on their sample size in the large majority cases. Although it would have been useful to score each study for their strength of evidence, because of this lack of clear reporting and the heterogeneity across studies it was too hard to quantify the strength of each study using the same scale.

Quality of This Review

A strength of this review is that we did not include studies in which participants were exposed to an active exposure capable of eliciting symptoms through physiological mechanisms (e.g., experiments altering the information given to participants about a genuine medication). Such studies do not assess the pure nocebo effect, described as the undesirable effects experienced from an inert exposure (Kennedy, 1961) and can prove more difficult to interpret (Neukirch & Colagiuri, 2015).

Our search resulted in a large number of results. As the term 'nocebo' is still not widely used and may be preferentially used by those studies identifying a significant increase in symptoms in their participants, we deliberately adopted a broader search strategy than that used in previous reviews, for example, Petersen et al. (2014). Despite this, it is not certain that every study that met the inclusion criteria has been included, especially as nearly a quarter of included studies were identified through personal contacts. This inconsistent use of terminology makes the nocebo literature difficult to search and will continue to limit reviews in this area. We could have included terms such as 'adverse effects or negative outcome' in the search strategy but the number of results would be unmanageable as it would include many clinical trials that would not meet our inclusion criteria. On Medline alone, such search terms return over 97,000 results. This is also one of the reasons why we did not simply use 'placebo' as one of the search terms—every study which described itself as "placebo-controlled" would be returned.

In addition to limitations resulting from our search strategy, it is possible that some studies could have been falsely rejected after title and abstract screening (e.g., the main purpose of the study may have been on the placebo effect and therefore only placebo and not nocebo findings were reported in the abstract). We suspect that this is unlikely to have occurred often, however. In order to have been included such studies would have had to (a) manipulated factor(s) to affect nocebo responding or (b) looked at baseline measures as predictors of nocebo responding, which many do not do. Many studies which looked at the placebo effect passed through abstract screening as they mentioned participants experiencing negative symptoms or patients feeling worse after placebo exposure. However, going through the full manuscript the majority of these studies would not explore the possible reasons why, for example, baseline predictors. Therefore we feel this is not something to be too concerned about.

In addition studies published in non-European languages may have been less likely to have been identified as well as studies that were not reported in the conventional peer-reviewed literature.

Other limitations of the review reflect the way we grouped the results. We aggregated studies based on the independent variable. Because of this and because there are no direct replications each risk factor grouping contains several different outcomes. It is possible that an interaction exists between independent and dependent variables: for example, some outcomes may be more susceptible to the effects of changes in expectations than others. Unfortunately, we did not have enough data to explore this in depth.

Similarly as this review focused on identifying all the possible risk factors of nocebo effects that have been investigated in the literature, we included studies with different research populations, for example, students, healthy volunteers and patients. As such there could be differences between the groups in terms of which mechanisms are more likely to be at play. For example, it is likely the misattribution mechanism is more important for the development of nocebo effects in patient samples than healthy volunteers. However, looking at studies that had a patient sample we should interpret the results of those that just focused on baseline disease measures as support of the misattribution mechanism with caution. These studies did not measure actual baseline symptoms or emotions which are more likely to be subject to the misattribution mechanism, rather than disease status.

Finally, the interaction between the mechanisms, outcomes, and mode of delivery may also be important, but could not be explored in detail given the data available to us. For example, different forms of sham intervention for example, sham tablets versus sham caffeine versus sham EMF, may be more or less likely to trigger certain psychological mechanisms, and be more or less likely to affect certain outcomes, see Szemerszky, Dömötör, Berkes, and Köteles (2016).

Implications for Clinical Practice and Research

Our results suggest clinicians keen to reduce side effects induced by any nocebo effect associated with their interventions could (a) identify patient expectations of the adverse effects of an intervention and provide reassurance if these seem excessive, (b) avoid giving suggestions of side effects associated with the intervention, (c) down-play the dose that is being provided, and (d) reduce patient exposure to other patients experiencing side effects. Wells and Kaptchuk (2012) suggest the use of contextualized informed consent, whereby doctors should identify high-risk patients and tailor the medication side effect information so that these patients only receive drug specific side effect information, which is less susceptible to the nocebo response. Our review supports this and suggests that such tailoring may be especially required for those who have at-risk personality types. Clearly, these suggestions also have a downside, however, as they reduce informed consent and patient autonomy by restricting the information that is being provided. Alternative ways to reduce nocebo effects while maintaining the ability of a patient to give full informed consent are required. There is scope for researchers to develop innovative ways to reduce nocebo effects that does not require withholding of information. This has been shown by Crichton and Petrie (2015), who found that informing participants about nocebo effects effectively reduced symptoms to infrasound noise. In addition Bingel and the Placebo Competence Team (2014) provides some suggestions on how to avoid nocebo effects which are supported by this review such as improving the communication in patient information leaflets to make them more patient-orientated and reduce negative expectations of potential adverse effects.

Additional research should also aim to replicate risk factors which have so far received limited research, such as the more rarely investigated personality characteristics. It would also be advisable to look again at the risk factor ‘type of administration’ in a healthy volunteer sample and to assess this manipulation on expectations to explore possible mechanisms. It is also time for authors to use consistent terminology allowing easier identification of papers, and to enhance the quality of their research in this area. Simple acts such as being more explicit about randomization and blinding procedures and publishing protocols will enhance the transparency of the research in this area while also helping to alleviate some of the controversy surrounding nocebo research.

Conclusions

This review found that there is a mix of factors which predict whether someone will experience a nocebo effect. Given the implications nocebo effects have on patients’ quality of life and the health costs they create, it is important for research to start developing interventions to prevent nocebo effects from occurring while still trying to uphold informed consent. This systematic review provides a useful starting point for researchers to develop evidenced based interventions designed to negate nocebo effects, while also highlighting areas that need further investigation and improvement.

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Nocebo Effect of Informed Consent in Interventional Procedures

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Placebo and nocebo effects have recently emerged as an interesting template to appreciate some of the intricate underpinnings of the mind-body interaction. A variety of psychological mechanisms, such as expectation, conditioning, anxiety modulation, and reward, have been identified, and a number of neurochemical networks have been characterized across different conditions.[1] The nocebo effect, the mirror phenomenon to the placebo effect, occurs when the expectation of a negative outcome precipitates the corresponding symptom or leads to its exacerbation.[2] Unlike the placebo effect, there has been much fewer studies on the nocebo effect. A PubMed keyword search on "placebo" returned 185,249 entries, whereas that of "nocebo" returned only 334 entries. This editorial aims at revealing the potential conflict between nocebo and informed consent in interventional pain management and discussing possible strategies to minimize potentially harmful nocebo effects.

HISTORICAL ASPECT OF INFORMED CONSENT

In ancient Greece, patient participation in medical decision making was considered undesirable. It was generally accepted that the physician's primary task was to inspire the confidence of the patient. Any disclosure of possible difficulties might, therefore, erode the patient's trust.[3] During medieval times, doctors were encouraged to use their conversations with patients as an opportunity to offer comfort and hope, while emphasizing the need for the doctor to be manipulative and deceitful. It was widely held that for the treatment to be effective the authority must be coupled with obedience.[4]

During the Era of Enlightenment, new views emerged such that patients had the capacity to listen to the doctor; however, it was still felt that deception was necessary to facilitate patient care.[3] During the 1800s the medical profession was split over whether to disclose a dire prognosis to a patient. However, most physicians of the time argued against informing patients of their condition.[4]

The doctrine of assault and battery has its roots in early English Common Law. Common Law is the combination of customs, traditions, and case law. This Doctrine forms the basis for the possible "injury" or "liability" incurred from surgery without proper consent.[3] As the concept of informed consent gained popularity during the 20th century, the courts extended the English Common Law Tort doctrine of negligence to the field of surgery by equating negligence with breach of duty and breach of duty with an incomplete patient consent. The failure of a physician to provide adequate information to the patient about his or her own treatment is interpreted by the courts as a breach of duty by the physician.[4]

MODERN FORM OF INFORMED CONSENT

During the last few decades, the way in which medicine is practiced has changed dramatically. The previous paternalistic approach, which emphasized beneficence to the exclusion of other principles, particularly autonomy, has been largely eroded. Unfortunately, however, physicians are not always able to determine their patients' best interests.[5] The case of Schoendorff v. Society of New York Hospital in 1914 has had the most impact on the doctrine of informed consent, in which the patient with a tumor underwent an operation to which he had not agreed.[3] In this case, Justice Benjamin Cardozo summarized "Every human being of adult years in sound mind has a right to determine what shall be done with his own body; and a surgeon who performs an operation without his patients consent commits a battery for which he is liable in damages."[3]

In recent years, along with the increasing popularity of shared decision making in health-care delivery, more patients have become interested in embracing their roles in making decisions regarding their own health.[6] Informed consent is the process by which a person authorizes medical treatment after discussing with clinicians the nature, indications, benefits, and risks of treatment.[6] Information to be discussed includes diagnosis, procedure, available alternatives, potential outcomes of each option, risks and benefits of each alternative, and the values of each potential outcome.

ORIGIN OF NOCEBO EFFECT

The nocebo effect was first named by Kennedy[7] as "Placebo reaction" in 1961, subsequently elaborated by Kissel and Barrucand.[8] The nocebo hypothesis proposes that expectations of sickness and the affective states associated with such expectations cause sickness in the expectant.[9] Two variants of these nocebo responses exist: one is characterized by new symptoms or a symptom aggravation associated with drug or placebo intake, although the chemical agent itself is not able to trigger these symptoms. Another variation of nocebo responses is the reduced efficacy of clinical interventions due to negative expectations or prior experiences.[10]

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Nocebo effects exist and operate during routine treatments, negatively affecting clinical outcomes. Nocebo effects are the direct result of the psychosocial context or therapeutic environment on a patient's mind, brain, and body, involving multiple factors, such as verbal suggestions and past experience.[11] Negative information and prior unsuccessful therapies may be particularly important in mediating undesirable outcomes to routine therapy. Therefore, consideration of nocebo effects in the context of patient-clinician communication and disclosure of interventional procedures may be valuable in both minimizing the nocebo component of a given therapy and improving procedural outcomes.

Nocebo effects can modulate the outcome of a given therapy in a negative way, as do placebo effects in a positive way. Importantly, these effects operate in the absence of a traditional placebo, forming part of everyday treatments.[11] To this extent, a balance must exist between communicating important clinical information and ensuring that every attempt is made to minimize negative instructions and a negative therapeutic context. This fine balance must take into consideration the patient's autonomy to make a decision based on all relevant information, with attempts to reframe how information may be delivered in a nondeceptive, yet reassuring way.[11]

PROPOSED MECHANISM OF NOCEBO EFFECT

The psychological mechanism of nocebo is thought to involve negative expectations and anxiety.[12,13] Although conditioning paradigms are more powerful in triggering placebo effects, both verbal suggestion and learning induce similar effects on nocebo development.[14] Cholecystokinin has also been shown to be involved in the hyperalgesic nocebo response.[15] Further, Scott et al[16] showed that, although placebo responses were associated with greater dopamine and opioid activity, nocebo responses were associated with deactivation of dopamine and opioid release, demonstrating involvement of the brain circuitry implicated in the reward response and motivated behavior.

Taken together, the underlying mechanisms of nocebo responses are much less well understood than those of placebo responses. In particular, the contribution of similar overlapping and distinct trajectories mediating nocebo versus placebo responses requires further investigation.[10]

CONFLICT OF CONCERN OF NOCEBO EFFECT AND INFORMED CONSENT

The principle of informed consent obligates physicians to explain possible side effects when prescribing medications or performing interventional procedures. This disclosure may itself induce adverse effects through expectancy mechanisms—that is, nocebo effects—contradicting the principle of nonmaleficence. Rigorous research suggests that providing patients with a detailed enumeration of every possible adverse event can actually increase side effects.[17]

One of the primary missions of physicians, dating back to Hippocrates, is the principle of nonmaleficence, Primum non nocere: "Above all do no harm." At the same time, the pinnacle of modern bioethics is informed consent, respect for person, and transparency.[17]

The relevant parallel dilemma is when the harmfulness of the nocebo effect may outweigh the good in proper disclosure of medical information to the patient, and where the duty to inform may therefore be suspended.[2] In view of the nocebo effect of informed consent, the harm in point does not exist; rather, the physician risks creating it by merely mentioning its potentiality. Moreover, this harm can be biologically real and cannot be dismissed as "merely psychological." This raises a different, new moral dilemma, which demands a search for a new moral balance between respect for autonomy and paternalistic nonmaleficence, and which ethicists are called upon to investigate.[2] This is of special importance with respect to the clinical practice of informed consent, where the very disclosure of potential side effects or complications can bring them about through a nocebo effect.

STRATEGIES TO MINIMIZE NOCEBO EFFECT

Wells and Kaptchuk[17] advocate that the perceived tension between balancing informed consent with nonmaleficence might be resolved by recognizing that adverse effects have no clear black or white "truth." They believe informing a patient about side effects is not a mere presentation of "facts" but is an important component of the art of medicine and requires the practitioner's clinical judgment. They have proposed a pragmatic approach for providers to minimize nocebo responses while still maintaining patient autonomy through "contextualized informed consent," an ethical procedure in which the disclosed information is tailored in a way that reduces expectancy-induced side effects while still respecting patient autonomy and truth-telling.[17]

These differences in reported adverse effects indicate that the way in which adverse events are presented affects not only risk perception but, more importantly, clinical outcomes. Rather than merely delivering detailed lists of specific adverse effects, clinicians should incorporate in their communication positive framing and percentage formats as opposed to negative framing and frequency format, thus possibly reducing nocebo effects by minimizing attention on the negative aspects of the treatment.[11]

Studies have shown that pain increases when harsher words are used to describe an upcoming experience. For example, 1 study showed that the use of the word "pain" resulted in patients reporting more pain than use of the phrase "cool sensation,"[18] whereas another study found that saying "you will feel a bee sting" before injection of a local anesthetic resulted in more pain than saying that the anesthetic will "numb the area [so that] you will be comfortable during the [following] procedure."[19] Pain interventionists may need to pay special attention to which words to choose when describing interventional pain procedures to patients in the process of obtaining consent approval as well during procedures. It may be a good idea to explain to the patients more about how the procedures will be done, the mechanism of the action of the selected procedures, and how successful they are in other people, and of course a confident, competent, and compassionate bedside manner will always help.

In summary, clinicians' efforts should be devoted to avoiding instilling negative expectations during the informed consent process, procedural information, and follow-up assessments so that the most effective patient-clinician communication can be pursued while unwarranted and untenable nocebo responses can be avoided.[11] In particular, description of procedures, a common interaction from doctors such as interventional pain practitioners, requires understanding of the potential of nocebo-mediated responses and their implications.

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The nocebo effect in the context of statin intolerance

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Abstract: The nocebo effect, the inverse of the placebo effect, is a well-established phenomenon that is under-appreciated in cardiovascular medicine. It refers to adverse events, usually purely subjective, that result from expectations of harm from a drug, placebo, other therapeutic intervention or a nonmedical situation. These expectations can be driven by many factors including the informed consent form in a clinical trial, warnings about adverse effects communicated by clinicians when prescribing a drug, and information in the media about the dangers of certain treatments. The nocebo effect is the best explanation for the high rate of muscle and other symptoms attributed to statins in observational studies and clinical practice, but not in randomized controlled trials, where muscle symptoms, and rates of discontinuation due to any adverse event, are generally similar in the statin and placebo groups. Statin-intolerant patients usually tolerate statins under double-blind conditions, indicating that the intolerance has little if any pharmacological basis. Known techniques for minimizing the nocebo effect can be applied to the prevention and management of statin intolerance.

Characteristics of the nocebo effect

In 1985, Cairns et al[1] found that aspirin 325 mg qid significantly reduced total and cardiac mortality in a randomized placebo-controlled trial in patients with unstable angina, whereas the uricosuric agent sulfinpyrazone was ineffective. The investigators subsequently noted[2] that the frequency of minor gastrointestinal (GI) adverse events (AEs) in the study population (all patients regardless of treatment allocation) was much greater in 2 centers they denoted A and B, than in center C, as summarized in Table 1. Even more striking, discontinuations of blinded study medication due to minor GI AEs were 6 fold greater in centers A and B, compared with center C.

All participating hospitals were university affiliated and in Ontario. Study procedures were carried out in the same way by all 3 centers using a common procedures manual, including a uniform query for AEs. However, because of local ethical review committee requirements, the consent form differed among centers with regard to adverse effects. In centers A and B, the relevant section read "Side effects are not anticipated beyond occasional GI irritation and, rarely, skin rash." In center C, the consent form read "Sulfinpyrazone and aspirin are generally well tolerated … Occasionally a patient taking sulfinpyrazone or aspirin may develop a tendency to bleed but the risk of serious hemorrhage is extremely unlikely." Thus, study participants in centers A and B were informed of the potential for GI irritation, but at center C, they were not. The investigators concluded that this was the probable source of the differences in GI AEs.

To the best of our knowledge, this report[2] is the first convincing evidence of the nocebo (*Latin: I will harm*) effect in cardiovascular medicine. The nocebo effect (or phenomenon) is the inverse of the placebo effect; it refers to

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Table 1 Adverse events (AEs) in 555 patients with unstable angina allocated to aspirin, sulfinpyrazone, aspirin + sulfinpyrazone, or placebo[2]. All randomized patients included, irrespective of treatment group allocation

Centers (hospitals)	A (4)	B (3)	C (1)	χ^2	*P*
N	313	86	156		
GI AEs in consent form	Yes	Yes	No		
Minor GI AEs	143 (46%)	32 (37%)	25 (16%)	39.8	<.001
Major GI AEs*	8 (2.6%)	1 (1.2%)	6 (3.8%)	1.6	NS
DC due to minor AE†	61 (19%)	15 (17%)	5 (3%)	22.8	<.001
DC due to major AE	27 (9%)	7 (8%)	11 (7%)	3.1	NS

DC, discontinued; GI, gastrointestinal; NS, not significant.
*For example, GI bleeding, peptic ulcer.
†All due to GI AEs.

AEs, usually purely subjective, that result from expectations of harm from a drug, placebo, other therapeutic intervention, or a nonmedical situation. These expectations can be driven by many factors beyond the informed consent form in a randomized controlled trial (RCT), including warnings about adverse effects communicated by clinicians when prescribing a drug,[3,4] information on the Internet and in social media,[5] health scares propagated by broadcast and print media,[6] and simply observing the symptoms and behavior of others.[7,8] Just as an ineffective treatment can be subjectively effective in an uncontrolled setting due to the placebo effect, an innocuous treatment can be subjectively toxic due to the nocebo effect.[6,9] The placebo and nocebo effects reflect normal human neuropsychology and not drug efficacy or toxicity.

The differences reported by Myers et al[2] were not randomized comparisons, but there have since been many studies randomizing subjects to receive different information with follow-up for subsequent AEs. One of the few reports[10] involving a cardiovascular treatment stemmed from the perception at the time of the study that beta blockers commonly cause erectile dysfunction. A total of 96 male patients with hypertension or angina pectoris and normal sexual function completed a multidimensional quality of life questionnaire designed to assess the presence of erectile dysfunction (International Index of Erectile Function). They were then all treated with atenolol 50 mg daily, randomized into 3 groups of 32 receiving different information about the drug. The first group did not know what drug they were taking, the second knew but were not informed about the potential adverse effects, and the third knew they were taking atenolol and were further informed that atenolol could cause erectile dysfunction. The language used was "… it may cause erectile dysfunction but this is uncommon."

At the end of the 90-day treatment period, the same questionnaire was administered again. Erectile dysfunction was reported by 1 patient (3.1%) in the group blinded to treatment, 5 (15.6%) in the group that knew they were taking atenolol but were not informed about side effects, and 10 (31.2%) in the group that was informed about sexual dysfunction potentially attributable to atenolol ($P < .01$ for the informed patient group vs the blinded group). The authors concluded that erectile dysfunction in their study was psychogenic. This conclusion is supported by a review[11] of beta blocker RCTs, which concluded that these drugs rarely cause erectile dysfunction, contrary to widespread belief at the time.

Several reviews[3,7,12,13] have summarized studies reporting the nocebo effect in mostly noncardiovascular contexts. The most common manifestation of the nocebo effect is pain of various kinds, with or without other symptoms. Pain may be heightened because of negative expectations about a treatment or situation,[14] and it can be experienced in the total absence of a noxious stimulus, as in mass psychogenic illness, which is the most dramatic manifestation of the nocebo effect.[15] As shown by functional MRI, negative expectations that heighten pain lead to increased activity of regions involved in pain processing, including the prefrontal cortex, anterior cingulate cortex, and insula.[14] The nocebo phenomenon is thus well established. It hinders effective therapy, especially in the age of the Internet and social media, where misinformation can proliferate.

The nocebo phenomenon in randomized controlled trials vs observational studies

It is widely accepted that a well-performed double-blind RCT provides high-quality evidence because it is the most reliable way to evaluate the benefit, safety, and tolerability of a treatment.[16,17] Double-blind RCTs have the great advantage that bias is controlled (providing the blind remains secure), and the only factor (other than random error) determining the outcome of a properly performed RCT is allocation to the test treatment or the control. Because placebo and nocebo effects depend on expectations, they affect all blinded treatment arms equally.[16,17] The main disadvantage of large RCTs is that they are difficult to carry out, require a long time to complete, and are often very costly.

Observational studies can be useful to detect adverse effects that are too rare to be reliably apparent in RCTs, particularly when the background incidence is very low.[18] Before 2010, when simvastatin 80 mg was shown in an RCT to cause myopathy (unexplained muscle pain or weakness with creatine kinase >10X ULN) including rhabdomyolysis much more frequently than simvastatin 20 mg,[19] this rare adverse effect had been recorded in statin RCTs, but the numbers were too small for statistically significant differences, so its detection was essentially observational. In this case, observational data were reliable because the background incidence of idiopathic rhabdomyolysis is extremely low, so that any case occurring during statin therapy without another known cause is likely to be causally related to the statin. Cerivastatin was withdrawn from the market in 2001 because observational data derived from post-marketing surveillance revealed that the risk of rhabdomyolysis was much higher than that with other statins.[20]

Because the comparisons made in observational studies are not randomized, all observational studies, whether controlled or not, are at risk of confounding.[16,18] Evaluation of the contribution of placebo or nocebo effects is rarely possible. Statistical adjustment can reduce the risk of confounding but not eliminate it. There are numerous instances of observational findings later refuted by RCTs. In cardiovascular medicine, among the best known is estrogen therapy to reduce coronary heart disease (CHD) risk in post-menopausal women, which was strongly supported by numerous epidemiologic studies[21,22] and subsequently largely refuted by RCTs.[23–25] Another example relates to supplementation with the antioxidant vitamin E, which was associated with a reduced risk of cardiovascular events in several observational studies.[26] RCTs subsequently found no suggestion of cardiovascular benefit.[26,27] These examples and many others show that observational studies should be interpreted cautiously.[16,18]

Surveys and clinical practice medical records provide uncontrolled observational data. In contrast to double-blind RCTs, which measure only the pharmacologic properties of a drug (beneficial or adverse), these methods provide information on the net effect of the pharmacologic properties of the drug combined with background symptoms and any placebo or nocebo effect, subject to confounding factors such as recall or selection bias, if any. Surveys and medical records can provide information on AEs associated with a treatment but are of limited value for evaluating the causal relationship between the event and the treatment.

Statin intolerance in the clinic

Statin intolerance is a recent concept. The first statin, lovastatin, was introduced in 1987,[20] but the first article with "statin intolerance" in the title did not appear until 2005. A Medline search returns 9 such articles before the end of 2010 and 44 from 2011 until March 2016. Before the current decade, statins (other than cerivastatin) were generally regarded as a safe and well-tolerated class of drugs with a favorable benefit risk relationship.[20,28–30]

One in 4 Americans aged older than 40 years, about 25 million people, take a statin.[31] Statin therapy is a long-term endeavor, sometimes lifelong. As with any chronic therapy intended to prevent adverse outcomes rather than treat symptoms, adherence can be problematic.[32] Compounding the problem, a significant minority of patients report AEs during treatment with statins, which may lead to discontinuation. In a retrospective cohort study in eastern Massachusetts, 18,778 (17%) of 107,835 statin-treated patients had a statin-associated AE.[33] Of these, 11,124 (10%) patients discontinued their statin, at least temporarily, and were thus intolerant. From a multinational survey of 810 statin prescribers—mainly cardiologists—Hovingh et al[34] estimated an overall average of 6% as the percentage of patients who are statin intolerant (defined as unable to tolerate the recommended statin dose). The range was wide, even within Western Europe, where the percentage was 2% in Italy, Spain, and Sweden, 4% in Germany, 6% in France, and 11% in the United Kingdom. English-speaking countries (Australia, Canada, the United Kingdom, and the United States) all reported percentages of 8% to 12%, with the 12% US value similar to the 10% reported previously by Zhang et al.[33] Cultural factors, including local language media misinformation that can create the nocebo effect, likely play a role in this distribution. The most common complaints of statin-intolerant patients are related to muscle, occurring in 64% in an international survey,[34] and over 90% in a specialist lipid clinic.[35] In the study by Zhang et al the percentage of patients who discontinued statins because of muscle symptoms is not provided; however, of 18,778 patients with AEs, of whom 11,124 discontinued their statin, 27% had myalgia.[33] Overall, perhaps about half of all statin discontinuations caused by AEs are due to muscle symptoms. Taking 10% as an overall average for the percentage of patients who are statin-intolerant and one half as the proportion in whom the intolerance is caused by muscle symptoms, roughly 5% of all statin-treated patients are intolerant due to muscle symptoms. These symptoms are rarely accompanied by significant elevations in creatine kinase (CK) or other objective changes,[35] and no pathophysiological explanation for muscle symptoms during statin therapy has been found.[36] As discussed in the following section, RCTs demonstrate that muscle and other intolerable symptoms are generally not caused by the statin.

Statin intolerance in randomized controlled trials

In contrast to the substantial AE rate under the uncontrolled open-label conditions of clinical practice, in randomized placebo-controlled trials, the incidence of muscle symptoms[37] and of discontinuations due to any AE[38] are consistently similar in the patient group allocated to the statin and the group allocated to placebo.[37] Recently, the HOPE 3 investigators reported a small excess of patients with muscle symptoms in patients allocated to rosuvastatin 10 mg daily compared with placebo (5.8% vs 4.7%, respectively, $P = .005$), but no significant difference in the number of patients permanently discontinuing study treatment because of these symptoms (1.3% vs 1.2%, respectively).[39] Meta-analyses of placebo-controlled studies have shown no significant difference between statin and placebo in the rates of muscle symptoms.[40,41] Table 2 summarizes AEs pooled from 17 placebo-controlled trials with atorvastatin (the statin most commonly prescribed) across the 10- to 80-mg dosage range. Table 2 is reproduced from the US LIPITOR (atorvastatin) prescribing information and therefore has been reviewed and approved by the US Food and Drug Administration, which had access to the raw data. The 20-mg and 40-mg doses were used in few studies, so data with these doses are sparse and less reliable. There is no suggestion that atorvastatin increases the incidence of any of these AEs, including muscle symptoms. Indeed, there is a trend to fewer AEs with the maximal 80-mg dose compared with lower doses and placebo. This may reflect the play of chance and the fact that most studies did not include all doses.

Randomized controlled trials in statin-intolerant patients

The first study specifically in statin-intolerant patients was a proof-of-concept N-of-1 placebo-controlled study in 8 patients.[42] No difference between statin and placebo was observed. ODYSSEY ALTERNATIVE[43,44] was an RCT in 361 patients with statin intolerance due to muscle symptoms that included a rechallenge over 24 weeks with atorvastatin 20 mg, with the PCSK9 inhibitor alirocumab and ezetimibe as comparators in a parallel design. In an exploratory analysis, there was no significant difference in withdrawal due to muscle AEs, which were recorded in 16% of patients allocated to alirocumab, 20% to ezetimibe, and 22% to atorvastatin ($P > .20$); 82%, 75%, and 75% of study participants in these 3 groups, respectively, did not have an AE of any type causing discontinuation.

In the most recent and largest rechallenge RCT in statin-intolerant patients, GAUSS-3,[45,46] 491 patients with well-documented statin intolerance were randomly allocated to atorvastatin 20 mg or placebo for 10 weeks or until they experienced intolerable muscle symptoms. After a 2-week washout period, they were crossed over to the other treatment for an additional 10 weeks or until the onset of intolerable muscle symptoms. This sequence comprised Phase A of the study, the results of which were subject to an exploratory analysis without predefined methods in the statistical analysis plan.[46]

Overall, 133 patients (27.1%) experienced intolerable muscle-related symptoms while taking both treatments or had no symptoms on either treatment. Intolerable symptoms were experienced by 209 patients (42.6%) on atorvastatin but not placebo, and 130 (26.5%) on placebo but not atorvastatin. Taking the results at face value, the excess of 79 of 491 (16%) participants relative to placebo could represent patients whose muscle symptoms were due to the pharmacologic properties of atorvastatin. Symptoms in the remaining 84% can be accounted for by the nocebo effect.

Before settling on this conclusion, it should be noted that the GAUSS-3[46] results contain features that complicate interpretation. Most obviously, in the first period, the Kaplan–Meier cumulative probability curves do not start to separate until at least 50 days after randomization (period length was 70 days). Muscle symptoms causing statin intolerance can occur at any time but typically arise within the

Table 2 Adverse events as listed in the LIPITOR (atorvastatin) US prescribing information

	Any dose	10 mg	20 mg	40 mg	80 mg	Placebo
Adverse reaction*	N = 8755	N = 3908	N = 188	N = 604	N = 4055	N = 7311
Nasopharyngitis	8.3	12.9	5.3	7.0	4.2	8.2
Arthralgia	6.9	8.9	11.7	10.6	4.3	6.5
Diarrhea	6.8	7.3	6.4	14.1	5.2	6.3
Pain in extremity	6.0	8.5	3.7	9.3	3.1	5.9
Urinary tract infection	5.7	6.9	6.4	8.0	4.1	5.6
Dyspepsia	4.7	5.9	3.2	6.0	3.3	4.3
Nausea	4.0	3.7	3.7	7.1	3.8	3.5
Musculoskeletal pain	3.8	5.2	3.2	5.1	2.3	3.6
Muscle spasms	3.6	4.6	4.8	5.1	2.4	3.0
Myalgia	3.5	3.6	5.9	8.4	2.7	3.1
Insomnia	3.0	2.8	1.1	5.3	2.8	2.9
Pharyngolaryngeal pain	2.3	3.9	1.6	2.8	0.7	2.1

Clinical adverse reactions occurring in ≥2% in patients treated with any dose of LIPITOR and at an incidence greater than placebo regardless of causality (% of patients).

*Adverse reaction > 2% in any dose greater than placebo.

first few weeks of treatment.[36] Of the 262 patients in GAUSS-3 who reported intolerable symptoms during period 1, about 70% had reported these symptoms by 50 days after randomization. This is consistent with the findings of a retrospective cohort study in a US specialist lipid clinic, in which 52% of patients who could not tolerate a statin (due to muscle symptoms in over 90%) reported symptoms within the first month of therapy.[35] Therefore, if atorvastatin could produce reproducible muscle symptoms in these statin-intolerant patients, the excess over placebo in intolerable symptoms should have been substantial in the early weeks after randomization. But the period 1 Kaplan–Meier cumulative probability curves are virtually superimposable up to 50 days.

In GAUSS-3, the muscle symptom end point is purely subjective, and intolerable muscle symptoms on at least 2 statins was an entry criterion. In this situation, maintaining the blind is crucial, as without it virtually all subjects would report muscle symptoms on atorvastatin but not placebo, but in any study, participants may self-unblind if given the opportunity.[47,48] Crossover designs are particularly vulnerable because all subjects have access to the 2 dosage forms and can compare them.[47] In GAUSS-3, participants had the ability to self-unblind either by obtaining a lipid profile outside the study or by removing the overencapsulation from a dose of study medication.[48] Some participants may have felt that a placebo-controlled rechallenge questioned the credibility of their symptoms or exposed them to the potential embarrassment of being found intolerant of placebo, either of which would have created a motive for self-unblinding. In addition, only patients who in phase A had experienced intolerable symptoms on atorvastatin but not placebo could enter phase B of the study, in which they would be randomly allocated to either the PCSK9 inhibitor evolocumab or ezetimibe for 24 weeks, followed by open-label evolocumab in phase C for 2 years. The mean baseline low-density lipoprotein cholesterol in GAUSS-3 was very high—5.5 mmol/L (212 mg/dL), one third had CHD, and all subjects believed they could not tolerate a statin. Some sites may have been able to offer another evolocumab study to participants in GAUSS-3 not proceeding to phases B and C, but participants at other sites who wanted to be sure of access to evolocumab (in phase C) would have had an additional motive to self-unblind. This triad of a crossover design, unusual motivating factors, and a purely subjective end point is not present in most RCTs (for which the overencapsulation method used in GAUSS-3 may suffice). Self-unblinding would most likely commence toward the end of the period 1, when participants who had not yet reported intolerable symptoms might well have started to have doubts about their ability to distinguish atorvastatin from placebo before the period ended. This would create bias that can explain the delayed separation of the Kaplan–Meier curves toward the end of period 1, a phenomenon that is otherwise not easily explained, and the continuing separation in period 2. Therefore, bias caused by self-unblinding explains the results of phase A in GAUSS-3 at least as plausibly as an appreciably greater frequency of intolerable muscle symptoms on a statin compared to placebo, a phenomenon never previously demonstrated. Future rechallenge studies in statin-intolerant patients should use designs that minimize incentives and opportunities to unblind and should avoid overencapsulation by contracting with a statin manufacturer to use established tablet matching techniques that minimize the risk of unblinding.[47] It is easier to make a placebo tablet matching simvastatin, which is tasteless, than atorvastatin, which is bitter.

As previously noted (under "Statin intolerance in the clinic" section), the incidence of statin intolerance due to muscle symptoms in statin-treated patients appears to be roughly 5%. If the 16% excess in the statin-intolerant patients studied in GAUSS-3 could be shown to accurately reflect intolerance with a pharmacologic basis, as opposed to self-unblinding, then the incidence of discontinuation of statin therapy due to muscle AEs caused by the statin would be about 1% in unselected patients. A difference between statin and placebo in discontinuations due to AEs has not been observed in earlier clinical trials[38] or the recent HOPE 3 study,[39] as previously noted. A new UK National Institute for Health Research N-of-1 study in 200 patients[49] may shed more light on statin intolerance under double-blind conditions.

Taken together, GAUSS 3, ODYSSEY ALTERNATIVE, and the small N-of-1 study of Joy et al[42] provide evidence that intolerance usually depends on patients knowing they are taking a statin.[37,50,51] Added to the massive amount of information provided by cardiovascular outcome and other statin RCTs, these rechallenge studies provide further evidence that the predominant cause of statin intolerance is the nocebo effect, which is totally dependent on patient awareness of a treatment and its potential adverse effects. Under double-blind conditions, patients do not know what they are taking (as long as the blind is secure), so expectations are the same regardless of treatment allocation; the nocebo effect can increase the frequency of an AE in the study population[2,10] but cannot cause differences between the treatment and control groups.

The nocebo effect and statin intolerance in the clinic

Muscle symptoms are subjective and common in untreated middle-aged or elderly patients. In the Heart Protection Study,[52] which compared simvastatin 40 mg and placebo in over 20,000 patients during a follow-up period of 5 years, participants were directly questioned at every visit about muscle symptoms (in addition to the standard general query for AEs typically used in clinical trials). At each visit, about 6% of patients in both groups reported muscle symptoms, and 32.9% and 33.2% reported these symptoms at least once during the trial in the simvastatin and placebo groups, respectively. The Heart Protection

Study illustrates the high prevalence of muscle symptoms in middle-aged to elderly people who are taking a placebo, are queried at regular intervals about muscle symptoms, and have been informed that a statin can cause muscle injury.

The risk of myopathy and rhabdomyolysis is prominent in statin patient information leaflets, and clinicians warn patients to report muscle symptoms; furthermore, Internet searches bring up mainly disturbing misinformation about statin adverse effects. This is the fate of many advances in medicine, such as vaccination programs and fluoridation of water.[5] Aggravating this problem, there is an inbuilt bias in news outlets and social media; "Statins have very few adverse effects" is not newsworthy, but "Cholesterol drugs taken by millions are dangerous" often is. These influences appear to have set up a powerful belief system. Therefore, some patients will expect muscle and other symptoms[6,9] and may associate background symptoms with their statin use—the nocebo effect. Furthermore, normal healthy people can experience pain in the absence of any painful stimulus, as previously noted.

In recent years, various objections have been raised to the reassuring adverse effect profile demonstrated in statin RCTs, which include over 170,000 patients followed for several years.[30] Some have argued that the statin trials do not reflect clinical practice and therefore fail to reliably assess adverse effects.[53–56] For example, the NLA Task Force on Statin Safety has written[55] "One of the major limitations of using randomized controlled trials (RCTs) for the evaluation of safety is that the populations studied are very restricted in their study entry characteristics and often patients with multiple comorbidities and previous statin intolerance are excluded. Thus there is limited generalizability of patients in RCTs compared with the general clinical population, which tends to have more comorbidity and frailty."

We disagree. We have previously challenged the argument that any exclusion of patients with statin intolerance casts doubt on the tolerability data in RCTs.[38] Also, while it is true that individual statin RCTs, in common with RCTs in general, had inclusion and exclusion criteria, over 170,000 patients[30] have participated in the statin RCTs and among them are large numbers with multiple comorbidities. Table 3 summarizes discontinuation rates due to any AE in 8 large cardiovascular outcome trials with statins comprising over 45,000 participants, many female or elderly, with complex medical histories including one or more of CHD, stroke, diabetes, chronic kidney disease, and heart failure. Taking the participants in the cardiovascular outcome RCTs with statins as a whole, the entry characteristics were very broad. Consequently, there is no good reason not to generalize these RCT results to clinical practice.

In any double-blind RCT, the difference between the active and placebo treatments in discontinuation rates due to any AE is a good measure of tolerability. The discontinuation rates in the broad array of patient types summarized in Table 3 were consistently similar in participants allocated to statin and placebo, and withdrawal due to any AE in the 8 studies pooled was 8.0% (1814/22,714) and 8.1% (1843/22,715) in patients allocated to statin and placebo, respectively. Thus, there was no intolerance in these studies, not because of the characteristics of the participants, whose comorbidities were at least that of patients in most clinical practices, but because statins are well tolerated when treatment is blinded.

The authors[53–56] dismissing statin RCTs appear not to have considered the possibility that the nocebo effect could lead to high rates of subjective AEs attributed to statins in uncontrolled observational studies, in contrast to RCTs, which consistently show little difference between statin and placebo. This is not surprising because there are few reports of the nocebo effect in cardiovascular medicine. A Medline search on March 19, 2016 using the terms "nocebo" and "cardiovascular" in any field revealed only 6 publications. Substituting "pain" for "cardiovascular" returned 151 publications. As far as we are aware, the first explicit mention of the nocebo effect in the context of statins was in a review of AEs in statin RCTs by Finegold et al.[57]

Although most cases of statin intolerance can be adequately explained by the nocebo effect, it remains a clinical problem. Virtually all patients and some clinicians are convinced that the intolerance has a pharmacologic basis. In a typical scenario, a clinician prescribes a statin, the patient returns complaining of muscle symptoms with no obvious cause, the clinician or patient stops the statin, and the symptoms resolve. This sequence of events convinces the patient that the symptoms are caused by the statin, especially if symptoms recur during rechallenge. But this scenario is readily explained by the nocebo effect, and there is no reason for the clinician to invoke drug toxicity that somehow fails to appear in RCTs.[37,38] However, this does not make the symptoms any less relevant.

Although the nocebo effect reflects normal human neuropsychology, very few patients will accept that their symptoms are psychogenic; any such suggestion is stigmatizing for many people and should generally be avoided. This is seen most clearly when the nocebo phenomenon is manifested in a group setting as mass psychogenic illness; those affected often vigorously reject any psychological explanation.[15] On the other hand, knowing that purely subjective symptoms during statin therapy are unlikely to be caused by the statin helps the clinician to preempt statin intolerance and to deal with it if it does occur, as discussed in the following section.

Devoting effort to restarting treatment with a statin is important because the only class of lipid-lowering agent capable of matching the efficacy of high-intensity statin therapy is the PCSK9 inhibitors, but as of April 2016, these lack cardiovascular outcome and long-term safety data. In addition, atorvastatin 80 mg, the maximum dose of the most commonly prescribed generic statin and capable of producing a mean reduction in low-density lipoprotein

Table 3 Discontinuation due to any adverse event (AE) in randomized double-blind placebo-controlled cardiovascular outcome trials of statins in patients with advanced disease

							Discontinuation due to AEs (%)	
Trial*	N	Drug, dose (mg)	Duration (y)†	Patient type	Age (y)†	% Female	Statin	Placebo
4S	4444	S 20-40	5.4	CHD	59	19	5.7	5.7
HPS	20,536	S 40	4.9	Mixed‡	64	25	4.8	5.1
ALERT	2102	F 40-80	5.1	Renal transplant	50	34	14.8	16.3
4D	1255	A 20	4.0	Diabetes on dialysis	66	46	11.8	8.2
SPARCL	4731	A 80	4.9	Stroke/TIA§	63	40	17.5	14.5
CORONA	5011	R 10	2.7	Heart failure	73	24	9.6	12.1
GISSI-HF	4574	R 10	3.9	Heart failure	68	23	4.6	4.0
AURORA	2776	R 10	3.8	Hemodialysis	64	38	14.9¶	16.8¶
Total	**45,429**						**8.0**	**8.1**

A, atorvastatin; CHD, coronary heart disease; F, fluvastatin; HPS, Heart Protection Study; R, rosuvastatin; S, simvastatin; TIA, transient ischemic attack.

*Trials are listed in order of publication date of the main results.

†Mean or median.

‡65% CHD, 16% cerebrovascular disease, and 29% diabetes.

§69% stroke and 31% TIA.

¶Included end point events.

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cholesterol of about 55%, is obtainable for less than $100 per year of treatment in the United States. The US list price of both marketed PCSK9 inhibitors, alirocumab and evolocumab, was over $14,000 per year of treatment at launch in 2015.

Minimizing the nocebo effect during statin therapy

Prevention of statin intolerance is better than cure. The prescribing information for all statins advises warning patients about the risk of myopathy (unexplained muscle pain or weakness with CK >10X ULN), including rhabdomyolysis, and to promptly report unexplained muscle symptoms. Because warning patients about a subjective AE can substantially increase the risk that it will occur,[2,4,6,10,58,59] the frequency of subjective AEs can be strongly influenced by clinician–patient communication.[3,4,9,59] The goal of the nocebo-conscious clinician is to avoid creating negative expectations and to counter any that already exist. Therefore, it is important to emphasize to the patient that myopathy including rhabdomyolysis is rare, occurring in less than 1 in 1000 patients, and to put this very small risk in the context of the proven substantial benefits of statins. Patients starting a statin can be reminded that muscle aches and pains are very common background symptoms in middle-aged and older people. They can also be informed that in the event of any new muscle symptoms with no reason such as vigorous exercise, a simple blood test can determine whether the statin is the likely cause (if CK is >5X ULN) or far more commonly not (if CK is <3X ULN). Clinicians can also advise patients that statins are safe medicines in clinical use for nearly 30 years, and that statins as a common cause of muscle and other symptoms is a recent myth perpetuated on the Internet and elsewhere.

The nocebo minimization approach summarized here is very different from the advice of the National Lipid Association Statin Intolerance Panel, whose recommendations to patients include "About 1 in 10 people who try taking a statin will report some kind of intolerance, most commonly muscle aches in the legs, trunk, or shoulders and upper arms….".[56] This is more explicitly negative than the patient information examples provided at the beginning of this article,[2,10] which produced large nocebo effects. Patients need to know about proven serious adverse effects, as described in the *Patient Counseling* or equivalent section of the prescribing information; what other patients report is not useful.

In patients stopping their statin because of subjective AEs (such as muscle symptoms without a significant elevation of CK), rechallenge is usually successful,[33] although not necessarily with the same statin or at the same dose. Patient expectations are critical.[6] Communicating an optimistic outlook[3,9] can reverse or reduce the effect of previous negative expectations.[5] Patients need to know that intolerance is a soluble problem that responds to therapy adjustments. It is also useful to remind the patient of the proven cardiovascular benefits of statins and to explore any ambivalence about the need to take a statin. Knowing the value of a treatment reduces the nocebo effect.[9] There is some evidence[60] that the nocebo effect is attenuated if a choice of treatments is available, so it may be worth asking a patient agreeing to rechallenge, which option he or she prefers—switching to a different statin, lowering the dose of the existing statin, or just giving the statin another try at the same dose.

In summary, the nocebo effect is a well-established phenomenon that is under-appreciated in cardiovascular medicine. It is the best explanation to account for the high rate of muscle and other symptoms attributed to statins in observational studies and clinical practice, in contrast to RCTs where muscle symptoms, and rates of discontinuation due to any AE, are consistently similar in the statin and placebo groups. Statin-intolerant patients usually tolerate statins under double-blind conditions, indicating that the intolerance has little if any pharmacologic basis. Known techniques for minimizing the nocebo effect can be applied to the prevention and management of statin intolerance.

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Exhibit A40-7

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Fright factors about wind turbines and health in Ontario newspapers before and after the Green Energy Act

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Fright factors about wind turbines and health in Ontario newspapers before and after the Green Energy Act

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In this article, we analyse coverage of the health effects of wind turbines in Ontario newspapers relative to the Green Energy Act using published risk communication fright factors. Our aim was to provide insights into the health risk information presented in newspapers serving Ontario communities where wind turbines are located. We selected five geographically discontinuous wind energy installations in Ontario and their surrounding communities based on 2006 Canadian Census data. We identified the newspapers serving each community and searched for articles from May 2007 to April 2011 on wind turbine technology and human health, identifying a total of 421 articles from 13 community and 4 national/provincial newspapers. We found that most newspaper articles included the fright factor of 'dread' (94%) and well over half (58%) included the fright factor of 'poorly understood by science'. 'Involuntary exposure' and 'inequitable distribution' were fright factors occurring in somewhat fewer than half of the newspaper articles (45% and 42%, respectively). Of note was that four of the fright factors – 'dread', 'poorly understood by science', 'inequitable distribution' and 'inescapable exposure' – occurred more frequently in community newspaper articles than in national/provincial ones ($p < 0.001$). Although the total number of occurrences of each fright factor increased following the Green Energy Act, only 'dread' ($p < 0.05$) and 'poorly understood by science' ($p < 0.01$) increased significantly. We conclude that Ontario newspapers contain fright factors in articles about wind turbines and health that may produce fear, concern and anxiety for readers.

Keywords: risk communication; public health; mass media; wind turbines

Introduction

The Government of Ontario, Canada has established goals for reducing greenhouse gas emissions through the Climate Change Action Plan (MOE 2010). Part of this plan involves phasing out coal-fired power plants and supporting renewable energy technologies, such as wind, solar, hydro, biomass and biogas. The objective of this programme is to double the amount of electricity from renewable sources by 2025, positioning Ontario as one of the top energy producers in North America. By implementing the Green Energy Act in 2009, the province streamlined the approval process for many renewable energy technologies, notably wind energy installations. As a result, the number of wind turbines in Ontario increased from 10 in 2003 to almost 700 currently in place or planned (MOE 2010). The rapid and substantial increase in the number of wind turbines has caused concerns among individuals and community organisations, in part due to potential health effects.

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The health impact of wind energy installations has become a widely debated political issue in Canada (Knopper and Ollson 2011, Watson *et al.* 2012) and elsewhere (Pedersen 2011). In 2010, the Ontario Chief Medical Officer of Health concluded that the current scientific literature does not demonstrate a causal link between exposure and direct health effects (CMOH 2010). However, there are anecdotal reports which indicate a possible relationship between exposure and health effects such as dizziness, headaches and sleep disturbance (Pierpont 2009, Knopper and Ollson 2011). People living near wind turbines have reported prolonged annoyance and psychosocial stress, which may physically manifest as adverse health effects (Pedersen and Waye 2004). Media triggers, including conflicting opinions, high exposure and human interest through identification of victims, have made the potential public health risk of wind turbines a newsworthy story (Bennett 2010).

The public often gathers information relating to health consequences of environmental exposures from news reports, rather than more science-based sources such as health care practitioners (Lundgren and McMakin 2009, Riesch and Spiegelhalter 2011). However, many newspaper editors consider stories for publication in terms of economic, political or cultural relevance rather providing information about public health (Hillier 2006, McCarthy *et al.* 2008). Public perceptions of health risk can be influenced by the way the media frames and covers a risk story, especially how and what elements are reported (Rowe *et al.* 2000). Several factors including message content, tone of delivery, expert sources and information accuracy influence whether the public attends to, understands and acts on risk information (McCarthy *et al*. 2008). A diagnostic checklist of fright factors has helped to explain why some environmental health risks are more likely to trigger alarm, anxiety or outrage than others, independently of scientific estimates of their seriousness (Bennett 1999). Media stories that contain a large number of these fright factors provoke a strong public reaction (Bennett 2010). These fright factors have been shown in newspaper coverage of human papillomavirus (HPV) vaccination, avian flu, biosolids and genetically modified crops (Burke 2004, Goodman and Goodman 2006, Abdelmutti and Hoffman-Goetz 2009, Fung *et al.* 2011).

In the present study, we analysed newspaper coverage of the health effects of wind turbines in Ontario newspapers using a published typology of fright factors (Bennett 1999). Our aim was to provide insights into the public newspaper discourse about health risks from exposure to wind turbines using select Ontario communities. We chose Ontario, Canada as a case study because of recent major policy legislation on alternative energies, including wind turbines, known as the Green Energy Act. We did not evaluate the biological evidence for or against health effects of wind turbines but rather the occurrence of fright factors linked to possible health effects of wind installations.

Methods

We identified 37 wind turbine installations prior to September 2011 in Ontario using the CANWEA database (CANWEA 2011). From this list, three large and two small wind energy installations, which began operation between 2006 and 2009, were selected: large installations were Melanchton Phase II, Ontario Wind Power Farm and Prince Wind Farm with 88, 110 and 126 turbines, respectively; small installations were Dunnville Wind Turbine and Proof Line Wind Turbine with one and four turbines, respectively. We selected these turbines because they were geographically discrete, represented a diverse set of communities in Ontario and reflected differing magnitudes of installations throughout the province. Maps identifying the location of each of these wind energy developments can be found on the CANWEA database (http://www.canwea.ca/farms/index_e.php). We generated a list of communities within a 50 km radius of each installation using 2006 Canadian Census subdivisions maps. In addition, large urban centres (Toronto and Hamilton), which were located just beyond the 50 km radius, were included because of their potentially high influence on the public agenda about wind turbines and health. The approximate population of census subdivisions for Melancthon Phase II was 2,600,000 (including Toronto), for Ontario Wind Power Farm was 85,000, for Prince Wind Farm was 95,000, for Dunnville Wind Turbine was 750,000 (including Hamilton) and for Proof Line Wind Farm was 460,000. We identified the newspapers distributed in each census subdivision through the Canadian Newspaper Association database (CCNA 2011). Seventeen newspapers were included, with four considered national/provincial and thirteen considered community based on geographic reach, circulation size and frequency of publication (Table 1). The four national/provincial newspapers included the *Globe and Mail*, *National Post*, *Toronto Star* and *Hamilton Spectator*. The *Globe and Mail* and *National Post* are generally considered to be national newspaper sources because several editions are published across Canada. However, we used only 'Ontario' editions for this study. The *Toronto Star* and *Hamilton Spectator* are considered provincial newspapers, with the majority of their readership based in Toronto and Hamilton, respectively, and the remainder spread throughout neighbouring major cities.

Newspapers were searched using the LexisNexis database and individual newspaper websites from May 2007 to April 2011 (2 years before to approximately 2 years after the introduction of the Green Energy Act in May 2009). The following search terms alone and in combination were used to identify articles: (wind turbine* or wind farm* or wind energy or wind power or windmill* or green energy or renewable energy or turbine* or alternative power) and (health* or noise or vibration* or stress* or sleep* or flicker* or mood* or illness* or mental* or joint pain). Articles were excluded if they were duplicates, outside of date range, did not contain the terms 'health' and 'wind turbine' or 'wind farm' or contained 'health' not related to humans (such as economic health).

We undertook a directed content analysis to develop the coding instrument based on the fright factors that affect the public's perception of risk (Hsieh and Shannon 2005). This approach is guided by a structured process in which existing theory is used to identify key concepts or variables as coding categories. We developed operational definitions for each of the fright factors used in this study, and examples of their application to newspaper articles on wind turbines and health can be found in Table 2. We also coded articles by newspaper name, newspaper type (national/provincial, local), article date, article type (article, letter to editor, editorial/column), article main focus (human health, other) and number of references to health. We classified the main focus of an article as 'human health' if the article made a reference to health three or more times and as 'other' if human health was mentioned fewer than three times in the article. The 'other' category included topics such as the economy, politics and the environment.

One author coded all of the articles. However, to ensure reliability of data extraction, a randomly selected subset of 100 articles was coded by two independent readers, and inter-rater reliability was calculated. Cohen's kappa ranged from 0.813 to 1.00, with an average of 0.920, indicating excellent agreement for each variable. The readers/coders resolved discrepancies through discussions which informed the coding process.

We generated descriptive statistics (frequencies, means and percentages) on the fright factors mentioned in the articles (SPSS v20, SPSS Inc., Chicago, IL) and analysed differences in the frequency of fright factors across newspaper type and relative to the Green Energy Act using chi-square. We used Student's *t*-test to analyse the number of

Table 1. Summary of newspapers included in study.

Newspaper name	Category	Geographical distribution (census subdivisions)	Circulation size (Canadian Newspaper Association annual circulation for 2010)
Globe and Mail	National/ provincial	All	317,781 (daily)
Toronto Star	National/ provincial	All	292,003 (daily)
National Post	National/ provincial	All	158,250 (daily)
Hamilton Spectator	National/ provincial	All	91,716 (daily)
Orangeville Banner	Community	Melancthon, Shelburne, Southgate, Orangeville, Grey Highlands, Amaranth, Mulmur, Caledon	42,508 (twice weekly)
Orangeville Citizen	Community	Melancthon, Shelburne, Southgate, Orangeville, Grey Highlands, Amaranth, Mulmur, Caledon	14,412 (weekly)
Hanover Post	Community	Hanover, Brockton	14,868 (weekly)
Kincardine News	Community	Kincardine	2,838 (weekly)
Lucknow Sentinel	Community	Huron-Kinloss	1,412 (weekly)
The Owen Sound Sun Times	Community	Owen Sound	12,505 (daily)
Shoreline Beacon	Community	Arran-Elderslie, Saugeen Shores	3,765 (weekly)
Lakeshore Advance	Community	Lambton Shores, South Huron, North Middlesex	1,254 (weekly)
Sault Star	Community	Prince, Sault Ste. Marie, Rankin 15D, Garden River 14, Elliot Lake, Algoma	13,851 (daily)
Londoner	Community	London	145,200 (weekly)
Sarnia Observer	Community	Sarnia, Plympton-Wyoming	13,029 (daily)
Sarnia and Lambt on This Week	Community	Sarnia, Plympton-Wyoming	39,296 (weekly)
St. Catharines Standard	Community	St. Catharines	19,388 (daily)

Table 2. Diagnostic fright factors and application to wind turbine news media.

Fright factors (Bennett 1999, 2010)	Examples of application to wind turbine media coverage
Involuntary exposure	Location of wind turbine not under influence of community or nearby residents
Inequitably distributed	Wind turbines present in certain communities and absent in others
Inescapable by taking personal precautions	Unable to avoid vibration/noise/flicker unless physically distant from wind turbine
Cause hidden or irreversible damage	Some effects of low frequency vibration and noise (such as infrasound) cannot be seen or heard
Pose particular danger to small children or pregnant women	Potential effect of wind turbines on learning and behaviour of children, long-term fertility unknown
Arousing dread due to death, illness or injury	Threat of long-term illness unknown. Chronic migraines may increase risk of other health problems
Damage to identifiable victims	Specific cases of residents leaving homes within close proximity to turbine
Poorly understood by science	Lack of studies on health effects relating to wind turbine exposure
Subject to contradictory statements from responsible sources	Municipal governments/councils conflict with provincial governments (such as moratoriums)
Arises from unfamiliar or novel source	Not applicable
Result from man-made sources	Not applicable

mentions of health in each article by newspaper type and accepted. A *p*-value of <0.05 indicated that differences were not the product of chance.

We used a cluster analysis (SAS v9.2, SAS Institute Inc., Cary, NC) to identify distinct community subgroups based on demographic variables from the 2006 Canadian Census; these variables were population density, population with post-secondary education, house value and median income, which broadly reflected 'urban' and 'rural' community characteristics. The cluster technique groups communities that share similar socioeconomic and demographic characteristics. Classifying communities into various subgroups allowed us to determine whether the content of newspaper articles on wind turbines and health varied based on characteristics of the readership.

Findings

Coverage by newspaper and region

There were 421 newspaper articles retrieved from 17 newspapers. Of these, 150 articles were from 4 national/provincial newspapers and 271 articles were from 13 community newspapers. The number of newspaper articles about wind turbines and health published from each newspaper type increased substantially over time. In the national/provincial newspapers for full years of coverage, the number of articles were 13 in 2008, 52 in 2009 and 40 in 2010 ($X^2 = 22.8$, df = 2, $p < 0.001$). Also of note is that for the 4 months of data collection in 2011 (January–April), there were 34 articles on wind turbines and health appearing in the national/provincial newspapers. In the local newspapers, the number of articles on wind turbines and health also increased: 15 in 2008, 90 in 2009 and 107 in 2010 ($X^2 = 67.83$, df = 2, $p < 0.001$). For the 4-month period of January–April 2011, there were 49 articles on wind turbines and health in the local newspapers. The increase in newspaper articles over time was greater in community newspapers compared to national/provincial newspapers ($X^2 = 9.63$, df = 4, $p < 0.05$).

There were differences in news coverage based on wind energy development size. The small wind energy developments included in this study, Dunnville and Proof Line, accounted for 15% ($n = 42$) of the community newspaper coverage collected on wind turbines and health. The large wind energy developments, in contrast, contributed 85% ($n = 229$) of the community newspaper coverage on wind turbines and health.

Prevalence of fright factors

The most common fright factors linking wind turbine exposure to human health were 'dread', 'poorly understood by science', 'involuntary exposure' and 'inequitable distribution' occurring in 94% ($n = 394$), 58% ($n = 242$), 45% ($n = 188$) and 42% ($n = 177$) of articles, respectively. In the following extracts, we present illustrative examples of newspaper coverage highlighting the four most prominent fright factors.

Dread

We identified the fright factor 'dread' as a negative, loaded or fear-evoking description of health-related signs, symptoms or adverse effects of wind turbine exposure.

> Extract from *Lucknow Sentinel* (community newspaper), May 2009: In a recent interview…all made it clear that the [family's] environments had two changes occur simultaneously in November of 2007 [when the Ripley industrial wind turbine project was installed]. First there

was a change in the hydro configuration to their homes enabling electrical pollution to enter via a cross contamination from the wind turbine high voltage collection lines. The second change was the repetitive sound, both low frequency and audible from the blades of the industrial turbines that began rotating close to and above the height of their homes. Since these two changes, all began experiencing sleep deprivation, humming in the head and ears, stress, anxiety, heart palpitations, increased blood pressure, vibrations in the chest, earaches, headaches, an increased sensitivity to noise and sore eyes. It gets worse when the winds increase.

Extract from *Hanover Post* (community newspaper), Jan 2011: Stelling's comments, and a two-page letter he read to council outlining results of studies about adverse health issues resulting from the low frequency noise emitted by the turbines and suggestions that turbines have setbacks from 1 to 4.3 km from any residences, drew loud applause from those in attendance.

Poorly understood by science

We identified the fright factor 'poorly understood by science' as the need for a health study, the unknown effects or outcomes on health or the implementation of a moratorium until health effects are better studied.

Extract from *Sarnia & Lambton County this Week* (community newspaper), Oct 2008: The residents, 180 of [whom] signed a petition presented to council, are hoping the municipality will do a health study before making a decision about the project.

Extract from *Lucknow Sentinel* (community newspaper), Feb 2011: 'We haven't had the opportunity to do a lot of scientific research around the large-scale, very large-sized turbines that are generally the type most projects are installing,' Gillespie said.

Involuntary exposure

We operationalised the fright factor 'involuntary exposure' as a stated or implied statement that wind turbine placement was beyond the control of an individual or municipality, or that the Green Energy Act removed municipal rights over land development:

Extract from *Lakeshore Advance* (community newspaper), March 2009: They are just being whipped into place without due diligence, and now our Premier has decided to take out the role of the municipalities. Instead of working with them to solve issues, he is rolling over them.

Extract from *Kincardine News* (community newspaper), Aug 2010: The lakeshore community of Point Clark does not want to see this project move forward, but instead of the company demonstrating why it should be allowed to build, or recommending where the best place would be, the decisions have already been made and the public's opinion isn't a factor in determining where the turbines are erected, at all.

Inequitable distribution

We judged that the fright factor 'inequitable distribution' was present if the newspaper article mentioned (directly or indirectly) the risk of health effects from wind turbines increased with proximity or was higher in one group compared to another.

Extract from *Kincardine News* (community newspaper), Aug 2010: In the Ripley area, Lynn said 10%, or about 35 people living within the wind development area, have said they suffer as a result of proximity to the turbines.

Extract from *Lakeshore Advance* (community newspaper), Sept 2010: During a question-and-answer period, McMurtry agreed with one participant's assertion the projects are going

> up in rural Ontario, because urban residents are supporting the Green Energy Act without understanding its long-term impacts. 'Make no mistake about it. This is a targeting of rural Ontario.'

The other five fright factors occurred less frequently in the newspaper articles: 'identifiable victims' in 19% of articles (n = 80), 'inescapable' in 15% of articles (n = 64), 'contradictory statements from reliable sources' in 9% of articles (n = 39), 'damage to future generations' in 6% of articles (n = 23) and 'hidden or irreversible damage' in 3% of articles (n = 12). In the following extracts, we present illustrative examples newspaper coverage highlighting these less common fright factors linking wind turbines and human health.

Identifiable victims

We identified the fright factor 'identifiable victims' as occurring in newspaper articles if there was a reference to a named individual who was affected by wind turbines.

> Extract from *Kincardine News* (community newspaper), April 2009: 'I consider myself a green person, but there's controversy on how green (wind turbines) actually are,' said Norma Schmidt of Bruce Twp. who lives west of Underwood and came to protest because of the perceived health impacts it has had on her and her family. With wind turbines erected around her property, she and her husband Ron have experienced sleeping problems and headaches since the commissioning of the project.
>
> Extract from *the Owen Sound Sun Times* (community newspaper), July 2009: 'We can't live in our house anymore. We bought a house and moved to Kincardine. My son and daughter-in-law and two-year-old who live on a different farm... the wind company is paying for them to stay in Kincardine,' said Glen Wild, one of a half-dozen speakers at a public information session on the dangers of living too close to wind turbines.

Inescapable

We identified the fright factor 'inescapable' if a newspaper article stated that an individual or family was unable to modify their exposure to the health risk or were forced to leave their home.

> Extract from the *Londoner* (community newspaper), Dec 2010: As more wind farms are built, more stories are emerging of farmers having to leave their homes because of health issues attributed to wind turbines.
>
> Extract from *Toronto Star* (national/provincial newspaper), Jan 2011: Too many Ontario families have already been made ill and forced to flee from their homes as a result of hastily developed wind energy projects with inadequate setbacks.

Contradictory statements

We identified the fright factor 'contradictory statements' as occurring in newspaper articles which emphasised that experts (such as medical health officers and government officials) were on opposite sides of the issue.

> Extract from *Globe and Mail* (national/provincial newspaper), Jan 2011: To support his client's case in court, Mr. Gillespie will present evidence from three physicians who say turbine noise and vibration can cause high stress, sleep deprivation and headaches among people who live near them. The government argues, in a document filed with the court, that

the doctors' conclusions are suspect, and that it reviewed all the literature available on the issue, and held public consultations before creating the guidelines.

Extract from *Toronto Star* (national/provincial newspaper), Jan 2011: Their case was bolstered last May after the provincial medical officer of health, Dr. Arlene King, issued a report saying no scientific evidence exists to show that wind turbines harm human health. (Dr.) McMurtry countered that this is because no one has ever conducted a proper study - which is why he wants one.

Damage to future generations

Newspaper articles that contained the fright factor 'damage to future generations' had statements which identified the health of pregnant women, infants, children or teenagers as being adversely influenced by wind turbine exposure.

Extract from *Lucknow Sentinel* (community newspaper), May 2009: 'We have taken three-year-old Keiara to the emergency room 10 times with problems and Dr. McMurtry said my daughter shouldn't be there (at their home in the Ripley Wind Project). Melissa as well because she is pregnant,' said Kent Wylds.

Extract from *Toronto Star* (national/provincial newspaper), April 2010: They claim the turbines cause low-frequency noise and have sickened 106 Ontario residents, causing a variety of health ailments ranging from hypertension to sleeplessness and nosebleeds in children.

Hidden or irreversible damage

We recognised the fright factor 'hidden or irreversible damage' as being present in newspaper articles which stated that individuals did not know the source of their symptoms or that exposure to wind turbines may result in lasting health effects.

Extract from *Lucknow Sentinel* (community newspaper), June 2009: Krogh compared the situation to discovering the harmful effects of tobacco adding that there is no long-term investigation into the effects of wind turbines in 10 to 20 years.

Extract from *Kincardine News* (community newspaper), Feb 2011: Remember thalidomide and second-hand smoke, both perceived as acceptable at one time until science proved otherwise. Unfortunately this approach is being taken again with the blind acceptance of wind farms in close proximity to humans.

The fright factors of 'dread', 'poorly understood by science', 'inequitable distribution' and 'inescapable' occurred more frequently in community newspapers than in national/provincial ones ($X^2 = 12.11$, df = 1, $p < 0.001$; $X^2 = 36.19$, df = 1, $p < 0.001$; $X^2 = 15.45$, df = 1, $p < 0.001$; $X^2 = 17.61$, df = 1, $p < 0.001$, respectively). National/provincial and community differences in the occurrence of the four most common fright factors are shown in Figure 1. The remaining, less prevalent fright factors are shown in Figure 2. Article focus (human health vs. other) differed between newspapers, with community newspapers focused more on human health than national/provincial newspapers ($X^2 = 36.193$, df = 1, $p < 0.001$). There was an average of 5.01 ± 3.9 (SD) mentions of health per article from community newspapers and 2.53 ± 2.4 (SD) mentions per article from national/provincial newspapers ($t = 8.0$, df = 416, $p < 0.001$).

Influence of the Green Energy Act

The number of occurrences of each fright factor increased after the Green Energy Act, with dread and poorly understood by science increasing significantly ($X^2 = 4.76$, df = 1,

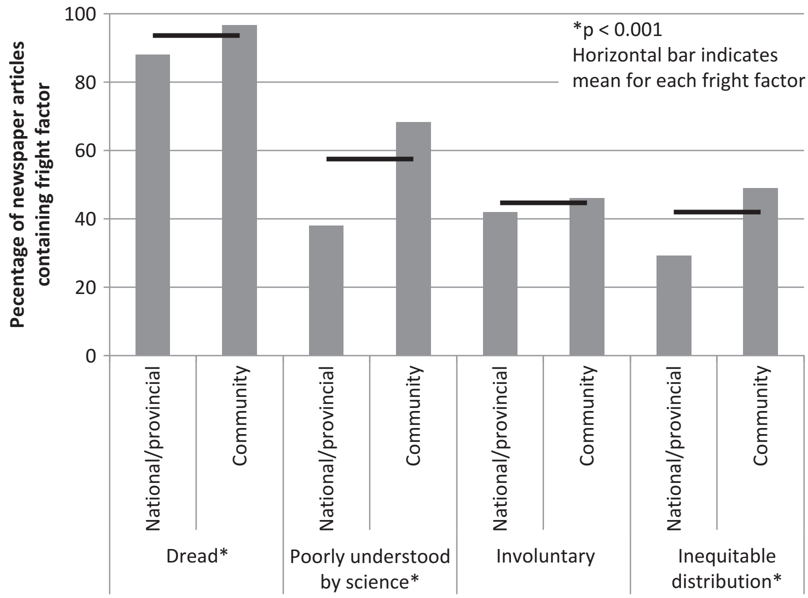

Figure 1. Presence of most commonly mentioned fright factors in Ontario newspaper articles.

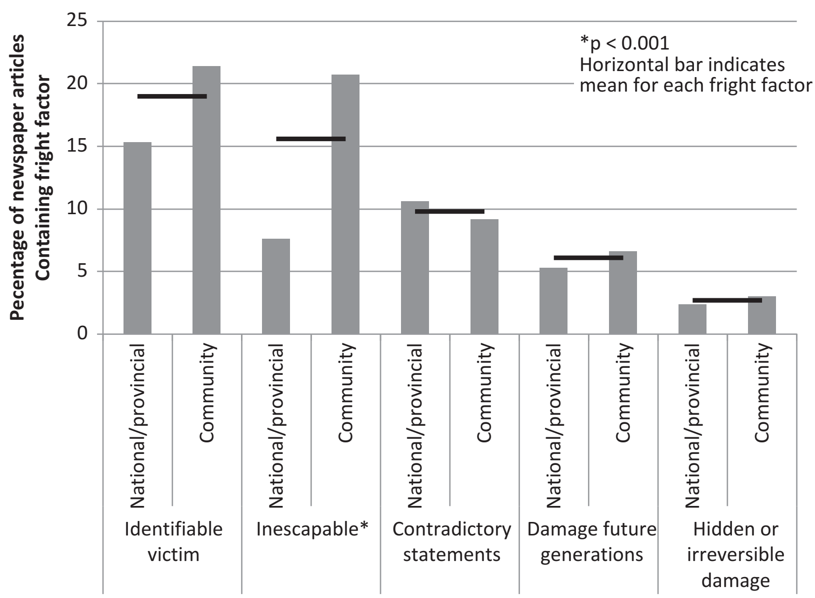

Figure 2. Presence of less commonly mentioned fright factors in Ontario newspapers articles.

p < 0.05 and X^2 = 7.66, df = 1, p < 0.01, respectively). The fright factor identifiable victims occurred less often after the Green Energy Act (X^2 = 25.35, df = 1, p < 0.001) (Table 3). Both community and national/provincial newspapers were more likely to focus on human health following compared to before the Green Energy Act (X^2 = 19.36, df = 1, p < 0.001).

Table 3. Presence of fright factors before vs. after the Green Energy Act in Ontario.

Fright factor	Before Green Energy Act (total number of articles = 99)		Following Green Energy Act (Total number of articles = 322)		Chi-square	p-value
	Number of articles with fright factor	Percentage of articles with fright factor	Number of articles with fright factor	Percentage of articles with fright factor		
Arousing dread	88	88.9	306	95.0	4.759	0.029
Poorly understood by science	45	45.5	197	61.2	7.662	0.006
Involuntary exposure	46	46.5	142	44.1	0.171	0.679
Inequitable distribution	38	38.4	139	43.2	0.711	0.399
Identifiable victim	36	36.4	44	13.7	25.348	0.001
Inescapable	14	14.1	50	15.5	0.113	0.737
Contradictory statements	8	8.1	31	9.6	0.215	0.643
Damage to future generations	8	8.1	15	4.7	1.717	0.190
Hidden or irreversible damage	2	2.0	10	3.1	0.322	0.570

Cluster analysis

To explore whether community characteristics influenced the occurrence of fright factors in newspaper articles about wind turbines and health, we conducted a cluster analysis based on demographic census characteristics. Three subgroups were identified: Cluster 1 characteristics included communities with higher population density (>400 persons/km^2), education levels above the provincial mean, average house values between $300,000 and $400,000 and a median income of $61,000; examples of communities in Cluster 1 included Toronto, Hamilton, Sarnia, Orangeville and Kincardine. Cluster 2 included communities with a lower population density (<400 persons/km^2), education levels below the provincial average, average house values between $100,000 and $200,000 and a median income of $30,000. Examples of communities in Cluster 2 included Hanover, Owen Sound, Arran-Elderslie, Elliot Lake and Algoma. Together, these two clusters accounted for almost 60% of the variation in demographic characteristics of census subdivisions. A third cluster capturing four communities did not have a distinct census profile, explained only 20% of the variation in demographic characteristics and was excluded from further analysis. Within the two clusters, we identified the community newspaper with the largest number of articles and compared these for type and prevalence of fright factors. The representative community newspaper for Cluster 1 was the *Kincardine News* (n = 53), and the representative community newspaper for Cluster 2 was *the Owen Sound Sun Times* (n = 72).

None of the fright factors occurred significantly more often in the representative community newspapers as a function of the community cluster characteristics. However, ‘involuntary exposure’ tended to be mentioned more often in articles from Cluster 2 (n = 34) compared with Cluster 1 (n = 16) ($X^2 = 3.69$, df = 1, $p = 0.055$). With respect to timing relative to the Green Energy Act, newspaper articles from Cluster 2 had a significantly greater number of occurrences of the fright factor ‘involuntary exposure’ after vs. before the Green Energy Act (n = 30 vs. n = 4) ($X^2 = 5.26$, df = 1, $p < 0.05$). In the following extracts, we present illustrative examples newspaper coverage highlighting ‘involuntary exposure’ in Cluster 2 both before and after the Green Energy Act.

Before the Green Energy Act

> Extract from *the Owen Sound Sun Times*, March 2009: The primary issues of concern for Grey Highlands are that the act will remove local planning control over renewable energy projects as well as concerns over health issues and loss of property values.
>
> Extract from *the Owen Sound Sun Times*, April 2009: Protesters questioned how much wind generation is actually reducing greenhouse gas emissions and raised concerns about the visual impact on the landscape and the loss of local control over projects if the provincial Green Energy Act is made law.

After the Green Energy Act

> Extract from *the Owen Sound Sun Times*, Oct 2009: Municipalities with projects in their areas know, firsthand, how much trouble they are. When they tried to stop existing projects from expanding, they were taken to the Ontario Municipal Board where they were told they had to allow turbines because the provincial government said so.
>
> Extract from *the Owen Sound Sun Times*, March 2011: The minister addressed concerns raised by critics of the government’s renewable energy policies contained in the Green Energy and Green Economy Act which takes away planning approval powers by local and county councils and replaces it with a poorly-defined consultation process.

Discussion

A content analysis of newspaper media is a convenient, low-cost and non-intrusive technique used to build understanding of how the public interprets health risk when risk perception surveys are not available (Driedger 2007, Mistry and Driedger 2012). In the study on which this article is based, we used systematic counting and recording to produce a quantitative description of fright factor content on wind turbines and health in Ontario newspaper articles relative to a major policy initiative. To our knowledge, no previous media analysis has documented the issue of wind turbines and health. The study of these results may help to fill gaps in the literature regarding newspaper media framing of wind energy and health.

Of the fright factors associated with environmental risks and human health (Bennett 1999), we found the most commonly reported were 'dread', 'poorly understood by science', 'involuntary exposure' and 'inequitable distribution'. The high number of citations for 'dread' and 'poorly understood by science', which we identified, is consistent with the literature on perceived risk associated with other technologies – electromagnetic fields (EMFs), power lines, cell phone radiofrequencies and cell phone base towers (Slovic 2000, Frick *et al.* 2002, Cousin and Siegrist 2011, Khiefets *et al.* 2010). The rapid rate of change in many technological sectors has made it difficult to characterise and study exposures prospectively, resulting in a knowledge deficit in both scientific and lay communities (Slovic 1987). The combination of dread and unknown consequences, when associated with technology, may lead to greater risk perceptions and result in stigmatisation and avoidance (Finucane *et al.* 2000). This effect may be exaggerated when coupled with frequent and dramatic news media coverage.

Local conditions, and their consequences, are experienced more directly by local media than national media (Viswanath *et al.* 2008). Therefore, our finding that both fright factors of 'dread' and 'poorly understood by science' were identified more frequently in community compared with national/provincial newspaper articles is not surprising. The audience for community newspapers generally have closer ties with local reporters, and expect information that affects their daily quality of life (Kaniss 1991). Subscribers to community newspapers are more likely to be local residents who live in a closer proximity to wind turbines. Thus, there may be an association between how often the fright factors 'dread' and 'poorly understood by science' were mentioned in the articles and the physical proximity of community residents to the actual wind energy installations; these fright factors were increasingly likely to occur in newspaper articles when the risk of exposure to wind turbines was greater. This potential relationship between locality of wind turbines, resident responses and public media discourse is an area for future research.

The fright factors of 'involuntary exposure' and 'inequitable distribution' were present in about half of the articles, with community newspapers emphasising inequitable distribution more often than national/provincial newspapers. This finding may reflect wind turbine locations in rural areas where community newspapers feature prominently. National/provincial newspapers, in contrast, are generally published in cities more distant from wind energy installations. Therefore, residents of rural areas might have a higher exposure than urban populations to the potential health risk of wind turbines. This represents an inequitable distribution of risk and may enhance and reinforce perceived risk among Ontario residents located near wind energy developments. Whether the perception of inequitable risk by local residents parallels the occurrence of this fright factor in the community newspaper reports remains to be determined.

A major function of the Green Energy Act was to streamline the approval process for wind energy installations in Ontario. This removed the ability of municipal governments to control the location of renewable energy sources in their communities. We expected to see an increase in the reporting of the fright factors 'involuntary exposure' and 'inequitable distribution'. However, only 'dread' and 'poorly understood by science' were reported more often after the Green Energy Act. Although our data do not indicate why the newspaper reporting of the fright factor 'poorly understood by science' increased after the Green Energy Act, this may reflect public dissatisfaction with the level of scientific evidence regarding wind turbines and potential health effects. Of note is that public calls for scientific study have been successful in altering behaviours towards other environmental and technological health risks, such as cell phones on airplanes, pesticides in schools and polyvinyl chloride children's toys (Kriebel *et al.* 2001). We also found a decreased prevalence in newspaper articles of the fright factor 'identifiable victims', following the Green Energy Act. The drop in the occurrence of this fright factor may be due to a greater collective voice and mobilisation of community groups, rather than concerns expressed by individuals. For example, the largest wind turbine opposition group in Ontario was established in late 2008 and has since grown to about 60 grass-root organisations (WCO 2011).

We used cluster analysis to study geographic variations in public health (Pedigo *et al.* 2011). Our intention was to contrast the prevalence of fright factors in newspaper articles in different communities. Following the Green Energy Act and extrapolating from a representative newspaper in each cluster with the greatest number of articles, Cluster 2 ('rural communities') had more articles linked to the fright factor of 'involuntary exposure' than did Cluster 1 ('urban communities'). The excerpts from the representative Cluster 2 newspaper showed that 'involuntary exposure' almost exclusively refers to the loss of municipal control over the placement of wind energy developments after the implementation of the Green Energy Act. Residents of rural communities may also feel disproportionately affected by legislation that removes municipal control, leading to feelings of powerlessness and a decreased ability to regain this control compared with urban communities.

The significant increase in news articles on wind turbines and potential health effects over time suggests that this topic is newsworthy. An increase in news coverage of an issue can result in audience negativism independent of the nature of the risk itself, and repeated public reactions to media can itself induce health consequences (Mazur and Lee 1993, Young *et al.* 2008). This is especially true of public exposure to new health information, which has been shown to increase health concerns for up to 2 weeks after the receipt of the information (Cousin and Siegrist 2011). Alternatively, an increase in newspaper coverage of an issue can lead to positive health behaviours, such as reporting on the H1N1 outbreak and increased demand for diagnostic testing (Olowokure *et al.* 2012). The increased frequency of newspaper coverage that focuses on human health reflects not only greater public discourse about health effects of wind turbines but a growing influence of the media in this debate.

The study on which this article is based had limitations. Our results and conclusions were restricted to a select number of Ontario newspapers, a handful of wind energy installations in the province, and did not reflect risk information presented in other important media outlets such as television or the internet. Newspaper articles were also retrieved through an online database, and manually searching newspaper websites and archives, which could potentially have biased their collection. The search string used to collect articles from the online database included terms such as illness and stress, which may have biased our results to overrepresent negative news articles. However, the inclusion of these terms was necessary to capture the complete public discourse on health effects of wind turbines for the time period studied. A potential bias in this study is that more than half of the newspapers were owned by a single publisher. Although there is a variety of evidence to suggest that collective media ownership does not result in concentration of media content (Soroka 2002), there was still the possibility that newspaper coverage might reflect specific editorial agendas and selection bias rather than community concerns. We excluded duplicate articles from our analysis, which eliminated the potential syndication of stories across newspapers from the same publisher. Moreover, although each newspaper included in the study was publically available, they were generally sold individually or by subscription. Only those residents with the financial ability to purchase newspapers would have consistent exposure to fright factors embedded within news articles. We also recognise that there is the potential to miss relevant themes in the public discourse about wind turbines and health in Ontario because of the closed coding methods used. Although outside of the scope of this study, a qualitative analysis of these newspaper articles may identify several important emergent themes and contribute to building theory for future risk perception research. For example, the theme of political lobbying may be identified in a preliminary reading of the text, and further examined to reveal subthemes (Crabtree and Miller 1999).

Conclusion

Ontario newspaper articles on wind turbines and health contained a large number of fright factors, especially ‘dread’ and ‘poorly understood by science’, which both increased in frequency after the introduction of a major policy initiative and occurred more often in community relative to national/provincial newspapers. The information presented in mass media can affect public opinion related to wind turbines and influence the acceptance or resistance to renewable energy technology programmes in Ontario and potentially elsewhere (Dearing and Rogers 1996). Newspapers reporting of health concerns have widespread influence on the uptake of health campaigns, such as the HPV vaccination programme (Abdelmutti and Hoffman-Goetz 2009) and on consumer behaviours, such as purchasing genetically modified foods (Frewer *et al.* 2002). Findings from this content analysis represent a first step in documenting possible effects of newspaper reporting on the issue of wind turbines and health effects on individual, social or cultural norms (Riffe *et al.* 1998). Similar quantitative content analyses have contributed to understanding the public discourse about health risks in Canadian newspapers (Rachul *et al.* 2011, Holton *et al.* 2012). We suggest that other methodological approaches (for example, surveys or interviews) will be necessary to make inferences and predications about the effects of exposure to fright factors in the media on public perceptions on health risks from wind turbines.

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The Pattern of Complaints about Australian Wind Farms Does Not Match the Establishment and Distribution of Turbines: Support for the Psychogenic, 'Communicated Disease' Hypothesis

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Abstract

Background and Objectives: With often florid allegations about health problems arising from wind turbine exposure now widespread, nocebo effects potentially confound any future investigation of turbine health impact. Historical audits of health complaints are therefore important. We test 4 hypotheses relevant to psychogenic explanations of the variable timing and distribution of health and noise complaints about wind farms in Australia.

Setting: All Australian wind farms (51 with 1634 turbines) operating 1993–2012.

Methods: Records of complaints about noise or health from residents living near 51 Australian wind farms were obtained from all wind farm companies, and corroborated with complaints in submissions to 3 government public enquiries and news media records and court affidavits. These are expressed as proportions of estimated populations residing within 5 km of wind farms.

Results: There are large historical and geographical variations in wind farm complaints. 33/51 (64.7%) of Australian wind farms including 18/34 (52.9%) with turbine size >1 MW have never been subject to noise or health complaints. These 33 farms have an estimated 21,633 residents within 5 km and have operated complaint-free for a cumulative 267 years. Western Australia and Tasmania have seen no complaints. 129 individuals across Australia (1 in 254 residents) appear to have ever complained, with 94 (73%) being residents near 6 wind farms targeted by anti wind farm groups. The large majority 116/129(90%) of complainants made their first complaint after 2009 when anti wind farm groups began to add health concerns to their wider opposition. In the preceding years, health or noise complaints were rare despite large and small-turbine wind farms having operated for many years.

Conclusions: The reported historical and geographical variations in complaints are consistent with psychogenic hypotheses that expressed health problems are "communicated diseases" with nocebo effects likely to play an important role in the aetiology of complaints.

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Introduction

The attribution of symptoms and disease to wind turbine exposure is a contentious "modern health worry" [1] which has seen increasing attention from governments, their regulatory agencies and courts after organised opposition to wind farms, predominantly in Anglophone nations. Two broad hypotheses have been advanced about those reporting symptoms they attribute to exposure to wind turbines.

1. both audible noise and sub-audible infrasound generated by wind turbines can be directly harmful to the health of those exposed.
2. psychogenic factors – including nocebo responses to the circulation of negative information about their putative harms – are likely to be relevant to understanding why of those exposed, only small proportions claim to be adversely affected.

The evidence for a physical basis for these symptoms remains largely anecdotal. There has been a profusion of claims mostly by wind farm opponents about harms to exposed humans and animals (currently numbering 223 different diseases and symptoms) [2]. Despite this, 18 reviews of the research literature on wind turbines and health published since 2003 [3–20] have all reached the broad conclusion that the evidence for wind turbines being directly harmful to health is very poor. These suggest that only small minorities of exposed people claim to be annoyed by wind turbines – typically less than 10% [14]. They conclude that the relationship between wind turbines and human responses is "influenced by numerous variables, the majority of which are non-physical" [14].

Variables associated with wind turbine annoyance include pre-existing negative attitudes to wind farms [14], including their impact on landscape aesthetics [21], having a "negative personality" [22], subjective sensitivity to noise [14], and being able to see wind turbines [5,23]. Similarly, deriving income from turbines [24] or enjoying reduced power bills can have an apparent "protective effect" against annoyance and health symptoms [18]. Such factors, which are similar to characteristics of other psychogenic illnesses ("New Environmental Illnesses" [25] and "Modern Health Worries" [26]) were found to be more predictive of symptoms than objective measures of actual exposure to sound or infrasound [14].

A large literature on nocebo effects exists about reported pain [27], but these effects have also been documented for other imperceptible agents such as electro-magnetic and radio frequency radiation [28–30]. Perceived proximity to mobile telephone base stations and powerlines, lower perceived control and increased avoidance (coping) behaviour were associated with non-specific physical symptoms in a study which found no association between reported symptoms and distance to these sources of electromagnetic radiation [31].

The psychogenic theory about wind turbine "illness" is supported by a recent New Zealand study [32], in which healthy volunteers exposed to both sham and true recorded infrasound who had been previously given information about possible adverse physiological effects of infrasound exposure reported symptoms aligned with that information. The adverse effects information provided to subjects was sourced from anti wind farm internet sites which the authors concluded indicated "the potential for symptom expectations to be created outside of the laboratory, in real world settings."

A psychogenic contagion model may be applicable to this phenomenon. Mass Psychogenic Illness (MPI) is described [33–35] as a constellation of somatic symptoms, suggestive of an environmental cause or trigger (but with symptoms without typical features of the contaminant, varying between individuals, and not related to proximity or strength of exposure) which occurs between two or more people who share beliefs related to those symptoms and experience epidemic spread of symptoms between socially connected individuals. The rapid development of fear and anxiety is key to the transmission of disease by disruption of behaviour and activities of those involved. Transmission or contagion is increased by the general excitement related to the phenomenon, including media reports, researcher interest, and labeling with a specific clinical diagnostic term.

Boss' review of factors promoting mass hysteria noted that "media reports are used as cues by potential cases for appropriate illness behavior responses and can initially alarm those at risk …Too often, it is the media-created event to which people respond rather than the objective situation itself … Development of new approaches in mass communication, most recently the Internet, increase the ability to enhance outbreaks through communication." [33].

While modern wind farms have operated since the early 1980s [36], the earliest claims alleging that wind turbines might cause health problems in those exposed appear to date from 2003 (see below); this increased rapidly after 2008, following publicity given to a self-published book, "Wind Turbine Syndrome" [37], by US physician Nina Pierpont, whose partner edits a virulent anti wind farm website [38]. Google Trends data of web-based searches for "Wind turbine noise", "Wind Turbine Syndrome" and "wind turbine health" show that "noise" began to appear from 2007 and that "syndrome" and "health" began to track together from 2008, suggesting the book generated this sudden interest in the phenomenon, rather than riding a wave of interest. Furthermore, a 2007–11 Ontario study of newspaper coverage of wind farms showed that 94% of articles featured "dread" themes [39].

"Labeling" of an illness is one of the key features associated with spread of mass psychogenic illness, along with community and media interest [33]. There have been three attempts to popularise portentous quasi-scientific names for health problems said to be caused by wind turbines: Wind Turbine Syndrome, Vibro Acoustic Disease [40] and Visceral Vibratory Vestibular Disturbance [41], although none of these have gained scientific acceptance as diagnostic terms. As described earlier, many features of MPI apply to Wind Turbine Syndrome. Furthermore, the most reported symptoms in over one third of all MPIs of nausea/vomiting, headache, and dizziness [33], are also frequently featured as common symptom complaints arising with wind turbines, suggesting these symptoms may be plausibly explained as psychogenic.

Wind farm opponent groups have been very active in the last five years in three Australian states (Victoria, NSW and South Australia) publicising the alleged health impacts of turbines. This has created insurmountable problems for researching the psychogenic and nocebo hypotheses using either cross-sectional or prospective research designs because it is unlikely that any communities near wind farms now exist which have not been exposed to extensive negative information. For this reason, audits of the history of complaints are essential because they allow consideration of whether health and noise complaints arose during years prior to the "contagion" of communities with fearful messages about turbines.

To date, there has been no study of the history and distribution of noise and health complaints about wind turbines in Australia. The two theories (the "direct effects" and the "psychogenic"), would predict differing patterns of spatial and temporal spread of disease. We sought to test 4 hypotheses relevant to the psychogenic argument.

1. Many wind farms of comparable power would have no history of health or noise complaints from nearby residents (suggesting that exogenous factors to the turbines may explain the presence or absence of complaints).
2. Wind farms which have been subject to complaints would have only a small number of such complaining residents among those living near the farms (suggesting that individual or social factors may be required to explain different "susceptibility").
3. Few wind farms would have any history of complaints consistent with claims that turbines cause acute health problems (suggesting that explanations beyond turbines themselves are needed to explain why acute problems are reported).
4. Most health and noise complaints would date from after the advent of anti wind farm groups beginning to foment concerns about health (from around 2009) and that wind farms subject to organised opposition would be more likely to have histories of complaint than those not exposed to such opposition (suggesting that health concerns may reflect "communicated" anxieties).

Table 1 sets out both the predictions of the "direct effects" model of causation, and the observed findings of our historical

Table 1. Prediction of "direct effects" model versus observations explained by psychogenic model.

Key hypotheses re distribution of complainants	Characteristic	Predictions of Direct Effects Model	Observations with Psychogenic Model
Spatial (geographic)	Distribution of wind farms with complaints	All wind farms (especially those with >1 MB turbines) should have complainants	Inconsistent distribution associated with presence or absence of anti wind farm activity
	Proportion of complainants residing around wind farms	Only in those "susceptible" but should be similar across all wind farms	Generally very low, but higher at wind farms targeted by anti wind farm groups
Temporal	Timing and latency of first complaints	Turbine exposure followed by both acute (immediate) and chronic health effects	Absence of or long delays in reporting acute effects common

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review of the distribution and timing of complaints, which are more consistent with a psychogenic model.

Methods

Information on the commencement of turbine operation, the number of turbines operating, average turbine size and the megawatt (MW) capacity of each wind farm was located from public sources such as wind farm websites.

Wind farm operators have clear risk management interest in any reactions of nearby residents to the farms they operate. In the planning, construction and power generation phases of wind farm operation they monitor local community support and complaints submitted to them, in news media and via any complaint notifications from local government. In Victoria, companies are required by law to register all complaints with the state government. In September 2012 all wind farm owners in Australia were asked to provide information on:

- the actual or estimated number of residents within a 5 km radius of each wind farm they operated. Google Maps and census data were also used to obtain this data (see below).
- whether the company had received or was aware of any health and/or noise complaints, including sleeping problems, that were being attributed to the operation of their wind farms.
- the number of individuals ("complainants") who had made such complaints (direct complaints to the companies, those voiced in local media, to local government or state or national enquiries).
- the date at which the first complaint occurred.
- whether there had been any anti wind farm activity in the local area such as public meetings addressed by opponents, demonstrations or advertising in local media.

Any documentation of complaints such as internet links or news clips about public was requested. Companies were explicitly asked to de-identify any private complaints which could identify those complaining, unless these complaints had been made public by the complainants.

It is possible that wind companies may nonetheless be unaware of some health and noise complaints about their operations or that they might downplay the extent of complaints and provide underestimates of such complaints. To corroborate the information on the number of complainants provided by the companies, we therefore reviewed all 1,594 submissions made to three government enquiries on wind farms: the 2011–2012 Senate enquiry into the Social and Economic Impact of Rural Wind Farms (1,818 submissions) [42]; the 2012 NSW Government's Draft NSW Planning Guidelines for Wind Farms (359 submissions) [43]; and the Renewable Energy (Electricity) Amendment (Excessive Noise from Wind Farms) Bill 2012 (217 submissions) [44]. We searched all submissions for any mentions by residents living in the vicinity of operating wind farms (as opposed to those being planned) of their health or sleep being adversely affected or that they were annoyed by the sound of the turbines.

We also searched daily media monitoring records supplied to the Clean Energy Council by a commercial monitoring company from August 2011 (when the monitoring contract began) until January 2013. This monitoring covered print news items, commentary and letters published in Australian national, state and regional newspapers mentioning any wind farm, as well as television and radio summaries about all mentions of wind farms. It was important to use this source of monitoring rather than use on-line databases like Factiva, as the latter do not cover all small rural news media which is where much coverage of debate about rural wind farms was likely to be found.

Finally, a pre-print of this paper was published on the University of Sydney's e-scholarship repository on March 15 2013. In the next six months the paper was opened over 10,800 times, making it the most opened document among 7761 in that repository across these 4 months. This generated considerable correspondence, and in one case (Hallett 2), information was provided about extra complainants who had complained via a legal case. These were then included.

In reviewing the submissions and media monitoring, only complaints from those claiming to be personally affected by the operation of an existing wind farm in Australia were noted. Expressed concerns about possible future adverse effects or that wind turbines *could* be harmful were not classified as evidence of personal experience of harm or annoyance. There were many of these. Third party statements, such as comments about unnamed neighbours with problems, were not accepted as evidence of harm.

Where the numbers of complainants determined from this corroborative public source searching exceeded the numbers provided to us by the wind companies, we chose the larger number. Where the numbers determined from public sources were less, we used the larger number provided by the companies. Our estimate of the number of complainants thus errs on the least conservative side. Nearly all those who publicly complained did not seek anonymity, being named in media reports or not electing to have their parliamentary submissions de-identified. However, we have chosen not to list their names in this report.

The companies provided estimates of the number of residents currently living within 5 km of each wind farm. Some companies

Table 2. Complainant numbers at 51 Australian wind farms, 1993–2013.

Wind farm name (state) *owner*	Installed Capacity (MW)+(number of turbines)+average turbine size MW	Date commenced operation & total years (to Dec 2012)	Approx. population within 5 km	Health or noise complainants (Y/N) & number (persons unless specified)	Date of first complaint (months since opened)	Local or visiting opposition group activity?
A: Farms with total >10 MW capacity						
Albany/Grasmere (WA) *Verve*	35.4 (18) 1.96	Oct 2001 (11y 2m)	200	N	–	N
Bungendore/Capital/ Woodlawn (NSW) *Infigen*	189 (90) 2.1	Nov 2009 (3y 1m)	76 houses 198	Y:10	Dec 2009 (1 m)	Y
Canunda (SA) *International Power*	46 (23) 2.0	Mar 2005 (7y 10m)	20 houses 52	N	–	N
Cape Bridgewater (Vic) *Pacific Hydro*	58 (29) 2.0	Nov 2008 (4y 1m)	68 houses 177	Y:6	2 Feb 20110 (16m)	Y
Cape Nelson South (Vic) *Pacific Hydro*	44 (22) 2.0	Jun 2009 (3y 6m)	170 houses 425	Y:2	10 Feb 2010 (8m)	Y
Cathedral Rocks (SA) *TRUenergy, Acciona & EHN*	66 (33) 2.0	Sep 2005 (7 y 3 m)	0	N	–	N
Challicum Hills (Vic) *Pacific Hydro*	52.5 (35) 1.5	Aug 2003 (9 y 4 m)	55 houses 143	N	–	N
Clements Gap (SA) *Pacific Hydro*	56.7 (27) 2.1	Feb 2010 (2 y 10 m)	41	Y:3	On-going from earlier	Y
Codrington (Vic) *Pacific Hydro*	18.2 (14) 1.3	Jun 2001 (11 y 6 m)	50	N		N
Collgar/Merriden (WA) *Collgar*	206 (111) 1.85	May 2011 (1 y 7 m)	15	N	–	N
Cullerin Range (NSW) *Origin*	30 (15) 2.0	Jul 2009 (3 y 5 m)	50	N	–	N
Emu Downs (WA) *APA*	80 (48) 1.66	Oct 2006 (6 y 2 m)	50	N	–	N
Gunning/Walwa (NSW) *Acciona*	46.5 (31) 1.5	May 2011 (1 yr 7 m)	25 houses 65	Y:1	Jan 2012 (8 m)	N
Hallett 1/Brown Hill (SA) *AGL*	95 (45) 2.11	Sep 2008 (4 y 3 m)	120	N		Y
Hallett 2/Hallett Hill (SA) *AGL*	71.4 (34) 2.1	Mar 2010 (2 y 9 m)	120	Y:13*	On-going from earlier	Y
Hallett 4/North Brown Hill (SA) *AGL*	132 (63) 2.1	May 2011 (1 y 7 m)	200	Y:1	On-going from earlier	Y
Hallett 5/Bluff Range (SA) *AGL*	53 (25) 2.1	Mar 2012 (9 m)	140	Y:1	Apr 2012 (1 m)	Y
Lake Bonney (SA) *Infigen*	278.5 (112) 2.8	Mar 2005 (7 y 9 m)	255	Y:2	June 2012 (7 y 3 m)	N
MacArthur (Vic) *AGL/ Meridian*	420 (140) 3.0	Sep 2012 (3 m)	15	Y:8 houses = 21	2 days after 2/140 turbines commenced operation	Y
Mortons Lane (Vic) *CGN Wind Energy Ltd*	19.5 (13) 1.5	Dec 2012	14 houses 36	N	–	N
Mt Millar (SA) *Meridian*	70 (35) 2.0	Feb 2006 (6 y 10 m)	10 houses 26	N	–	N
Oaklands Hill (Vic) *AGL*	67.2 (32) 2.1	Feb 2012 (10 m)	250	Y:6	On-going from earlier	Y
Snowtown (SA) *Trust Power*	100.8 (47) 2.14	Nov 2008 (4 y 1 m)	4 houses 10	N	–	N
Starfish Hill (SA) *Ratch*	34.5 (23) 1.5	Sep 2003 (9 y 3 m)	200	N	–	N
Toora (Vic) *Ratch*	21 (12) 1.75	Jul 2002 (10 y 5 m)	674	Y:2	Early (precise date not known)	Y
Walkaway (Alinta) (WA) *Infigen*	89.1 (54) 1.65	Apr 2006 (6 y 8 m)	3 houses 8	N	–	N

Table 2. Cont.

Wind farm name (state) *owner*	Installed Capacity (MW)+(number of turbines)+average turbine size MW	Date commenced operation & total years (to Dec 2012)	Approx. population within 5 km	Health or noise complainants (Y/N) & number (persons unless specified)	Date of first complaint (months since opened)	Local or visiting opposition group activity?
Waterloo (SA) *TRUenergy*	111 (37) 3.0	Dec 201 (2 y)	75 houses 195	Y:11	Feb 2011 (2 m)	Y
Wattle Point (SA) *AGL Hydro*	91 (55) 1.65	Nov 2005 (7 y 1 m)	560	N	–	N
aubra (Vic) *Acciona*	192 (128) 1.5	Mar 2009 (3 y 10 m)	283 houses 736	Y:29	13 Mar 2009 (immediate)	Y
Windy Hill (Qld) *Ratch*	12 (20) 0.6	Feb 2000 (12 y 10 m)	200	Y:1	Early (precise date not known)	N
Wonthaggi (Vic) *Transfield*	12 (6) 2.0	Dec 2005 (7 y)	6900	Y:~10	Feb 2006 (2 m)	Y
Woolnorth:Bluff Point (Tas) *Roaring 40 s & Hydro Tas.*	65 (37) 1.76	Aug 2002 (10 y 4 m)	NI	N	–	N
Woolnorth:Studland Bay (Tas) *Roaring 40 s & Hydro Tas.*	75 (25) 3.0	May 2007 (5 yr 7 m)	NI	N	–	N
34.Yambuk (Vic) *Pacific Hydro*	192 (128) 1.5	Jan 2007 (5 y 11 m)	88	N	–	N
Sub-total: 34 farms	3130.3 MW (1567 turbines)		12334	16 farms with 119 complainants		14
B: Farms with <10 MW capacity						
Blayney (NSW) *Eraring Energy*	9.9 (15) 0.66	Oct 2000 (12 y 2 m)	37	N	–	N
Bremer Bay (WA) *Verve*	0.6 (1) 0.6	Jun 2005 (7 y 6 m)	250	N	–	N
Coober Pedy (SA) *Energy Generation*	0.15 (1) 0.15	1999 (13 y)	3500	N	–	N
Coral Bay (WA) *Verve*	0.825 (3) 0.275	Oct 2006 (6 y 2 m)	200	N	–	N
Crookwell (NSW) *Union Fenosa/Eraring*	4.8 (8) 0.6	Jul 1998 (14 y 5 m)	200	Y:4	Jan 2012 (13 y 6 m)	Y
Denham (WA) *Verve*	1.6 (4) 0.4	Jun 1998 (14 y 6 m)	600	N	–	N
Esperance, 9 Mile Beach (WA) *Verve*	3.6 (6) 0.6	2003 (8 y)	50	N	–	N
Esperance, 10 Mile Lagoon (WA) *Verve*	2.025 (9) 0.225	1993 (19 y)	50	N	–	N
Hampton Park (NSW) *Wind Corp*	1.32 (2) 0.66	Sep 2001 (11 y 3 m)	150	N	–	N
Huxley Hill, King Island (Tas) *Hydro Tas*	2.458 (5) 0.49	Feb 1998 (14 y 1 m)	10 houses (26)	N	–	N
Hopetoun (WA) *Verve*	1.2 (2) 0.6	Mar 2004 (8 y 9 m)	600	N	–	N
Kalbarri (WA) *Verve*	1.6 (2) 0.8	Jul 2008 (4 y 5 m)	10	N	–	N
Kooragang, Newcastle (NSW) Energy Australia	0.6 (1) 0.6	1997 (15 y)	3–4 km from Mayfield 9000	N	–	N
Leonards Hill (Vic) *Community owned*	4.1 (2) 2.05	Jun 2011 (1 y 6 m)	232	Y:6	On-going from earlier	Y
Mt Barker (WA) *Mt Barker Power*	2.4 (3) 0.8	Mar 2011 (1 y 9 m)	2000	N	–	N
Rottnest Island (WA) *Rottnest Island*	0.6 (1) 0.6	Sep 2006 (6 y 3 m)	150	N	–	N
Thursday Island (Qld) *Egon Energy*	0.225 (2) 0.113	Aug 1997 (15 y 5 m)	2500	N	–	N

Table 2. Cont.

Wind farm name (state) *owner*	Installed Capacity (MW)+(number of turbines)+average turbine size MW	Date commenced operation & total years (to Dec 2012)	Approx. population within 5 km	Health or noise complainants (Y/N) & number (persons unless specified)	Date of first complaint (months since opened)	Local or visiting opposition group activity?
Sub-total:17 farms	38 MW 67 turbines		20405	2 farms with 10 complainants		2
Total:51 farms	3168.3 MW 1634 turbines		32739	18 farms with 129 complainants		16

NI = no information.
*13 residents submitted affidavits in a court case but only 2 complained to the company (*AGL*), and none to the local Council or Environmental Protection Agency.
Average residents per house in 2011:2.6 http://www.censusdata.abs.gov.au/census_services/getproduct/census/2011/quickstat/0.
doi:10.1371/journal.pone.0076584.t002

provided estimates of the number of individuals, while others provided data on the number of houses. In Table 2, we have multiplied cells showing the number of *houses* by 2.6, this being the average number of residents per household in Australia today, to give a total estimate of surrounding residents.

Results

Table 2 shows the history and distribution of complaints from all 51 Australian wind farms. Complaints came either from individuals or from households with several occupants each or collectively complaining. Some wind companies initially reported the number of complainants as *households*, while others reported individual complainant numbers. In these cases we sought clarification from companies about whether complaints came from single individuals, couples or more than two members of a family so as to report total the estimated total number of individual complainants.

Hypothesis 1: Many Wind Farms would have no History of Complaints

Of all 51 wind farms, 33 (64.7%) had never been subject to health or noise complaints, with 18 (35.3%) receiving at least one complaint since operations commenced. The 33 farms with no histories of complaints, and which today have an estimated 21,633 residents living within 5 km of their turbines, have operated for a cumulative total of 267 years.

Of the 18 wind farms which had received complaints, 16 were larger wind farms ($\geq$10 MW capacity). In summary, 18/34 (52.9%) of larger wind farms, and 15/17 (88.2%) of small farms have never experienced complaints. Wind farm opponents sometimes argue that it is mainly very large, "industrial" wind turbines which generate sufficient audible noise and infrasound to cause annoyance and health problems. If 1 MW is taken to define a "large" turbine, 18/34 (52.9%) of farms using large turbines had never attracted complaints while 15/17 (88%) of farms using smaller turbines had no histories of complaints. Both the total energy generating capacity of farms and whether the turbines used were over 1 MW were thus significant predictors of residents having ever complained, with small total capacity farms being far less likely to have complainants (88% vs 53%; $\chi^2 = 6.18$, 1 df, $p = 0.013$).

The distribution of farms which have ever received complaints is highly variable across Australia. Figure 1 shows no consistency between the percentages of farms receiving complaints in different states, whether they have many or few wind farms. Western Australia has 13 wind farms (3 with large turbines), including some of the longest running in Australia (Esperance 10 Mile Lagoon 1993, Denham 1998). No complaints have been received at any of these wind farms. Verve, which operates 8 farms in the state replied "we have never received any form of notification of health complaints in the vicinity of our wind farms." The three farms in Tasmania have also never received complaints.

Our hypothesis about many wind farms – including those with large turbines – having no history of complaints, with strong spatial (geographical) factors being associated with farms receiving complaints was thus strongly confirmed.

Hypothesis 2: There would be a Small Proportion of Complaining Residents

Nationally, a total of 129 individuals in Australia appear to have ever formally or publicly complained about wind farm noise or health problems affecting them. Of these, well over half (94 or 73%) came from residents living near just six wind farms (Waubra = 29, McArthur = 21, Hallett 2 = 13, Waterloo = 11, Capital = 10 and Wonthaggi ~10). Of the remaining farms which have experienced complaints, 9 had between 2 and 6 complainants, and 4 had only single complainants. Of 18 wind farms which had attracted complaints, 11 (72%) have had 6 or less complainants.

There are an estimated 32,789 people living within 5 km of the 50 wind farms for which we obtained residential estimates. Most (20,455 or 62%) live near the 17 smaller wind farms, while 12,334 live within 5 km of the 32 larger farms. In summary, nationally, an estimated 129 individuals have complained out of an estimated 32,789 nearby residents: a rate of about 0.4% or 1 in 254. Of the 34 wind farms with larger (>1 MW) turbines, their 124 complainants represented some 1 in 100 of the surrounding 12,366 residents. Large wind farms with relatively large surrounding rural populations and no histories of complaint include Wattle Point (560), Albany, Starfish Hill (each 200) and Challicum Hills (143).

Again, our hypothesis that the number of complainants living near those wind farms with any history of complaints would be a small proportion of the exposed population, was strongly confirmed.

Hypothesis 3: Few Wind Farms would have any History of Complaints Consistent with Claims that Turbines cause Acute Effects

Wind farm complainants describe both acute and chronic adverse effects. Acute effects are of particular interest to the psychogenic hypothesis because it is often claimed that even brief exposure to wind turbines can cause almost immediate onset of symptoms. For example, a recent report describes a visit to turbine-exposed houses where people become immediately affected: "The onset of adverse health effects was swift, within twenty minutes, and persisted for some time after leaving the study area" [45]. Symptoms are said to disappear when those affected move away temporarily, only to return as soon as they come back. A highly publicised Lake Bonney complainant who had hosted turbines on his previous property without complaint for six years today claims he and his wife are affected at their new address, further away, but that symptoms disappear as soon as they leave their new home for one or two days [46].

If wind turbine exposure can cause such "instant" problems, any history of delayed or non-reporting of such complaints and the absence of any reports about such complaints in the news media, months or sometimes years after various wind farms began operating creates serious coherency problems for such claims. Such delays would be incompatible with there being widespread or important "acute" effects from exposure.

Table 2 shows that first complaint timing ranged from immediately after turbines commenced operation (sometimes at only a fraction of full capacity) to many months and even many years later (eg: Crookwell, 13.5 years, Lake Bonney, over 7 years later. In five cases (Clements Gap, Hallet 2 & 4, Leonards Hill, Waubra), wind companies advised that complaints anticipating health problems were received before the farms commenced operation. Of the 51 wind farms, 33 (64.7%) have seen no complaints; 6 (11.8%) saw complaints commence at times ranging from 2 months to 13.5 years after turbine operation; and 12 (23.5%) saw either on-going complaints continue from before the wind farms commenced operation or within the first month.

Early complaints from some wind farms could be consistent with acute effects caused directly by turbine exposure but also with nocebo effects caused by anticipation of adverse effects [32]. However, gaps of months or sometimes years between the commencement of turbine operation and complaints are inconsistent with turbines causing acute effects. Moreover, if such effects were serious or common, clinical case reports would have almost certainly appeared in peer reviewed journals, given the many years that wind farms have operated in Australia. No such reports have been published.

Hypothesis 4: Most Complaints would Date from 2009 or Later, when Anti Wind Farm Groups began to Publicise Alleged Health Effects

The nocebo hypothesis would predict that the spread of negative, often emotive information would be followed by increases in complaints and that without such suggestions being spread, complaints would be less. Australia's first still operational wind farm commenced operation in 1993 at 10 Mile Lagoon near Esperance, Western Australia. However, objections to wind farms in Australia appear to date from the early years of the 2000 s when press reports mentioned negative reactions of some in rural communities to their intrusiveness in bucolic country landscapes ("behemoths" [47]), bird and bat strikes, the divisiveness engendered in communities by the perceived unfairness of some landowners being paid hosting fees of up to $15,000 per year per turbine while neighbours received none, and debates about the economics of green energy. Unguarded, frank NIMBYism "I'm quite happy to admit that this is a not-in-my-backyard thing, because my backyard is very special" was also evident in 2002 [47].

Groups explicitly opposing wind farms ostensibly because of agendas about preserving pristine bush and rural environments were active from these early years and included many branches of the Australian Landscape Guardians (for example Prom Coast (2002), Spa Country [48], Grampians-GlenThompson [49], Western Plains, Daylesford and District). Key figures in the Landscape Guardians have links with mining and fossil fuel industries [50]. Interests with overt climate change denial agendas also actively opposed wind farm developments, particularly in Victoria. Chief among these were the Australian Environment Foundation, registered in February 2005.

However, health concerns were marginal in these early oppositional years, with one early press report from September 2004 [48] noting "some objectors have done themselves few favours by playing up dubious claims about reflecting sunlight, mental health effects and stress to cattle".

An unpublished British report said to refer to data gathered in 2003 on symptoms in 36 residents near unnamed English wind farms is frequently noted by global wind turbine opponents as the first known report of health effects from wind turbines, although curiously, it does not appear to have been produced until 2007 [51]. The Daylesford and Districts Landscape Guardians referred to Harry's work in a 2007 submission opposing a wind farm at Leonards Hill [52].

In Australia, a rural doctor from Toora, Victoria, David Iser, produced another unpublished report [53] in April 2004 following his distribution of 25 questionnaires to households within 2 km of the local 12 turbine, 21 MW wind farm, which had commenced operation in October 2002. Twenty questionnaires were returned, with 12 reporting no health problems. Three reported what Iser classified as "major health problems, including sleep disturbances, stress and dizziness". Like that of Harry, Iser's report provides no details of sample selection; whether written or verbal information accompanying the delivery of the questionnaire may have primed respondents to make a connection between the wind turbines and health issues; whether those reporting effects had previous histories of the reported problems; nor whether the self-reported prevalence of these common problems were different to those which would be found in any age-matched population.

In the 10 years between the commencement of operation of the first Esperance wind farm and the end of 2003 when the Harry and Iser health impact reports [51,53] began being highlighted by turbine opposition groups, 12 more wind farms commenced operation in Australia. In that decade, besides two complainants from Toora, we aware of only one other person living near the north Queensland Windy Hill wind farm who complained of noise and later health soon after operation commenced in 2000. Importantly in that decade, five large turbined wind farms at Albany, Challicum Hills, Codrington, Starfish Hill and Woollnorth Bluff Point commenced operation but never received complaints.

With the exception of those just mentioned and Wonthaggi (~10 complainants in 2006, but none today) all other health and noise complainants (n = 116) first complained after March 2009– six years after Iser's Toora small, unpublished survey of health complaints [53] - and particularly from the most recent years when anti wind farm publicity from opposition groups focused on health has grown. Again, the nocebo and the 'communicated disease' hypotheses would predict this changed pattern and contagion of complaints, driven by increasing community concern. Sixty nine percent of wind farms began operating prior to 2009 while the majority of complaints (90%) were recorded after this date.

Responding to the nocebo hypothesis and the view that opposition groups were fomenting a 'communicated disease', the Waubra Foundation's Sarah Laurie stated: "There is also plenty of evidence that the reporting of symptoms for many residents at

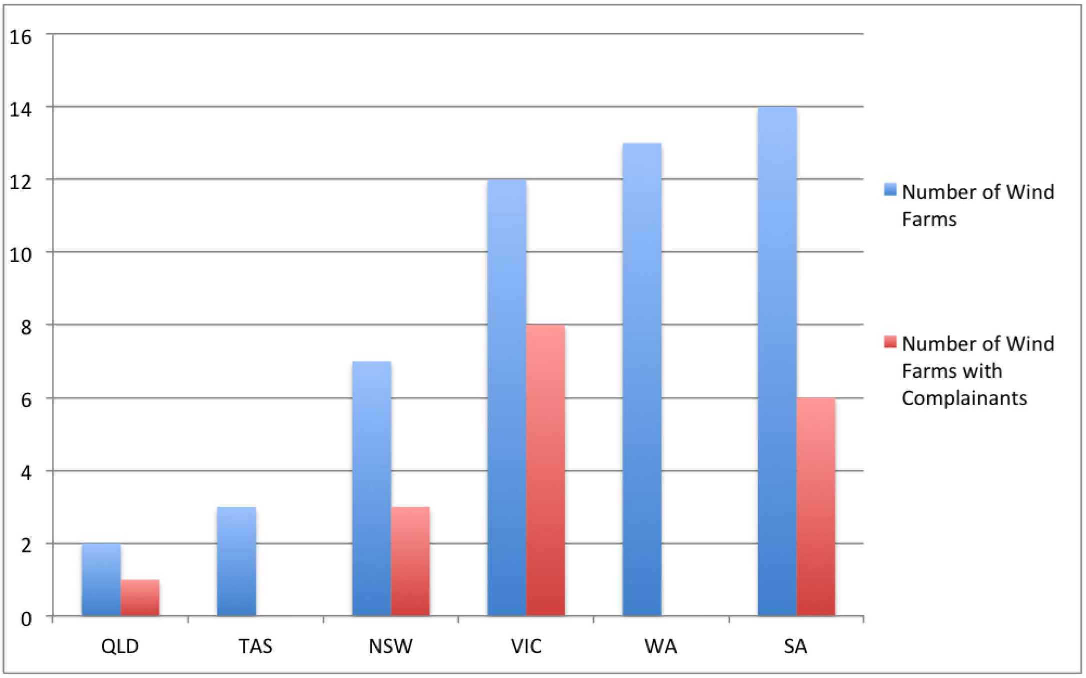

Figure 1. Farms with wind turbine complainants by state, Australia 1993–2012.
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wind developments in Victoria such as Toora, Waubra and Cape Bridgewater *preceded the establishment of the Waubra Foundation* (emphasis in original). In the case of Dr David Iser's patients at Toora the time elapsed is some 6 years." [54].

This statement neglects to note that the Waubra Foundation's registration in July 2010 was preceded by several years of virulent wind turbine opposition – which included health claims – by the Landscape Guardians and the Australian Environment Foundation. For example, in November 2009, 8 months before the formation of the Waubra Foundation the Western Plains Landscape Guardians published a full-page advertisement in the local Pyrenees Advocate newspaper headed "Coming to a house, farm or school near you? Wind Turbine Syndrome also known as Waubra Disease". It listed 12 common symptoms (e.g. sleeping problems, headaches, dizziness, concentration problems). Peter Mitchell is the founding chairman of the Waubra Foundation and in 2009 and at least until February 2011, was also actively advocating for the Landscape Guardians [55].

Table 2 shows that of the 18 wind farms which have seen complainants, 15 (83%) have experienced local opposition from anti wind farm groups. No wind farm with any history of wind turbine opposition avoided at least one health or noise complaint. We conclude that health and noise complaints were rare prior to the decision of anti wind farm groups to focus on these issues and that anti wind farm activists are likely to have played an important role in spreading concern and anxiety in all wind farms areas in which they have been active.

Discussion

This study shows there are large historical and geographical differences in the distribution of complainants to wind farms in Australia. There are many wind farms, large and small, with no histories of complaints and a small number where the large bulk of complaints have occurred. Just over half of wind farms with larger turbines have seen complaints, but nearly just as many have not. These differences invite explanations that lie beyond the turbines themselves.

Our historical audit of complaints complements recent experimental evidence [32], that is strongly consistent with the view that "wind turbine syndrome" and the seemingly boundless and sometimes bizarre range of symptoms associated with it has important psychogenic nocebo dimensions [2]. While wind turbines have operated in Australia since 1993, including farms with >1 MW turbines from 2001 (Albany and Codrington), health and noise complaints were very rare until after 2009, with the exception of Wonthaggi which saw about 10 complainants in 2006.

Several wind farm operators reported that many former complainants had now desisted. For example, Waubra management advised that not all complainants identified by our public searches had complained to them, and that more than half of the 17 complainant households who had complained to them, had had their complaints resolved. Similarly, Wonthaggi management said that none of some 10 complainants from 2006/2007 were still complaining today. Some of these former complainants from different farms had had their houses noise tested with the results showing they conformed to the relevant noise standard, some received noise mitigation (e.g. double glazing), while others simply stopped complaining.

Opponents sometimes claim that only "susceptible" individuals are adversely affected by wind turbines, using the analogy of motion sickness. Our data produce problems for that explanation: it is implausible that no susceptible people would live around any wind farm in Western Australia or Tasmania, around almost all older farms, nor around nearly half of the more recent farms. No credible hypotheses other than those implicating psycho-social factors have been advanced to explain this variability.

As anti wind farm interest groups began to stress health problems in their advocacy, and to target new wind farm developments, complaints grew. Significantly though, no older farms with non-complaining residents appear to have been targeted by opponents. The dominant opposition model appears to be to foment health anxiety among residents in the planning and construction phases. Health complaints can then appear soon after power generation commences. Residents are encouraged to interpret common health problems like high blood pressure and sleeping difficulties as being caused by turbines.

For example, sleeping problems are very common, with recent Australian and New Zealand estimates ranging from 34% [56], to moderately poor (26.4%) and very poor sleep quality (8.5%) [57]. A German study undertaken to obtain benchmark reference data on common symptoms and illnesses experienced in the past 7 days in the general population for comparison with those experienced by clinical trial enrollees presents data on several problems most often attributed to wind turbines. These include headache (45.3%), insomnia (25.6%), fatigue and loss of energy (19.1%), agitation (18.4%), dizziness (17%) and palpitations (8.6%) [58].

A case brought before The Ontario Environmental Review Tribunal by residents claiming to be affected by a wind farm, collapsed when the Tribunal requested that complaints supply their medical records to determine whether their complaints pre-dated the operation of the wind farm [59].

Wind farm opponents frequently argue complainants are legally "gagged" from speaking publicly about health problems, thus underestimating the true prevalence of those affected. This is said to apply to turbine hosts who are contractually gagged or to non-hosts who have reached compensation settlements with wind companies after claiming harm. The first claim is difficult to reconcile with the example provided by a high profile Lake Bonney wind farm host who continues to complain publicly without attracting any legal consequences [27]. Confidentiality clauses are routinely invoked in any legal settlement to protect parties' future negotiating positions with future complainants. They usually refer to the settlement figure rather than to the reasons for it.

We purposefully took a liberal view of what a "complainant" was, by including those who had voiced their displeasure about noise, sleep or health in news media or submissions even if they had never lodged a formal complaint with the relevant wind farm company. Despite this, the numbers complaining in Australia were very low and largely concentrated in a small number of "hotbeds" of anti wind farm activism.

A 2012 CSIRO report on nine wind farm developments in three Australian states found widespread acceptance among local residents of both operating and planned farms, and noted that: "The vocal minority are more often prominent in the media … These groups often contact local residents early in the project and share concerns about wind farms." And that "The reasons for opposition by some participants suggest that wind farms proposals are triggering a range of underlying cultural or ideological concerns which are unlikely to be addressed or resolved for a specific wind farm development. These underlying issues include pre-existing concerns that rural communities are politically neglected by urban centres, commitment to an anti-development stance, and opposition to a 'green' or 'climate action' political agenda." [60].

Limitations

The data we obtained on the number of individuals or occupied houses near the farms were current estimates. These numbers may have varied in different directions for different farms over the 20 year period that wind farms have operated in Australia. But no data are available on that variation. Our estimates of the ratios of complaints to population are therefore unavoidably fixed around the most current population estimates. They would include children who do not lodge complaints, but who are often mentioned by wind farm opponents as subject to health effects [2].

It is possible that there were other complainants who complained earlier than in the periods covered by our corroborative checks. However, this seems highly unlikely: Australian anti wind farm groups would have strong interests in widely publicising such complainants, had they existed. The Waubra Foundation for example, repeatedly refers to the 2004 Iser report [53], in its efforts to emphasise that health concerns had been raised before the Waubra Foundation became established [54] As wind farm opponents have not highlighted more complainants than we have identified, this strongly suggests there were no earlier health or noise complainants.

It is also possible that some of the health complainants are disingenuous, thereby inflating the true number of people actually claiming to experience turbine-related health problems when their objections may be only aesthetic. Controversy arose when an anti wind farm activist who lives 17 km from the Waterloo wind farm was recently accused of "coaching" residents who disliked the local wind farm to explicitly mention health issues [61].

We selected the 5 km distance from turbines as a compromise between the 2 km minimum setback distance designated by the Victorian government for future wind farm approvals, and the 10 km often named by the Waubra Foundation as the advisable minimum distance. We also note here, that one prominent critic of wind farms claims to to be able to personally sense low frequency noise up to 100 km away from wind turbines under certain conditions [62]. Had we chosen the 10 km distance counseled by the Waubra Foundation, this would have significantly increased the numbers of people exposed but not complaining.

The estimates provided by the wind companies of the number of residents within 5 km of wind farms need to be seen as approximations. Census data is available by local government areas and by the Australian Bureau of Statistics statistical regions. However, these do not correspond with the 5 km zone of residence of interest here. The wind companies which provided this data obtained it from their own knowledge of the number of residences near their wind farms and we checked local township sizes from Australian census data. This information is typically obtained during the planning stages of wind farm development when development applications often require such estimations to be provided. At least one company used Google Earth photography to calculate their estimate of the number if dwellings. However, such estimates will always be imprecise and approximations only. They nonetheless provide "ballpark" denominators against which the known number of complainants can be compared.

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Author Contributions

Analyzed the data: SC AStG KW VC. Wrote the paper: SC AStG KW VC. Conceived of study: SC. Collected data: SC AStG KW VC. Contributed to writing: SC AStG KW VC.

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Can road traffic mask sound from wind turbines? Response to wind turbine sound at different levels of road traffic sound

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ABSTRACT

Wind turbines are favoured in the switch-over to renewable energy. Suitable sites for further developments could be difficult to find as the sound emitted from the rotor blades calls for a sufficient distance to residents to avoid negative effects. The aim of this study was to explore if road traffic sound could mask wind turbine sound or, in contrast, increases annoyance due to wind turbine noise. Annoyance of road traffic and wind turbine noise was measured in the WINDFARMperception survey in the Netherlands in 2007 (n=725) and related to calculated levels of sound. The presence of road traffic sound did not in general decrease annoyance with wind turbine noise, except when levels of wind turbine sound were moderate (35–40 dB(A) Lden) and road traffic sound level exceeded that level with at least 20 dB(A). Annoyance with both noises was intercorrelated but this correlation was probably due to the influence of individual factors. Furthermore, visibility and attitude towards wind turbines were significantly related to noise annoyance of modern wind turbines. The results can be used for the selection of suitable sites, possibly favouring already noise exposed areas if wind turbine sound levels are sufficiently low.

1. Background

Wind power plays a small but significant role in the ongoing conversion to renewable energy sources. Installed electric wind power is increasing with an annual rate of 27% globally (IEA, 2008), meaning that the number of operational wind turbines is rapidly growing. Wind power is generally favoured by the public, though at the same time wind turbines often are opposed in the local community (Ek, 2005; Breukers and Wolsink, 2007). Wind turbines are by some viewed upon as visual and audible intruders, destroying the landscape scenery and emitting noise (Pedersen et al., 2007). Remote places with a low population density were considered suitable locations for wind farms, but long distances to the existing power grid are costly. Also, remote places often are otherwise unspoiled landscapes with high values for recreation and tourism that could decrease with the construction of a wind farm. Suitable places for wind farms are therefore more often sought after also in populated areas.

One of the parameters to assess the suitability of a location could be the existing background sound level due to natural or man-made sources. It seems plausible that high levels of background sound can reduce annoyance by masking the noise from a wind farm, either physically when the sound cannot be heard, or cognitively when the sound is perceived as attracting less attention. If this is true, a row of turbines could cause less noise annoyance when placed next to a motorway instead of a quiet agricultural area. One modern 2–3 MW turbine at high speed produces a sound power level (105–108 dB(A)) that is approximately equal to a car on a motorway (see road traffic sound power levels in Jabben et al., 2001). Siting wind turbines next to a motorway could thus be an attractive alternative, certainly if they then also would be perceived as visually less intrusive as they serve as visible 'milestones' along the motorway. However, it is not yet clear if road traffic can indeed mask wind turbine sound and to what extent. Physical masking of wind turbine sound by wind induced noise in vegetation has been investigated by Bolin (2007) and masking by sea waves by Appelqvist et al. (2007). The capacity for masking will change with time as high turbine sound levels can occur at low levels of vegetation or wave noise, either on a short time scale during wind gusts or on a longer time scale associated with changes in the vertical wind profile. Also, wind turbine sound can be audibly amplitude modulated due to differences in wind speed over the area swept by the rotor blades (van den Berg, 2005). Amplitude modulations in a sound are more easily detected by the human ear (Fastl and Zwicker, 2007) than a constant sound. Masking will

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also depend on the spectral distribution of the masking sound relative to the masked sound. Wind turbine and road traffic sound are not very different in this respect as both have high levels of sound at roughly 1–2 kHz (due to trailing edge and tyre noise respectively) at close distance and high levels at low frequencies due to inflow turbulent sound and engine sound. Here we assume that road traffic sound needs to exceed the actual level of wind turbine sound in order to be able to mask wind turbine noise.

When placing a wind farm close to another noise source, the other source could (at least for part of the time) mask the sound from the wind farm, but synergetic effects cannot be excluded: the response to exposure from one noise source could be enhanced due to exposure from another noise source. The prevalence of annoyance due to road traffic noise has been found to be significantly *higher* in areas with high exposure of both road traffic and railway noise, in comparison with areas with only high exposure of road traffic (Ahlstrom et al., 2007). On the other hand, the prevalence of annoyance due to high levels of railway noise was *lower* when high levels of road traffic sound were present compared to when they were not (Lercher et al., 2007). Vos (1992) found no synergetic effect when people were simultaneously exposed to sound from gunfire, aircraft and/or road traffic: the annoyance was shown to depend on the total sound level (logarithmic summation of sound level from each source), though sound levels were corrected with penalties to account for the difference in dose–response relations. Synergetic effects, if present, hence appear to depend on the character or origin of the sounds, or other circumstances related to the source, and can differ for each type and perhaps level of sound exposure.

Observed synergetic effects could also be due to confounders. Variables known to moderate the response to noise are noise sensitivity (Miedema and Vos, 2003) and attitude towards the noise source (Job, 1988). An association between annoyances with two noise sources could hence be due to individual factors that change the threshold for a negative appraisal and not actually to a synergetic effect. For wind turbines, the prevalence of annoyance with the noise increased if the wind turbines could be seen from the dwelling or outside the dwelling by the receiver (Pedersen and Larsman, 2008), is possibly due to a multi-sensory effect where the ability to detect and recognize external stimuli is enhanced when more than one sense is involved (Calvert, 2001). Also road traffic noise has been found to be more annoying if the road is visible than if it is not (Bangjun et al., 2003). It could be presumed that in landscapes where the noise sources are easily visible the possibility of noise annoyance increases due to the multi-modal stimuli, rather than annoyance with one noise source enhancing annoyance with a second source. Thus, situational factors also have to be taken into account when a possible synergetic effect is studied.

The objective of this paper is to explore if road traffic sound can mask wind turbine sound. To put it more precisely: Is perception and annoyance with wind turbine sound reduced when road traffic sound dominates the wind turbine sound?

2. Methods

The analyses are based on data from a large cross-sectional study that was carried out in the Netherlands (Pedersen et al., 2009). The objective was to evaluate human responses to exposure from wind turbines, especially for people living close to modern wind farms. The study included three different settings in order to vary background sound levels: built-up areas, rural areas with a main road (within 500 m from a selected wind turbine) and rural areas without a main road. Wind turbines were selected (from all wind turbines in the Netherlands) when they had a nominal power of 500 kW or more and another turbine within 500 m, and were not (re)placed in the previous year. A stratified sample of 1948 people living within different levels of wind turbine sound outside their dwellings was chosen for the study. Of those, 725 completed and returned a questionnaire (response rate 37%) measuring perception and annoyance with environmental factors, including wind turbine and road traffic sounds. The questionnaire also comprised questions about attitude towards the noise sources and individual factors such as health symptoms and perceived stress. A follow-up survey found no differences between respondents and non-respondents regarding the main annoyance question (Pedersen et al., 2009).

2.1. Assessments of sound levels

Coordinates for all respondents were available from the sampling process and used for calculating the distance to all wind turbines within 20 km of each respondent's dwelling. Emission (sound power) levels of wind turbines were obtained from technical specifications published by manufacturers and consultancies. Equivalent immission levels in dB(A) of wind turbine sound outside the dwelling of each respondent were calculated in accordance with ISO-9613 (1993) for a wind speed of 8 m/s at 10 m height and a wind profile in a neutral atmosphere. The sound levels at each respondent's dwelling due to all wind turbines in the area were summarized logarithmically.

In the European Union, two time averaged sound levels are now recommended: Lden and Lnight. Lden is the average sound pressure level (A-weighted) over a longer period of time, including a penalty of 5 dB(A) in the evening and 10 dB(A) at night; Lnight is the average sound pressure level (A-weighted) over the night time period only (EU, 2003). We will use the difference between Lden from wind turbines and Lden from road traffic, as Lden is the usual metric related to annoyance. Lnight would be a more proper choice when investigating sleep disturbance. The calculated immission levels (at 8 m/s wind speed) were transformed into levels of day–evening–night values (Lden) by adding 4.7 dB as proposed by van den Berg (2008). In this article all sound levels are expressed in dB(A) Lden.

The Dutch National Institute for Public Health and the Environment (RIVM) supplied calculated day–evening–night sound immission levels (Lden) due to road, air and rail traffic in 5 dB intervals and for a 25 m by 25 m grid over the entire country. The levels are based on traffic volumes in 2002. Mopeds, motor bicycles, and local traffic on minor roads are not included in the road traffic sound level, and overflying (i.e. not taking of or landing) aircraft are not included in the aircraft sound level. For (nearly) all respondents there is no railroad or airport nearby, so road traffic will dominate the Lden value. The Lden values of background (=not wind turbine) sound ,thus, are an approximation of the road traffic sound level. For each respondent the value at the nearest grid point has been used. To obtain a best approximation for the road traffic sound level, the midpoint value of each interval (2.5 dB below the maximum value of the interval) is used.

2.2. Statistical analyses

In the questionnaire annoyance was measured with several questions. It was therefore possible to derive factor scores for annoyance with turbine sound (5 items, Cronbach's alpha=0.892) and for annoyance with road traffic sound (6 items, Cronbach's alpha=0.863). Such factors scores are a more reliable measurement of annoyance than if only the response to one question is used. In this case, principal component analyses were used. The derived factors have a mean value of 0 and a standard deviation of 1. A factor score below 0 means lower than average of the total sample, a factor score above 0 higher than average.

Symptoms of stress were also measured with several items of which six were suitable for constructing a factor score as described above (Cronbach's alpha=0.840). The six items were: feeling tense or stressed, feeling irritable, having mood changes, being depressed, suffering from undue tiredness and having concentration problems.

The study sample was divided into three sub-samples corresponding to the difference between the level of wind turbine and road traffic sounds. In the 'WT dominant' sub-sample the level of wind turbine sound for each respondent was more than 5 dB higher than the level of road traffic sound. In the 'RT dominant' sub-sample the reverse is true. In the 'No dominant source' sub-sample the difference between the two sound levels was 5 dB or less. The 5 dB cut-off approach has previously been used by, for example, Cremezi et al. (2001) and Lim et al. (2008).

Differences between sub-samples were tested with ANOVA for continuous variables and Chi-square test for binary variables. Associations between two variables were tested with the Pearson's moment correlation (r) for continuous variables, the Spearman's rank correlation (r_s) for ordinal scales and with the Mann–Whitney U-test for differences between sub-samples (Z_{MWU}). The association between several independent variables and one dependent variable was tested in models using multiple linear regression. The association between several independent variables and two dependent variables was tested with multivariate general linear model. A p-value <0.05 was taken as an indication of statistical significance, though the number of tests were carried out calls for precaution. All respondents had not answered all questions in the questionnaire. Missing cases were not substituted in any way, while some analyses include a lower number of respondents than the total number in the study. The number of respondents are noted in the tables listing the results of multiple or multivariate modelling.

2.3. Overview of variables used in the analyses

The following variables were used in the analyses:

- WT sound: wind turbine sound outside the dwelling of the respondent; WT sound level is Lden in dB(A) on a continuous scale.
- RT sound: road traffic sound outside the dwelling of the respondent; RT sound level is Lden in dB(A) in 5 dB intervals, but here treated as a continuous scale.
- WT annoyance: annoyance with wind turbine sound. Factor score. continuous scale. Five items: (i) "Below are a number of items that you may notice or that could annoy you when you spend time outdoors at your dwelling. Could you indicate whether you have noticed these or whether these annoy you." (sound from wind turbines; 5-point verbal scale from "do not notice" to "very annoyed"), (ii) same question but indoors, (iii) "To what extent are you affected by wind turbines in your living environment? Please indicate for each item whether you notice or are annoyed by it in your living environment." (sound from rotor blades; 5-point scale verbal from "do not notice" to "very annoyed"), (iv) "To what extent are you annoyed by the sound of wind turbines when you are outdoors at your dwelling?" (11-point scale from 0="I am not at all annoyed" to 10=I". am extremely annoyed"), and (v) the same but for indoors.
- RT annoyance: annoyance with road traffic sound. Factor score. Continuous scale. Six items: (i) "Below are a number of items that you may notice or that could annoy you when you spend time outdoors at your dwelling. Could you indicate whether you have noticed these or whether these annoy you." (road traffic sound; 5-point verbal scale from "do not notice" to "very annoyed"), (ii) same question but sound indoors, (iii) "To what extent are you affected by busy roads in your living environment? Please indicate for each item whether you notice or are annoyed by it in your living environment." (sound indoors; 5-point scale verbal from "do not notice" to "very annoyed"), (iv) same question but sound outdoors, (v) "To what extent are you annoyed by the sound of busy roads when you are outdoors at your dwelling?" (11-point scale from 0="I am not at all annoyed" to 10="I am extremely annoyed"), and (vi) the same but for indoors.
- Hear wind turbines: no or yes as answer of the question "Can you hear a wind turbine from your dwelling or your garden/balcony?"
- Hear busy road: no or yes as answer to the question "Can you hear the sound of busy roads from your residence or garden/balcony?"
- WT visibility: no or yes as answer to the question "Can you see a wind turbine from your dwelling or your garden/balcony?"
- RT visibility: no or yes as answer of the question "Can you see a busy road from your residence or garden/balcony?"
- WT attitude: attitude towards wind turbines, measured with the question "What is your opinion on the impact of wind turbines on the landscape scenery?" on a 5-point scale from "very positive" to "very negative" and dichotomized into "not negative" (point 1, 2 or 3) and "negative" (point 4 or 5).
- RT attitude: attitude towards road traffic, measured with the question "What is your opinion on the impact of busy roads on the landscape scenery?" on a 5-point scale from "very positive" to "very negative" and dichotomized into "not negative" (point 1, 2 or 3) and "negative" (point 4 or 5).
- Noise sensitivity: noise sensitivity measured on a 5-point scale from "not at all sensitive" to very sensitive and dichotomized into "not sensitive" (scale point 1, 2 or 3) and "sensitive" (scale point 4 or 5).
- Stress: factor score constructed from six items with a 4-point scale rated from "(almost) never" to "(almost) daily". Continuous scale with zero as mean value and standard deviation 1.

3. Results

3.1. Descriptive

The mean levels of wind turbine and road traffic sound in each of the three sub-samples are shown in Table 1 together with response to the sounds and variables possibly influencing the response. The mean Lden of wind turbine sound as well as road traffic sound differed significantly among the sub-samples (all $p<0.001$) with the highest WT sound levels in the WT dominant sub-sample and the highest RT sound levels in the RT dominant sub-sample. In the WT dominant sub-sample a larger proportion of respondents could hear the wind turbine sound ($p<0.001$), was annoyed by the sound ($p<0.001$), and could see wind turbines from their dwellings ($p<0.001$), in comparison to the other two sub-samples. Also a larger proportion of respondents was negative to the impact of wind turbines on the landscape scenery in the WT dominant sub-sample than in the other sub-samples ($p<0.001$), and, vice versa, a larger proportion of respondents in the RT dominant sub-sample was negative to the visual impact of busy roads ($p<0.001$). No significant differences

Table 1
Description of sound levels, response to sound and variables possibly influencing the response in the three sub-samples.

	WT dominant (n=150)	No dominant source (n=230)	RT dominant (n=338)
WT sound Lden in dB(A), mean (SD)	46.5 (5.5)	40.7 (5.6)	36.2 (4.3)
RT sound Lden in dB(A), mean (SD)	31.6 (4.9)	40.9 (5,.5)	42.5 (5.5)
Difference between WT and RT sound Lden, mean (SD)	15.1 (4.9)	−0.2 (4.0)	−14.7 (4.9)
Age, mean (SD)	50 (13)	53 (15)	57 (15)
Gender, %male	47	56	46
Hear wind turbines, %yes	82	49	28
Hear busy road, %yes	32	50	59
WT annoyance, mean (SD)	0.29 (0.96)	0.08 (1.06)	−0.21 (0.93)
RT annoyance, mean (SD)	−0.34 (0.65)	−0.08 (0.93)	0.20 (1.12)
Noise sensitive, %sensitive	24	31	30
WT visibility, %yes	91	71	53
RT visibility, %yes	48	50	41
WT attitude, %negative	30	34	40
RT attitude, %negative	13	18	21
Economical benefits from WT, %yes	41	11	3
Stress, mean (SD)	0.01 (1.02)	−0.06 (0.89)	0.03 (1.06)

Table 2
Difference between levels of WT sound and RT sound at 5-Lden intervals of WT sound in the three sub-samples.

	WT dominant			No dominant source			RT dominant		
WT sound intervals Lden	WT sound mean Lden	RT sound mean Lden	*Diff*	WT sound mean Lden	RT sound mean Lden	*Diff*	WT sound mean Lden	RT sound mean Lden	*Diff*
30–35				33.4	35.4	*2.0*	32.9	48.7	*15.8*
35–40	37.5	27.5	*10.0*	37.2	38.6	*1.4*	37.7	50.2	*12.5*
40–45	42.0	28.8	*13.2*	42.4	41.8	*0.5*	41.9	56.7	*14.8*
45–50	47.4	32.7	*14.7*	47.4	46.1	*1.4*	47.4	59.6	*12.1*
50–55	52.3	34.2	*18.1*	51.8	50.0	*1.8*			

between the sub-samples were found for noise sensitivity and stress. More than 40% of the respondents in the WT dominant sub-sample benefited economically from the wind turbines, in comparison with 11% in the no dominant source ($p<0.001$) and 3% in the RT dominant sub-sample ($p<0.001$). Economical benefits decreased the possibility for noise annoyance, but not the possibility to hear the sound (Pedersen et al., 2009). Economical benefits are thus an important moderating factor and should therefore be considered in the analyses when annoyance is explored.

Table 2 shows the differences between levels of WT and RT sounds in relation to 5-dB(A) intervals of wind turbine sound. The WT sound levels clearly exceeded the RT sound levels at all intervals in the WT dominant sub-sample. Similar, the RT sound clearly exceeded the WT sound in the RT dominant sub-sample.

3.2. Possibility to hear wind turbine sound in different levels of background sound

The proportion of respondents that could hear a wind turbine from their dwelling or garden/balcony increased with increase in levels of wind turbine sound as expected. However, in the WT dominant sub-sample the possibility of hearing the wind turbine sound remained constant for WT sound levels up to 50 dB(A) and at levels up to 45 dB(A) the proportion of respondents that could hear the sound was larger than in the other sub-samples (Fig. 1). At levels below 45 dB(A) the difference between the WT dominant sub-sample and the others was statistically significant ($Z_{MWU}=-3.01$, $p<0.01$; $Z_{MWU}=-3.22$, $p<0.01$). Fig. 1 looks the same when respondents who benefited economically are excluded (data not shown).

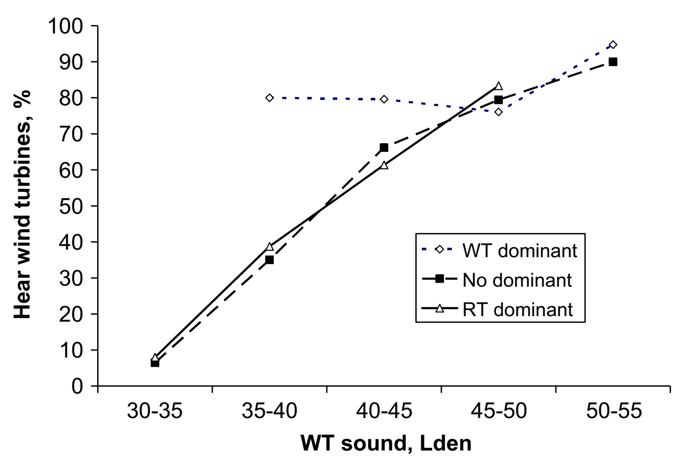

Fig. 1. Proportion of respondents that could hear wind turbine sound at their dwelling or garden/balcony (%) related to levels of wind turbine sound (Lden) for sub-samples with either WT or RT sound as the dominant sound or none of both. All respondents (n=706). Only points representing >5 respondents are depicted.

3.3. Annoyance with wind turbine noise in different levels of background sound

Annoyance with wind turbine noise increased with increase in levels of wind turbine sound (r=0.374, n=622, $p<0.001$) and was approximately the same in the three sub-samples at lower levels (<45 dB(A)) of wind turbine sound (Fig. 2). Although annoyance was highest in the sub-sample dominated by road traffic sound at 45–50 dB(A) WT sound levels, this difference was not statistically significant.

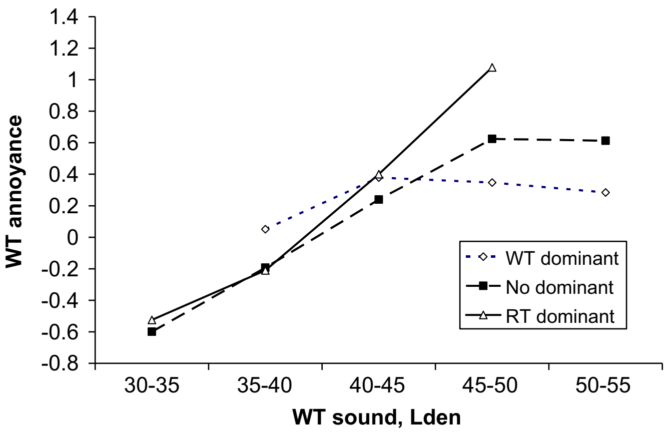

Fig. 2. Mean annoyance score for wind turbine noise in relation to sound levels of wind turbine sound (Lden) for sub-samples with either WT or RT sound as the dominant sound or none of both. All respondents (n=617). Only points representing >5 respondents are depicted.

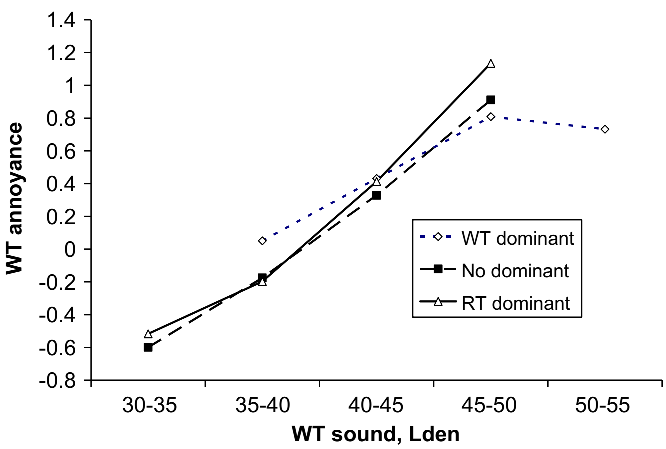

Fig. 3. Mean annoyance score for wind turbine noise in relation to levels of wind turbine sound (Lden) for sub-samples with either WT or RT sound as the dominant sound or none of both. Only respondents that did not benefit economically from wind turbines (n=511). Only points representing >5 respondents are depicted.

Of the respondents that owned wind turbines or otherwise had economical interests in wind turbines (n=100), 64% belonged to the sub-sample dominated by wind turbine sound (Table 1). These respondents showed very little or no annoyance from WT sound. When they were withdrawn from the sample no differences in annoyance scores remained between sub-samples at any level of wind turbine sound (Fig. 3); differences of mean annoyance scores were tested for each interval of sound level and found to be not statistically significant. A comparison between Figs. 2 and 3 shows that the mean value of annoyance with wind turbine sound is in both figures is the same in the RT dominant sub-sample but higher in Fig. 3 than in Fig. 2 for the two other sub-samples. This is in agreement with the fact that almost no one in the RT dominant sub-sample benefited economically from wind turbines and therefore this annoyance score was indifferent to the withdrawal of respondents with economical benefits.

The observation that annoyance with wind turbine noise was *not* lower in the sub-sample dominated by road traffic sound could be due to differences between the sound levels being too small for a masking effect to occur. Also, the average differences between the two sound levels were rather similar for all intervals of WT sound. To investigate this the no dominant sound and RT dominant sub-samples were taken together and divided into

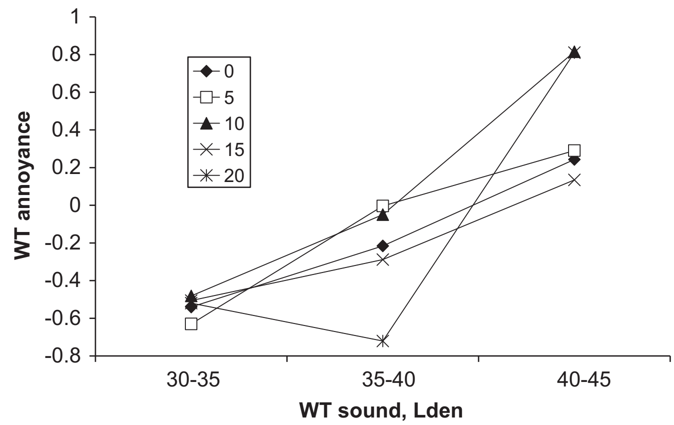

Fig. 4. Mean annoyance score for wind turbine noise in relation to levels of wind turbine sound (Lden) for five situations where RT sound level exceeds WT sound level with 0–5, 5–10, 10–15, 15–20 or >20 dB(A) Lden.

groups with levels of RT sound exceeding those of WT sound with 0–5, 5–10, 10–15, 15–20 or >20 dB(A) in order to explore a possible masking effect when the difference increased. Fig. 4 shows that WT annoyance was reduced when the RT sound level exceeded WT sound level with 20 dB(A), but only in the WT sound interval 35–40 dB(A). This reduction in WT annoyance was significantly different only with respect to the WT annoyance where RT sound exceeded WT sound with 5–10 dB(A) ($t=-0.69$, $p<0.05$); no other differences were statistically significant.

Thus, Fig. 4 indicates that there is a decrease in the WT annoyance and thus a possible masking effect from RT sound at an intermediate level of WT sound, but this masking effect vanishes at higher levels of WT sound for all levels of RT sound studied. A possible synergetic effect at these high levels is explored in the next paragraph.

3.4. Interaction effects between annoyance with wind turbine and road traffic noise

The influence of annoyance with road traffic noise on the relationship between sound levels and wind turbines was modelled with multiple linear regression within the total sample and the three sub-samples. Both respondents that benefited economically and those that did not were included, but all models were adjusted for economical benefits from wind turbines. The continuous annoyance score for wind turbine noise was assigned as dependent variable. The direct influences of the two sound levels were first explored for WT sound only, then WT sound and RT sound simultaneously. Annoyance with wind turbine noise increased with increase in levels of wind turbine sound in the total sample, and road traffic sound at higher or lower levels had no influence on this (Table 3, model 2) as already seen in Fig. 3. Annoyance with road traffic noise was in the third model entered into the regression to explore a possible enhancing effect on annoyance with wind turbine noise (Table 3, model 3). Annoyance with road traffic noise was correlated with sound levels of road traffic (r=0.387, n=587, $p<0.001$), but this correlation did not change the outcome of the regression: WT annoyance did not change substantially when RT sound level was removed (Table 3, model 4). When exploring the sub-samples, road traffic sound level was found to have a negative effect, i.e. a masking effect, on annoyance (Table 3, model 3) with wind turbine noise in the sub-sample dominated by road traffic sound, but not in the others. This reduction due to RT sound *level* was, however, balanced by an increase in WT annoyance caused by RT *annoyance*. Noise annoyance with road traffic was associated with noise

Table 3
Linear regression models exploring the influence of wind turbine sound, road traffic sound and annoyance from road traffic sound, on annoyance with wind turbine sound. Independent variables in the models are wind turbine sound level and/or road traffic sound level and/or road traffic noise annoyance.

	Total		WT dominant		No dominant		RT dominant	
	Beta	*p*	Beta	*p*	Beta	*p*	Beta	*p*
Model 1[a], R-square[b]	*0.20 (n=609)*		*0.07 (n=145)*		*0.22 (n=201)*		*0.21 (n=263)*	
WT sound	**0.53**	< **0.001**	0.19	0.054	**0.152**	< **0.001**	**0.047**	< **0.001**
Model 2[a], R-square[b]	*0.20 (n=609)*		*0.09 (n=145)*		*0.25 (n=201)*		*0.22 (n=263)*	
WT sound	**0.53**	< **0.001**	0.13	0.220	**0.39**	< **0.001**	**0.51**	< **0.001**
RT sound	0.02	0.571	0.11	0.260	**0.18**	< **0.05**	−0.09	0.166
Model 3[a], R-square	*0.25 (n=525)*		*0.08 (n=122)*		*0.29 (n=159)*		*0.27 (n=244)*	
WT sound	**0.50**	< **0.001**	0.21	0.087	**0.35**	< **0.001**	**0.51**	< **0.001**
RT sound	−0.06	0.137	0.04	0.712	0.08	0.433	**−0.17**	< **0.05**
RT annoyance	**0.24**	< **0.001**	0.10	0.283	**0.30**	< **0.001**	**0.23**	< **0.001**
Model 4[a], R-square	*0.25 (n=525)*		*0.08 (n=122)*		*0.29 (n=159)*		*0.26 (n=244)*	
WT sound	**0.51**	< **0.001**	**0.24**	< **0.05**	**0.40**	< **0.001**	**0.43**	< **0.001**
RT annoyance	**0.22**	< **0.001**	0.10	0.102	**0.32**	< **0.001**	**0.18**	< **0.01**

[a] Adjusted for economical benefits from wind turbines.
[b] *R*-square for the model, i.e. the proportion of variation in the dependent variable explained by all the independent variables in the model.

Table 4
Associations between explorative variables (tested one by one) on the one hand and annoyance with wind turbine and road traffic noises on the other hand, respectively.

	WT annoyance		RT annoyance	
WT sound	r=0.374	$\boldsymbol{p<0.001}$	r=0.027	p=0.513
RT sound	$r=-0.029$	p=0.474	r=0.387	$\boldsymbol{p<0.001}$
Age	r=0.012	p=0.775	r=0.002	p=0.965
Gender	$Z_{MWU}=-1.20$	p=0.231	$Z_{MWU}=-0.06$	p=0.956
Noise sensitive	r_s=0.127	$\boldsymbol{p<0.01}$	r_s=0.343	$\boldsymbol{p<0.001}$
WT visibility	$Z_{MWU}=-12.99$	$\boldsymbol{p<0.001}$	$Z_{MWU}=-1.51$	p=0.131
RT visibility	$Z_{MWU}=-5.57$	$\boldsymbol{p<0.001}$	$Z_{MWU}=-9.34$	$\boldsymbol{p<0.001}$
WT attitude	r_s=0.289	$\boldsymbol{p<0.001}$	r_s=0.153	$\boldsymbol{p<0.001}$
RT attitude	r_s=0.118	$\boldsymbol{p<0.01}$	r_s=0.279	$\boldsymbol{p<0.001}$
Economical benefits from wind turbines	$Z_{MWU}=-3.14$	$\boldsymbol{p<0.01}$	$Z_{MWU}=-2.06$	$\boldsymbol{p<0.05}$
Stress	r=0.128	$\boldsymbol{p<0.01}$	r=0.177	$\boldsymbol{p<0.001}$

annoyance due to wind turbines in the sub-sample dominated by road traffic sound and that with no dominance, but not in the WT dominant. Also, none of the models explained more than 9% of the variance of annoyance with wind turbine noise in the WT dominant sub-sample meaning that other factors must be of importance in this sub-sample. In the total sample WT sound predicted 20–25% of the WT annoyance, but there was also a relationship between annoyances with the two sounds so that an increase in annoyance with road traffic sound increased annoyance with wind turbine sound. This could be a synergetic effect, or the effect of common confounders such as noise sensitivity leading to annoyance with both sounds. Possible confounders were therefore investigated in the next step.

3.5. Possible confounders

The association between annoyance with wind turbine noise and road traffic noise that was found in the regression models could be due to other underlying factors influencing both. Possible factors are listed in Table 4 with their relation to WT and RT annoyances, respectively. As expected, levels of wind turbine sound and visibility of wind turbines were correlated with annoyance due to wind turbine noise, but not with annoyance due to road traffic noise. Age and gender were not associated to either annoyance score. Noise sensitivity, stress and being negative to the visual impact of wind turbines and/or roads on the landscape scenery were variables that were all positively correlated with both the annoyance scores. Both annoyance scores were also higher for those who could see busy roads, in comparison with those who could not, but WT annoyance was related to the visibility of wind turbines only. Also, both annoyance scores were higher for those who did not benefit economically from wind turbines.

Variables that were found to be associated with one or both the annoyance scores in Table 4 were tested in a multivariate general linear model in which the association between explorative and two dependent variables were tested simultaneously, including all respondents. Dose–response relationships between sound levels and annoyance were found for wind turbines and road traffic, respectively, but levels of one sound did not influence annoyance with the other sound (Table 5). Visibility of a source did only influence annoyance with that source, and, similar, attitude towards a source was only related to annoyance with that specific source. Noise sensitivity and symptoms of stress were associated with *both* annoyance due to wind turbine and road traffic sounds.

4. Discussion

The expectation that the presence of road traffic sound would reduce the prevalence of annoyance due to noise from wind turbines in general was not confirmed in this systematical

Table 5
Result of multivariate general linear model where the association between possible explorative variables (column 1) and the two measurements of annoyance were tested simultaneously (n=480).

	WT annoyance		RT annoyance	
	Adj. R-sq.[a]=0.43		Adj. R-sq.[a]=0.38	
	P eta[b]	p	P eta[a]	p
WT sound	**0.12**	< **0.001**	0.01	0.140
WT visibility	**0.06**	< **0.001**	0.00	0.865
WT attitude	**0.17**	< **0.001**	0.00	0.413
RT sound	0.00	0.615	**0.13**	< **0.001**
RT visibility	0.00	0.253	**0.11**	< **0.001**
RT attitude	0.00	0.942	**0.04**	< **0.001**
Noise sensitive	**0.01**	< **0.05**	**0.06**	< **0.001**
Stress	**0.01**	< **0.05**	**0.01**	< **0.05**

[a] R-square for the dependent variable, i.e. the proportion of variation in the dependent variable explained by all the independent variables in the model.
[b] Partial eta-squared value; describes the proportion of total variability attributable to a factor; adjusted for economical benefits from wind turbines.

analysis of a large data set. The relationships between sound levels and annoyance with the noise were in most cases separate for wind turbine and road traffic, respectively, and not interacting. Several interesting findings could however guide future planning for wind farms.

Wind turbine sound is, as found in other studies (Pedersen and Persson Waye, 2004; 2007), very easily perceived and about 80% of the respondent in this study could hear the sound at levels as low as 35–40 dB(A) Lden when background sound levels were low. Wind turbines were less easily heard when road traffic sound dominated over wind turbine sound, but this did not result in a change in annoyance: the dose–response relationship between levels of wind turbine noise and annoyance were about the same despite levels of road traffic sound. The exception is that high levels of road traffic sound (> 55 dB(A)) did seem to have a masking effect on wind turbine sound, but only at moderate levels of wind turbine sound (35–40 dB(A)). This statistically significant finding was confirmed in the regression models where an *increase* in road traffic noise led to a *decrease* in annoyance of wind turbine noise in the sub-sample dominated by road traffic noise. This is consistent with previous findings (for the same data set) of a reduction of annoyance with wind turbine noise in rural areas with a main road as opposed to areas without (Pedersen et al., 2009). The effect at 35–40 dB(A) vanished when the wind turbine sound level increased further. It is hence possible to reduce the prevalence of annoyance with wind turbine noise if the turbines are placed in areas with high levels of road traffic noise, but the levels of wind turbine noise need to be held back even at these sites. The reduction as yet cannot be predicted due to the low number of respondents with road traffic noise exceeding wind turbine noise with more than 20 dB(A). An explanation for the low masking potential of even relatively high levels of background sound may be that the Lden background level in fact averages over fluctuations in traffic intensity and daily patterns (rush hour) and over slower variations related to weather (down/upwind). Wind turbine sound may not be masked at times of low background sound levels (the 'troughs' in the level over time) and these times may determine annoyance, perhaps independent of the time length of the exposure. Wind turbine sound levels do not follow the same behaviour as road traffic noise levels. Road traffic usually calms at night, whereas modern, tall wind turbines may produce more sound at night than in daytime. Also, there is less difference between downwind and upwind audibility due to the fact that the source is high above ground and thus for an upwind situation the sound shadow is further away than it is for a low source (road traffic). Only at relatively very high background sound levels, the troughs are not deep enough to reach the level of the wind turbine sound.

Except for the masking at 35–40 dB(A) wind turbine sound, no other effects were found. This study shows that being exposed to road traffic noise as well, did not lead to more annoyance related to wind turbine noise. The observed relation between annoyance with road traffic and wind turbine noises could be explained by common confounders, in this case noise sensitivity and stress. Noise sensitivity is usually not seen as a result of annoyance, but as a personal trait independent of exposure (Job, 1999). It is reasonable to believe that individual factors enhance the possibility of annoyance both with wind turbine and road traffic noises, and that no other interaction between annoyances with the two noise types takes place.

5. Application to wind farm planning

In the sometimes heated local debates about wind farm proposals it is important to consider the qualities of the proposed sites if the conversion from electricity generation based on fossil fuels to that of wind is to be successful and not cause adverse effects on residents and local communities. The presence of other noise sources such as road traffic is one of these qualities.

Residents near busy roads are less likely to oppose potential wind farm developments (van den Horst, 2007). Placing wind farms in areas with low background levels is more delicate. This is not unique for wind turbines; also annoyance due to aircraft noise is higher in low background sound regions in comparison to those with high background levels (Lim et al., 2008). It is not clear if indeed the differences in background levels between areas cause the difference in noise annoyance or another, possibly related factor such as landscape type. Landscape values are strongly related to the acceptability to wind farms; industrial areas and military grounds are considered suitable, while landscapes with natural and cultural preservation values are rated as not suitable (Wolsink, 2007).

The present study shows that road traffic noise can provide a significant masking of wind farm noise, but only at intermediate levels of wind turbine sound (35–40 dB(A)), not at higher or lower levels. This only occurs if the road traffic is substantially louder (+20 dB) than the wind turbines. These intermediate levels are within the range where most countries have noise limits for wind turbines (35–45 dB(A)).Thus, one would expect less noise annoyance from a not too near wind farm if residents are already exposed to road traffic sound levels of 55–60 dB(A).

Acknowledgement

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BEFORE THE PUBLIC UTILITIES COMMISSION
OF THE STATE OF SOUTH DAKOTA

IN THE MATTER OF THE APPLICATION OF
CROWNED RIDGE, LLC FOR A FACILITIES PERMIT TO
CONSTRUCTION 300 MEGAWATT WIND FACILITY

Docket No. EL19-003

REBUTTAL TESTIMONY AND EXHIBITS

OF RICHARD LAMPETER

May 24, 2019

INTRODUCTION AND QUALIFICATIONS

Q. PLEASE STATE YOUR NAME AND BUSINESS ADDRESS.

A. My name is Richard Lampeter. My business address is 3 Mill & Main Place, Suite 250, Maynard, MA 01754.

Q. BY WHOM ARE YOU EMPLOYED AND IN WHAT CAPACITY?

A. I am employed at Epsilon Associates, Inc. ("Epsilon"). I am an Associate at the company and manage the Acoustics Group.

Q. PLEASE DESCRIBE YOUR BACKGROUND AND QUALIFICATIONS

A. I have over 15 years of experience in conducting impact assessments for various developments across the United States. Prior to joining Epsilon, I graduated from Lyndon State College in Vermont with a B.S. in Environmental Science. While at Epsilon, I have been involved in approximately 90 wind energy projects evaluating potential impacts from sound and/or shadow flicker. The projects I have worked on ranged in size from 1.5 megawatts ("MW") to over 300 MW. I utilize the WindPRO software package to calculate shadow flicker durations in the vicinity of a project on both a worst-case and expected basis. As part of project evaluations, I have assisted in refinements in wind turbine layouts to minimize shadow flicker at residences, evaluated curtailment options, and analyzed the impact of existing vegetation to modeled shadow flicker durations. My other areas of expertise include the measurement of ambient sound levels, modeling sound levels from proposed developments, evaluation of conceptual mitigation, and compliance sound level measurements. I have conducted impact assessments for power generating facilities, commercial developments, industrial facilities, and transfer stations. In addition to conducting and/or managing the impact assessments, I have presented the results of the analyses at public meetings to county and township boards. Additional detail regarding my education, background and experience is contained in my curriculum vitae, which is attached as Exhibit RL-R-1.

Q. HAS THIS TESTIMONY BEEN PREPARED BY YOU OR UNDER YOUR DIRECT SUPERVISION?

A. Yes.

Q. HAVE YOU PREVIOUSLY TESTIFIED BEFORE THE SOUTH DAKOTA PUBLIC UTILITIES COMMISSION?

A. No.

Q. PLEASE DESCRIBE THE PURPOSE OF YOUR REBUTTAL TESTIMONY.

A. The purpose of my testimony is to respond to Staff witness David Hessler and the Intervenors' proposed conditions as set forth in Staff witness Darren Kearney's Exhibit DK-8.

SOUND STUDY

Q. STAFF WITNESS HESSLER'S TESTIMONY AT PAGE 3, LINES 11-22 ASSERTS THAT CROWNED RIDGE WIND, LLC ("CRW") SHOULD HAVE CONDUCTED A BASELINE SOUND SURVEY(S) TO INFORM THE DESIGN OF THE WIND PROJECT. DO YOU AGREE?

A. I do not agree with Mr. Hessler that a baseline sound level of existing conditions should have been conducted. The applicable sound level limits in the counties are based on sound generated from wind turbines at either the property line or at a non-participating structure (residence, business, or government building). Collecting baseline ambient sound levels would be of minimal value as it is not applicable to these limits. This is because to evaluate the limits one simply compares the modeling sound pressure level to the sound level limit stated in the regulation. It would not involve combining the existing sound levels with predicted future sound levels due to the wind turbines or calculating a delta between total future sound levels (Project + Existing) and the existing ambient sound levels. Therefore, sound level modeling is sufficient to evaluate these limits. In addition, evaluating an increase over background limit is problematic as there are many factors which impact sound levels, making it difficult to assign one number as the background sound level. For example, sound levels will vary over time and will vary under differing wind conditions. In addition, ambient sound can be presented using different metrics, which in turn results in different sound levels. This type of limit, i.e., increase over background, leads to greater uncertainty for the developer\owner\operator as compared a static Project Only sound level limit.

INFRASOUND

Q. THE INTERVENORS' PROPOSED CONDITIONS 6, 7, AND 23 (KEARNEY EXHIBIT DK-8) INCLUDE REQUIREMENTS FOR CRW TO MEASURE INFRASOUND. DO YOU AGREE INFRASOUND SHOULD BE MEASURED?

A. I do not agree. Low frequency noise and infrasound are present in the environment due to other sources besides wind turbines. For example, refrigerators, air conditioners, and washing machines generate infrasound and low frequency sound, as do natural sources such as ocean waves. The frequency range of low frequency sound is generally from 20 hertz ("Hz") to 200 Hz, and the range below 20 Hz is often described as infrasound. However, audibility can extend to frequencies below 20 Hz if the energy is high enough. Since there is no sharp change in hearing at 20 Hz, the division between low frequency noise and infrasound should only be considered practical and conventional. The threshold of hearing is standardized for frequencies down to 20 Hz (Acoustics - Normal equal-loudness-level contours, International Standard ISO 226:2003, International Organization for Standardization, Geneva, Switzerland, (2003)).

Also, the Massachusetts Department of Environmental Protection ("MA DEP") and the Massachusetts Department of Public Health commissioned an expert panel who found that: "Claims infrasound from wind turbines directly impacts the vestibular system have not been demonstrated scientifically. Available evidence shows that the infrasound levels near wind turbines cannot impact the vestibular system." (*Wind Turbine Health Impact Study: Review of Independent Expert Panel,* Massachusetts Department of Environmental Protection and Massachusetts Department of Public Health, January 2012.) (attached as Exhibit RL-R-2).

As noted in a report prepared for the National Association of Regulatory Utility Commissioners ("NARUC") in 2011, "the widespread belief that wind turbines produce elevated or even harmful levels of low frequency and infrasonic sound is utterly untrue as proven repeatedly and independently by numerous investigators..." (Assessing Sound Emissions from Proposed Wind Farms & Measuring the Performance of Completed Projects, NARUC, prepared by Hessler Associates, Inc., October 2011.) (attached as Exhibit RL-R-3).

The findings presented in the peer reviewed journal article I co-authored (*Low frequency noise and infrasound from wind turbines,* R. O'Neal et al, Noise Control Engineering J., 59(2), 2011.), which is attached as Exhibit RL-R-4, found for the wind turbines studied that there was no audible infrasound either outside or inside homes at 1,000 feet from a wind turbine. Additional findings included that sound levels met the American National Standards Institute ("ANSI") standard for low frequency noise in bedrooms, classrooms, and hospitals, met the ANSI standard for thresholds of annoyance from low frequency noise, and met the ANSI standard for vibration of light-weight walls or ceilings. In homes there may be slightly audible low frequency noise beginning at around 50 Hz (depending on other sources of low frequency noise); however, the levels are below criteria and recommendations for low frequency noise within homes.

SOUND MONITORING

Q. THE INTERVENORS' PROPOSED CONDITION 6 (KEARNEY EXHIBIT DK-8) WOULD REQUIRE A PRECONSTRUCTION SOUND STUDY ANALYSIS, INCLUDING INFRASOUND, OF NON-PARTICIPATING PROPERTIES, OUTSIDE AND INSIDE THE PRINCIPLE STRUCTURE TO BE CONDUCTED BY A THIRD-PARTY. DO YOU AGREE WITH SUCH AN APPROACH?

A. A pre-construction sound study as described is not necessary. A pre-construction sound study sufficient to address the regulatory requirements has already been conducted. That study, submitted by CRW witness Jay Haley, modeled future operational sound levels and compared those sound levels to each county's sound level limit. Since the sound level limit in each county is a single sound pressure level and not individual limits for particular frequencies, the collection of specific infrasound measurements is unnecessary to evaluate compliance with respect to these sound level limits.

A pre-construction measurement program would not be needed for the reasons discussed previously in the response to Hessler's comment regarding pre-construction sound level measurements.

Q. THE INTERVENORS' PROPOSED CONDITION 7 (KEARNEY EXHIBIT DK-8) WOULD REQUIRE CRW TO CONDUCT SOUND MONITORING, INCLUDING

INFRASOUND, DURING CONSTRUCTION. DO YOU AGREE THAT SOUND MONITORING, INCLUDING INFRASOUND, SHOULD BE COMPLETED DURING CONSTRUCTION?

A. I am unaware of any specific applicable state or county sound limit during construction. In my experience, sound level limits for the construction of wind energy facilities are atypical. Nonetheless, I understand that CRW witness Mark Thompson will address how CRW will implement measures to mitigate sound during construction.

Q. THE INTERVENORS' PROPOSED CONDITION 7 (KEARNEY EXHIBIT DK-8) WOULD REQUIRE CRW TO CONDUCT SOUND MONITORING, INCLUDING INFRASOUND, DURING OPERATION AND MAINTENANCE. DO YOU AGREE THAT SOUND MONITORING, INCLUDING MONITORING OF INFRASOUND, SHOULD BE COMPLETED DURING OPERATION AND MAINTENANCE?

A. I agree that a condition on post-construction sound monitoring of operating conditions would be appropriate, but do not agree that a condition requiring sound monitoring during maintenance or that monitoring of infrasound is necessary or appropriate. The Commission's past permits require post-construction sound monitoring. For example, in Dakota Range I and II, Crocker Wind Farm, and most recently in Dakota Range III, the Commission ordered the following: "The Project, exclusive of all unrelated background noise, shall not generate a long-term average sound pressure level (equivalent continuous sound level, L_{eq}), as measured over a period of at least two weeks, defined by Commission Staff, that includes all integer wind speeds from cut in to full power . . . ."

Inclusion of this condition in the facility permit for the CRW wind facility would address the monitoring of sound during operation. Since the sound level limit in each county is a single sound pressure level and not individual limits for particular frequencies, the collection of specific infrasound measurements is unnecessary to evaluate compliance with respect to these sound level limits.

Sound level limits are typically applied to standard operating conditions. Therefore, the sound limits, such as those presented in the county ordinances and implemented by the Commission in past cases, would not be applicable to limited and intermittent maintenance sounds that occur over the course of the project's life.

Q. THE INTERVENORS' PROPOSED CONDITION 7 (KEARNEY EXHIBIT DK-8) WOULD REQUIRE CRW TO CONDUCT SOUND MONITORING, INCLUDING INFRASOUND, DURING DECOMMISSIONING. DO YOU AGREE THAT SOUND MONITORING, INCLUDING INFRASOUND, SHOULD BE COMPLETED DURING DECOMMISSIONING?

A. No, I do not. Similar to construction, I am unaware of any state or county limit on sound during decommissioning. Therefore, the monitoring of sound during this temporary condition would be unnecessary.

POST CONSTRUCTION SOUND MONITORING METHODOLOGY AND REPORTING

Q. THE INTERVENORS' PROPOSED CONDITIONS 19, 20, AND 21 (KEARNEY EXHIBIT DK-8) WOULD REQUIRE CRW TO MEASURE SOUND DBA AT L_{10}. DO YOU AGREE WITH THIS APPROACH?

A. I do not. Based on my experience, the L_{eq}, or equivalent sound level, is the most widely used metric in the United States and the appropriate sound level metric for evaluating sound level impacts from wind energy facilities. As I stated previously, three recent permits in South Dakota have required post construction sound level monitoring using the L_{eq} metric.

In addition, the L_{eq} is directly comparable to the model output of pre-construction predictive models provided by CRW witness Jay Haley, as the modeling incorporates the L_{eq} sound power levels provided by the wind turbine manufacturers.

The L_{10}, or the sound level exceeded 10 percent of the time, is more susceptible to wind gusts and other extraneous events than the L_{eq}, which can result in elevated sound levels unrelated to the operation of the wind turbines.

Q. THE INTERVENORS' PROPOSED CONDITION 19 (KEARNEY EXHIBIT DK-8) WOULD REQUIRE CRW TO ENGAGE A THIRD PARTY TO MEASURE SOUND EVERY YEAR OUTSIDE AND INSIDE NON-PARTICIPATING LANDOWNERS' HOMES WITHIN 2 MILES OF THE BOUNDARY FOOTPRINT AND THE WAVERLY SCHOOL. DO YOU AGREE WITH UTILIZING SUCH AN APPROACH?

A. No. A condition to require sound level measurements every year at all non-participating homes is onerous and unnecessary. All compliance sound level evaluations are done at a reasonable subset of possible monitoring locations considering distance, modeled sound levels, turbine types, and proximity to other monitoring locations in order to determine compliance for the facility as a whole.

As the sound level limits are exterior limits, there is no additional value in attempting to collect sound levels within a residence, which would be more difficult to obtain, subject to extraneous noise (conversations, television, etc.), and would be lower than sound levels measured at the exterior of the home. In other words, Mr. Haley's modeling would only indicate what would be experienced outdoors, and, therefore, the sound level experienced indoors due to the wind turbines would be less due to the sound transmission loss of the house itself.

Q. THE INTERVENORS' PROPOSED CONDITION 19 (KEARNEY EXHIBIT DK-8) WOULD REQUIRE CRW TO CONDUCT SOUND MONITORING DURING EVEN NUMBERED YEARS IN THE SPRING AND FALL FOR 14 DAYS 24 HOURS CONTINUOUS. DURING THE ODD NUMBERED YEARS THE MEASUREMENT WOULD BE IN THE SUMMER AND WINTER FOR 14 DAYS 24 HOURS CONTINUOUSLY. DO YOU AGREE WITH SUCH AN APPROACH?

A. I disagree with the approach proposed. One properly designed sound level measurement program of an adequate duration is sufficient to determine compliance with respect to sound at the wind energy facility.

SOUND THRESHOLDS

Q. THE INTERVENORS' PROPOSED CONDITIONS 19, 20, AND 21 (KEARNEY EXHIBIT DK-8) WOULD REQUIRE THAT NOISE NOT EXCEED 40 DBA L_{10} AT THE PROPERTY LINE OF A NON-PARTICIPATING PROPERTY, INCLUDING DURING CONSTRUCTION, MAINTENANCE, OPERATION, AND DECOMMISSIONING. THE REQUIREMENT WOULD BE ENFORCED IN ALL AREAS WITHIN 2 MILES OF THE PROJECT BOUNDARY FOOTPRINT AND

WITHIN 2 MILES OF ANY HAUL ROAD FOR THE LIFE OF THE PROJECT. DO YOU AGREE WITH SUCH AN PROPOSAL?

A. I disagree with the proposed sound level limit. This proposal is unnecessarily more restrictive on multiple levels as compared to either of the Grant or Codington county sound level requirements. Further, the Intervenors have provided no support for lowering the sound limit to a 40 dBA threshold for non-participants at their property line. Also, this proposal incorporates the L_{10} sound level metric, which as described earlier, is not the preferred metric from a technical standpoint and is more restrictive. Thus, the Intervenors condition is not supported or appropriate.

Q. THE INTERVENORS' PROPOSED CONDITION 19 (KEARNEY EXHIBIT DK-8) WOULD REQUIRE SOUND TO BE MEASURED AT 40 DBA L_{10} BY A THIRD PARTY EVERY YEAR OUTSIDE AND INSIDE NON-PARTICIPATING LANDOWNERS' HOMES WITHIN 2 MILES OF THE BOUNDARY FOOTPRINT AND THE WAVERLY SCHOOL. DO YOU AGREE WITH SUCH A PROPOSAL?

A. I disagree with this proposed requirement. As stated previously, 40 dBA and L_{10} are inconsistent with the Grant and Codington county requirements, and there is no support provided by the Intervenors for imposing a 40 dBA limit. Further, compliance sound level evaluations are done at a reasonable subset of possible monitoring locations considering distance, modeled sound levels, turbine types, and proximity to other monitoring locations in order to determine compliance for the facility as a whole. Since the sound level limits are exterior limits, there is no additional value in attempting to collect sound levels within a residence given that they are more difficult to obtain, subject to extraneous noise (conversations, tv, etc.), and would be lower than sound levels measured at the exterior of the home. Thus, I do not support the Intervenors' proposed condition.

Q. DOES THIS CONCLUDE YOUR TESTIMONY?

A. Yes.

STATE OF MASSACHUSETTS)
) ss
COUNTY OF MIDDLESEX)

I, Richard Lampeter, being duly sworn on oath, depose and state that I am the witness identified in the foregoing prepared testimony and I am familiar with its contents, and that the facts set forth are true to the best of my knowledge, information and belief.

Richard Lampeter
Richard Lampeter

Subscribed and sworn to before me this 24 th day of May, 2019.

SEAL

Notary Public
ERIK R. REXFORD
My Commission Expires July 29, 2022

RICHARD M. LAMPETER, INCE

ASSOCIATE

EDUCATION

B.S., Environmental Science, Lyndon State College, 2001

PROFESSIONAL SUMMARY

Mr. Lampeter has more than 15 years of experience in conducting community sound level impact assessments. His areas of expertise include the measurement of ambient sound levels, modeling sound levels from proposed developments, evaluation of conceptual mitigation, and compliance sound level measurements. Mr. Lampeter has conducted impact assessments for power generating facilities, commercial developments, industrial facilities, and transfer stations. Richard's understanding of acoustical standards and modeling software has allowed him to provide accurate and reliable modeling results to developers and communities.

Since 2004, Mr. Lampeter has been involved in approximately 90 wind energy projects. In addition to performing numerous sound level impact assessments for wind energy facilities, Mr. Lampeter has conducted shadow flicker analyses for approximately 50 wind energy projects across the United States. Mr. Lampeter frequently presents key aspects of analyses to boards and committees and has provided sworn expert testimony.

Mr. Lampeter utilizes his diverse skill set as he serves in a variety of rolls on projects, ranging from project manager, to modeler, to field scientist. Richard is adept at using Larson Davis, Norsonic, RION, and CEL sound level meters and various modeling software packages including, Cadna/A and WindPRO.

Mr. Lampeter also has experience in air quality modeling and meteorological monitoring. Richard has used a variety of air dispersion models including CAL3QHCR, AERMOD, and CALPUFF and has displayed expertise in working with HOBO and NovaLynx portable weather stations.

Mr. Lampeter has co-authored several papers ranging in topics from wind energy to metal shredders, one of which appeared in a peer-reviewed journal. Mr. Lampeter has been a speaker at CanWEA's annual conference on the topic of low frequency noise from wind turbines and presented shadow flicker guidance and a regulatory update in a New England Wind Energy Education Project webinar.

PROFESSIONAL EXPERIENCE

Noise Impact Assessment – Power Projects – Renewable Energy

- *NextEra Energy Resources – Tuscola Wind II, Tuscola County, MI.* Project Manager for pre- and post-construction sound level impact assessments for a 100 megawatt (MW) wind energy facility composed of 59 GE wind turbines. Modeling was performed in order to demonstrate compliance with the sound level limits in each community. During multiple public hearings, Mr. Lampeter responded to questions and comments. Following construction, operational sound levels were measured in each of the four townships per ordinance requirements.

- *Boreal Renewable Energy Development – Christopher House Wind Turbine Generator Project, Worcester, MA.* Project Manager for a sound level impact assessment prepared for a wind turbine feasibility study. Measured ambient background sound levels and modeled wind turbine sound levels under two scenarios. Impacts were compared to the local zoning ordinance and the Massachusetts Department of Environmental Protection (MassDEP) Noise Policy.

- *Palmer Renewable Energy Project, Springfield, MA*. Predicted future sound levels from a proposed 38 MW renewable biomass energy plant using the Cadna/A software package. Impacts were compared to state and local regulations with the results presented in the Environmental Notification Form.

- *NextEra Energy Resources – Pheasant Run Wind Energy Center, Huron County, MI*. Project Manager for a post-construction sound level compliance evaluation for a wind power generation facility composed of 88 wind turbines and an electrical substation. Sound levels were measured and evaluated at 15 residential locations. Following the submittal of a comprehensive report, results were presented to the Huron County Planning Commission.

- *Zotos International, Inc. – Two Wind Turbine Project, Geneva, NY.* Conducted a sound level impact assessment for two proposed wind turbines at the existing Zotos International facility. Calculated future sound levels using the Cadna/A noise calculation software. Prepared a comprehensive report comparing modeled sound levels to local regulations and relevant criteria. Presented the sound level assessment to the City of Geneva Planning Board.

- *FPL Energy (now NextEra Energy Resources) – Horse Hollow Wind Energy Center, Taylor County, TX*. Assisted in the development and execution of multiple sound level measurement programs for the 735 MW wind farm which at the time of its in-service date it was the world's largest wind farm. Analyzed sound level data in conjunction with power output data provided by NextEra Energy Resources and assisted in the preparation for legal proceedings.

- *Iberdrola Renewables – Groton Wind, Groton, NH.* Assisted in the collection of pre-construction ambient sound levels for a proposed 48 MW wind energy facility. Conducted post-construction sound level measurement programs in order to address the requirements of the State of New Hampshire Site Evaluation Committee Order and the Certificate of Site and Facility with Conditions for the Groton Wind Project. Analyzed the data collected for the evaluation of applicable limits.

- *NextEra Energy Resources – Lake Benton II Wind Project, Pipestone County, MN*. Project Manager for a sound level assessment for a repower project in Minnesota. The assessment consisted of an ambient measurement program and sound level modeling of the proposed wind turbines and existing wind turbines in the vicinity of the project. The findings were presented in a comprehensive report.

- *Heritage Sustainable Energy – Big Turtle Wind Farm Phase 2, Huron County, MI.* Project Manager for a pre- and post-construction sound level assessment for a wind energy facility to consisting of 14 Gamesa wind turbines. Sound levels were evaluated with respect to limits in the Huron County Wind Energy Facility Overlay Zoning Ordinance. Presented the results of the post-construction compliance evaluation to the Huron County Planning Commission.

- *Confidential Project, OK.* Project Manager for a sound level impact analysis. Developed and executed sound level measurement program in response to complaints made by a resident living adjacent to the wind farm. Data were compared to a generally accepted guideline and presented in a letter report.

- *NextEra Energy Resources – Golden West Wind Energy Center, El Paso County, CO.* Project Manager for a post-construction sound level evaluation of 249.4 MW wind power generation facility composed of 145 GE wind turbines. Collected attended and unattended sound level and meteorological data during two measurement programs. Presented the findings of the study to the Board of County Commissioners.

- *NextEra Energy Resources – Eight Point Wind Energy Center, Steuben County, NY.* Assisted in the sound level modeling for the pre-construction impact assessment required as part of the NY State Article 10 process. Sounds levels were modeled using Cadna/A and incorporated CONCAWE meteorology.

- *NextEra Energy Resources – Lee/DeKalb Wind Energy Center, Lee and DeKalb Counties, IL.* Developed and executed a post-construction sound level measurement program for a 217.5 MW wind farm consisting of 145 GE 1.5xle wind turbines. Over 5,000 hours were collected over a 5-week period at 16 locations. The results of this program found that sound levels due to the wind turbines under worst-case conditions were at or below the Illinois Pollution Control Board noise limits.

- *FPL – St. Lucie Wind Turbine Generation Project, St. Lucie County, FL.* Assisted in the development and execution of an extensive sound level measurement and modeling program for a proposed wind farm in St. Lucie County, FL. Collected ambient sound level data and meteorological data. Calculated the sound levels resulting from the operation of the wind turbines using the WindPRO modeling software. Six wind turbines were proposed to be constructed along a beach in Florida.

- *Boreal Renewable Energy Development – Nauset Regional High School Wind Turbine Generator Project, Eastham, MA.* Conducted a sound level impact assessment for a wind turbine feasibility study. Prepared a comprehensive letter report comparing modeled sound levels to the MassDEP Noise Policy.

- *NextEra Energy Resources – Tuscola Bay Wind Energy Center, Tuscola, Bay, & Saginaw Counties, MI.* Managed a sound level impact assessment project for a proposed 120 MW wind power generation facility composed of 75 wind turbines. Modeling was performed in order to demonstrate compliance with the sound level limits in each community. During multiple public hearings, Mr. Lampeter responded to questions and comments. Following construction, operational sound levels were measured as required by the township's ordinance.

- *NextEra Energy Resources - Waymart Wind Farm, Waymart, PA*. Executed multiple post-construction sound level measurement programs around the 65 MW wind turbine facility. Analyzed pre- and post-construction sound level data. Summarized data in succinct letter reports.

- *Iberdrola Renewables – Wild Meadows, Alexandria & Danbury, NH.* Measured ambient sound levels for a proposed 75.9 MW wind energy facility. Sound levels were measured at eight locations representative of nearby residences in various directions from the proposed wind turbines.

- *NextEra Energy Resources – Pegasus Wind Energy Center, Tuscola County, MI*. Project Manager for a pre-construction acoustic study for a 62 wind turbine project. Both ambient sound level measurements and sound level modeling were components of the project. Presented analysis findings and responded to questions and comments during multiple public hearings.

- *John Deere Wind Energy – Michigan Wind 1 Wind Farm, Huron County, MI.* Measured and analyzed post-construction sound level data collected to assess compliance with the Huron County noise ordinance and address complaints. The wind farm is a 69 MW project consisting of 46 GE 1.5sle wind turbines. Sound levels were measured at 14 different locations over a 20-day period. Over 4,000 hours of data were collected and analyzed for this program.

- *Heritage Sustainable Energy – Big Turtle Wind Farm, Huron County, MI.* Project Manager for a sound level compliance evaluation for an existing 20 MW wind energy facility composed of 10 Gamesa wind turbines. Measured sound levels were evaluated with respect to limits in the Huron County Wind Energy Facility Overlay Zoning Ordinance.

- *Confidential Project, IA*. Project Manager for a sound level impact assessment for a wind farm in Iowa. Predicted future sound levels due to the operation of the wind turbines in areas surrounding the wind farm. Data were presented in tabular format and overlaid onto aerial photography.

- *NextEra Energy Resources – Osborn Wind Energy Center, MO.* Provided expert opinions regarding proposed amendments to the Clinton County Zoning Ordinance with respect to sound from a Wind Energy Conversion System. Provided sworn testimony under direct and cross examination at a Clinton County Planning & Zoning Commission hearing.

Noise Impact Assessment – Power Projects

- *Medical Area Total Energy Plant (MATEP), Boston, MA*. Managed multiple sound level measurement programs for the plant following the installation of two combustion turbines, gas compressors, and cooling towers. These programs included background sound level measurements, compliance operational sound level measurements, and evaluations of noise mitigation. The results of these measurement programs have been summarized in reports submitted to Veolia Energy and regulatory agencies. Assisted in the sound level modeling of a proposed 14.4 MW combustion turbine with a Heat Recovery Steam Generator. Collected sound level data for various rooftop equipment. Conducted post-construction sound level measurements for the evaluation of the MassDEP Noise Policy.

- *Lean Flame, Watervliet Arsenal, NY*. Project Manager for a sound level impact assessment for a proposed GE Frame 5 gas turbine on land leased from the Watervliet Arsenal. Developed and executed an ambient sound level measurement program. Calculated sound levels at various locations surrounding the site using modeling software. Presented the analysis in a comprehensive report.

- *Hollingsworth & Vose, Inc. Combined Heat & Power Project, West Groton, MA*. Conducted a sound level impact assessment for the proposed CHP. Sound levels were modeled using the Cadna/A noise calculation software. Evaluated multiple project designs. Presented the analysis to the local planning board.

- *National Grid – East Main Street Substation, Westborough, MA*. Managed a sound level impact assessment for the proposed expansion of a substation. The expansion included the installation of a 115/13.8 kV transformer. Predicted future sound levels were compared to existing sound levels for evaluation with the MassDEP Noise Policy. Presented the analysis in a concise report.

- *St. Joseph's Hospital Combined Heat & Power Project, Syracuse, NY*. Measured existing sound levels and conducted a modeling analysis for a project including a Solar Turbines Mercury 50 gas turbine with an electrical output of 4.5 MW and a Heat Recovery Steam Generator capable of producing 45,000 lbs. of steam. Sound levels were evaluated both in the community and in a patient room above the project. Summarized the results of the post-construction sound level measurement program in a concise letter report.

- *Advanced Power, Brockton Power Project, Brockton, MA*. Performed acoustical modeling for the 350 MW power generating facility using a noise prediction software package. Completed a Best Available Noise Control Technology (BANCT) Analysis which evaluated various noise control options. Assisted in the preparation for the Energy Facilities Siting Board (EFSB) hearings.

- *Braintree Electric Light Department – Thomas A. Watson Generating Station, Braintree, MA*. Measured sound levels at various locations for a proposed 116 MW natural gas and oil-fired simple cycle electric power generation facility. Assisted in the acoustical modeling, including several rounds of mitigation analyses. Team member for compliance sound level measurement programs.

- *Milford Power Company, Milford, CT*. Executed an ambient sound level measurement program over a three-day period for a combined cycle electric generating facility proposed in southern Connecticut. Participated in an additional sound level measurement program while construction was under way to collect sound level data during periods of steam venting.

- *Union College Combined Heat & Power Project, Schenectady, NY*. Conducted an analysis of the sound associated with the operation of a proposed gas-turbine based CHP plant for Bette & Cringe, LLC. The proposed plant will include a gas turbine generator package with an expected nominal gross power output of 1,804 kW. The NY DEC guidance document's 6 dBA increase over ambient limit was used as a guideline in evaluating noise impacts from the project.

- *Franklin Energy Center, Franklin, MA*. Conducted an ambient sound level measurement program around the Garelick Farms facility in Franklin to establish background sound levels before the construction of the cogeneration plant at the facility. Following construction of the plant, post-construction sound level measurements were taken. Drafted a sound level measurement letter report presenting the results of the program with respect to the Massachusetts Noise Policy.

- *FPL Energy - Jamaica Bay Peaking Facility, Far Rockaway, NY*. Participated in a sound level measurement program. Short-term and continuous measurements were made at the nearest residences.

- *Billerica Energy, Billerica, MA*. Assisted in the acoustical modeling using Cadna/A for a 480 MW simple cycle turbine facility. Modeled impacts under various scenarios and analyzed noise impacts at multiple locations.

- *Weaver's Cove Energy, Fall River, MA*. Assisted in the development and implementation of an extensive sound measurement program. Over a three-day period continuous and/or short-term measurements were taken at seven locations around the proposed liquefied natural gas (LNG) terminal. Obtained permission from local residences to install temporary noise equipment. Collected and organized the sound data for this project. Participated in an additional sound level measurement program to collect background sound level data in four communities which were in the vicinity of the proposed offshore berth.

- *Clifton Street Substation, Marblehead, MA*. Participated in multiple sound level measurement programs. Conducted a baseline noise measurement survey around the existing substation. Conducted a second survey after the existing transformer was replaced to assess compliance with permit conditions. Prepared a letter report summarizing the results.

Noise Impact Assessment – Quarries / Sand & Gravel / Asphalt

- *Aggregate Industries, Peabody, MA*. Project Manager for sound level measurement programs developed as part of the Special Permit requirements for the quarry and asphalt plant. Gathered data before and after mitigation measures were implemented, analyzed potential impacts due to a proposed relocation of equipment, and presented results at a Peabody Board of Health Meeting.

- *McCullough Crushing, Calais, VT*. Collected reference sound level data at an operating sand and gravel pit. Modeled future sound levels due to sand and gravel extraction and processing using Cadna/A. Prepared a comprehensive report evaluating potential community noise impacts.

- *Dalrymple Gravel & Contracting Co., Inc., Erwin, NY*. Measured reference sound levels for an off-road haul truck and associated hopper-loading activities at the existing Scudder Sand and Gravel Pit.

- *Massachusetts Broken Stone Company, Berlin, MA*. Executed a sound measurement program for an existing asphalt company. Measured sound levels during operational and background conditions. Prepared a letter report summarizing the results.

- *Ambrose Brothers Inc., Sandwich, NH*. Executed two sound level programs at a sand and gravel excavation site. The first program involved measuring sound levels at the house of a concerned neighbor with a portable crusher at its original location. The second program involved measuring sound levels at the same residence with the crusher at a new location. Prepared letter reports for each of the measurement programs.

Noise Impact Assessment – Industrial

- *General Electric Company, Hudson River PCBs Superfund Site, Hudson River, NY*. Assisted in the Phase 1 RAM through the routine collection of sound level data in the community surrounding the dredging activity and processing facility. Collected reference sound level data of noise sources for the project.

- *Cianbro Corporation – Metal Fabrication Plant, Georgetown, MA*. Conducted an operational sound level measurement program around the existing facility during which sound levels were continuously measured at a property line and sound levels associated with individual operations/equipment were measured at a reference distance. Summarized the program and identified mitigation options in a letter report.

- *Berwick Iron and Metal Recycling, Berwick, ME*. Modeled a proposed metal shredder at an existing metal recycling facility using Cadna/A and proposed mitigation to minimize sound level impacts to the community. Participated in a post-construction sound level measurement program to assess compliance with respect to local sound level limits.

- *Former Coal Tar Processing Facility, Island End River, Everett, MA*. Participated in multiple sound measurement programs at a former industrial facility. Measured sound levels under existing conditions before and after a pilot study. Measured sound levels at nine locations during a pilot program to generate information about the relationships between dredging operations and their effects on area sound levels. Took individual reference measurements for each of the various types of equipment operated during the pilot study. Collected sound level data during periods of pile driving activity during the sheet pile wall installation phase of the project.

- *Excel Recycling, Freetown MA*. Conducted attended sound level measurements and detailed sound level modeling to evaluate potential mitigation options for an existing metal shredding and processing facility.

- *FedEx Distribution Facility, Billerica, MA*. Conducted a third-party review of a noise study for a proposed distribution facility. The review was performed for BETA Group who was hired by the Town of Billerica. Presented findings at a Billerica Board of Health meeting.

Noise Impact Assessment –Transfer Stations / Landfills

- *Casella Waste Systems, Inc. - Juniper Ridge Landfill, Old Town, ME.* Conducted a sound level impact assessment for the proposed expansion of the existing Juniper Ridge Landfill. The analysis included mobile noise sources associated with the management of solid waste and a new stationary source, the proposed landfill gas to energy facility. Modeled sound levels were evaluated against both state and local regulations.

- *Holliston Solid Waste Transfer Station, Holliston, MA*. Participated in a sound level measurement program at a solid waste transfer station in Massachusetts. Coordinated with the transfer station and with local residences on the placement of noise equipment. Weekday and weekend measurements (short-term and continuous) were taken at up to six locations around the facility. Participated in additional sound level measurement programs following the enclosure of the C&D facility to evaluate various mitigation options.

- *Hardwick Landfill, Hardwick, MA*. Conducted multiple sound level measurement programs around an existing landfill. Sound levels were measured to evaluate the effectiveness of backup alarm mitigation and to compare levels with and without a gas flare operating. Presented the results of the measurement programs in concise letter reports.

- *Resource Recovery of Cape Cod Inc., Sandwich, MA*. Participated in a group effort in conducting two consecutive 12-hour ambient sound level measurements and one 5-hour ambient sound level measurement at multiple locations for a construction & demolition transfer station in Cape Cod. The study was conducted to establish background sound levels around the facility.

Noise Impact Assessment – Institutional

- *Town Hall Renovation, Orleans, MA*. Project Manager for a sound level impact analysis for the renovation of a town hall. Measured existing sound levels at several locations and calculated future sound levels from the proposed mechanical equipment at multiple evaluation points. Following construction and the installation of the new equipment, additional measurements were collected to compare current operational sound levels to background sound levels. All findings were summarized in concise letter reports.

- *Institute of Contemporary Art, Boston, MA*. Conducted a sound level measurement program at the future site of the ICA to determine the maximum noise impacts from airplanes taking off from Logan Airport. Coordinated with the Massport Noise Abatement Office to ensure that the desired runway was being used. Gathered detailed information characterizing the noise environment of the site.

- *Phillips Academy, Andover, MA*. Measured sound levels with and without the compressor system operating at the new ice hockey facility. Prepared a letter report comparing the results to the Massachusetts Noise Policy.

- *Harvard University, Boston, MA*. Conducted an ambient sound level measurement program. Sound levels were measured around the proposed Northwest Laboratory.

- *Northeastern University, Boston, MA*. Conducted an ambient sound level measurement program. The college was interested in constructing an additional building on campus and was concerned about the noise issues related to the project.

Noise Impact Assessment – Commercial / Residential

- *Stop & Shop Supermarkets*. Executed ambient sound level programs at numerous supermarket locations in New England. Gathered reference sound level data for mechanical equipment at an existing store. Analyzed the potential for impacts at residences due to the addition of mechanical equipment using the Cadna/A noise prediction software.

- *Washington Village Project, Boston, MA*. Evaluated predicted sound levels for the proposed redevelopment of an approximately 4.89-acre site in the South Boston neighborhood. The redevelopment will include eight new residential buildings with most containing ground floor retail, as well as new streets, plazas, and green spaces. Results of the analysis were presented in an Expanded Project Notification Form (PNF).

- *110 Broad Street Project, Boston, MA*. Conducted a sound level modeling analysis for the redevelopment of 7,680 square foot site. The project includes the restoration of the historic Bulfinch Building at 102 Broad Street and the construction of a new residential building with ground floor commercial/café space at 110-112 Broad Street. The predicted sound levels were evaluated with respect to the City of Boston noise standards with the results presented in an Expanded PNF.

- *55 India Street Project, Boston, MA*. Modeled and evaluated sound levels for mechanical equipment associated with a proposed 67,000 square foot building with ground floor commercial space and 44 residential units above. Results were presented in the Expanded PNF.

- *Parcel 1 Project, Boston, MA*. Analyzed sound level impacts from the mechanical equipment associated with the proposed residential/commercial development located in Boston's historic Bulfinch Triangle. Modeling was performed using Cadna/A with the results presented in the Expanded PNF.

- *Big Y Supermarket, Northampton, MA*. Measured sound levels during normal operations at the supermarket and gathered background sound levels without the supermarket operating.

- *Crosby's Market, Hamilton, MA*. Measured sound levels around the existing market at the nearest residences in response to concerns by neighbors over the renovation and expansion of the market.

- *Condominiums, Marblehead, MA*. Measured sound levels during the operation of condenser units located at a condominium. Prepared a letter report comparing the results to the town noise ordinance.

- *Banquet Hall, Whately, MA.* Conducted a sound level analysis for a proposed seasonal banquet hall. The noise source of concern was music being played during functions at the hall. Prepared a letter report comparing the modeling results to the MassDEP Noise Policy.

Noise Impact Assessment – Additional Projects

- *Chestnut Ridge Rod and Gun Club, Dover, NY.* Project Manager for a sound level impact analysis at an existing rod and gun club. Devised and executed a sound level measurement program. Developed mitigation strategies and calculated potential future noise impacts. Summarized all findings in a comprehensive letter report.

- *Storrow Drive Tunnel Reconstruction Project, Boston, MA.* Collected sound level data at various points along Storrow Drive. Presented the noise impact analysis during an Advisory Committee Meeting.

- *TMR Preserve, Dover, NY.* Conducted two sound level programs at a proposed sporting club. Took ambient measurements to document existing conditions in the area. Future conditions were simulated as individuals discharged several types of firearms at various shooting locations in the preserve. Compared measurements taken during these conditions to the existing conditions along with state and local noise regulations.

Shadow Flicker

- *Iberdrola Renewables – Desert Wind, Perquimans and Pasquotank Counties, NC.* Managed a shadow flicker impact assessment for a proposed wind power generation facility to be located in North Carolina. Shadow flicker from the 150 Gamesa G97 2.0 MW wind turbines was calculated. Separate reports were prepared for each county. Gave sworn testimony to the Board of Commissioners in each county.

- *NextEra Energy Resources – Tuscola Bay Wind Energy Center, Tuscola, Bay, & Saginaw Counties, MI.* Project Manager for a shadow flicker analysis for a proposed 120 MW wind power generation facility composed of 75 wind turbines. The expected duration of shadow flicker was calculated at sensitive receptors in the vicinity of the project. Responded to questions and comments at multiple public hearings.

- *Confidential Project, MA.* Calculated the duration of shadow flicker from a proposed wind turbine to be located in Massachusetts using the WindPRO shadow module.

- *State of Connecticut Siting Council, CT.* Contributor to the Epsilon project team providing professional consulting services for renewable energy projects to the Siting Council in CT. Examined analyses conducted, including shadow flicker, for a proposed wind energy project in CT. Reviewed submittals provided by the council and submitted comments.

- *State of New Hampshire, Concord, NH.* Conducted an independent review of the shadow flicker analysis for the proposed 24 MW Lempster Mountain Wind Power Project in Lempster, NH. Calculated the duration of shadow flicker using WindPRO software and compared the results to the developer's analysis.

- *Pioneer Green Energy – Great Bay Wind I, Somerset County, MD.* Calculated the expected annual duration of shadow flicker from a 25-wind turbine project. Multiple layouts and wind turbine types were evaluated for the project. Reductions in shadow flicker due to vegetation were calculated for individual residences. A scaling factor due to curtailments was incorporated into the analysis. The results were presented in a stand-alone report.

- *NextEra Energy Resources – Golden West Wind Energy Center, El Paso County, CO.* Project Manager for a shadow flicker modeling analysis of an operating 249.4 MW wind power generation facility composed of 145 GE wind turbines. Presented the findings of the study to the Board of County Commissioners.

- *NextEra Energy Resources – Lake Benton II Wind Project, Pipestone County, MN.* Project Manager for a shadow flicker modeling analysis for a repower project in Minnesota. Shadow flicker modeling was conducted for 44 proposed wind turbines and four alternates.

- *NextEra Energy Resources – Eight Point Wind Energy Center, Steuben County, NY.* Conducted the shadow flicker analysis for the proposed wind energy project required as part of the NY State Article 10 process. The shadow flicker analysis was performed to determine the location and duration of shadow flicker resulting from the proposed 31 GE wind turbines.

- *NextEra Energy Resources – Pegasus Wind Energy Center, Tuscola County, MI.* Project Manager for a pre-construction shadow flicker modeling study for a 62 wind turbine project. Provided recommendations for layout adjustments to reduce shadow flicker. Presented analysis findings and responded to questions and comments during multiple public hearings.

- *Eolian Renewable Energy – Antrim Wind, Antrim, NH.* Conducted a shadow flicker analysis for a proposed 28.8 MW wind power generation facility to be composed of nine (9) Siemens SWT-3.2-113 3.2 MW wind turbines. There were no federal, state, or local regulations limiting the amount of shadow flicker resulting from the operation of the proposed wind turbines for this Project. However, the predicted shadow flicker at occupied buildings in the vicinity of the project were put into context by comparing the annual duration of shadow flicker to a value of 30 hours per year.

- *Heritage Sustainable Energy – Big Turtle Wind Farm Phase 2, Huron County, MI.* Project Manager for a shadow flicker analysis for a proposed wind energy facility. Shadow flicker resulting from the operation of 15 Gamesa wind turbines was calculated at discrete modeling points and isolines were generated from a grid encompassing the area surrounding the wind turbines.

- *NextEra Energy Resources – Tuscola Wind II, Tuscola County, MI.* Project Manager for a shadow flicker analysis for a proposed 100 MW wind power generation facility composed of 59 wind turbines. Results were presented in reports for each of the four townships which would have a wind turbine. Responded to questions and comments at multiple public hearings.

- *Iberdrola Renewables – Blue Creek Wind Farm, Van Wert and Paulding Counties, OH.* Project Manager for a shadow flicker analysis for a proposed wind farm in Ohio consisting of Gamesa

G90 2.0 MW wind turbines. Results were presented in a comprehensive report which was submitted to the Ohio Power Siting Board.

- *First Wind - Weaver Wind, Hancock County, ME.* Sub-consultant to Normandeau Associates for a wind energy project consisting of approximately 15 wind turbines. Shadow flicker modeling was conducted for two options with the results compared to local regulations. The results of the analyses were presented at an Open House for the project.

- *NextEra Energy Resources – Montezuma Wind Farm, Solano County, CA*. Performed an analysis to estimate the hours per year of shadow flicker in the area surrounding the proposed wind farm. Impacts were presented visually as isolines overlaid onto an aerial image which was included in a concise letter report summarizing the results.

- *FPL – St. Lucie Wind Turbine Generation Project, St. Lucie County, FL*. Evaluated the potential for shadow flicker impacts at the nearest residences resulting from the operation of six wind turbines proposed as part of this project. Presented the results in a clear and concise report.

- *NextEra Energy Resources – Osborn Wind Energy Center, MO.* Provided expert opinions regarding proposed amendments to the Clinton County Zoning Ordinance with respect to shadow flicker from a Wind Energy Conversion System. Provided sworn testimony under direct and cross examination at a Clinton County Planning & Zoning Commission hearing.

Air Quality Modeling

- *Besicorp Empire Development Company, Rensselaer, NY*. Worked on modeling predicting $PM_{2.5}$ concentrations from truck and rail traffic associated with a newsprint facility and a cogeneration facility using CAL3QHCR. Produced graphics showing the estimated concentrations in the nearby area.

- *Alcoa Eastalco Works, Frederick, MD*. Assisted in the modeling of an existing aluminum facility. Worked closely with project managers in developing strategies to accurately address the numerous sources throughout the facility. Assisted in the running of CALMET, CALPUFF, and CALPOST. Developed various graphics to illustrate to the client the results of the modeling.

- *Storrow Drive Tunnel Reconstruction Project, Boston, MA*. Assisted in a microscale analysis using EPA MOBILE6 and CAL3QHC. Analyzed various reconfiguration scenarios. Presented the mesoscale and microscale analyses during an Advisory Committee Meeting.

- *Bangor-Hydro Electric Company, Bangor, ME*. Assisted in the renewal process for existing air permits for the Medway, Eastport, and Bar Harbor facilities of the Bangor-Hydro Electric Company. Utilized Satellite i-Steps for generating annual air emission statements.

- *JAMALCO, Jamaica*. Assisted with the modeling analysis for the Clarendon Alumina Works in Jamaica. ISCST3 was used to model various operating scenarios. Prepared graphics illustrating pollutant concentrations around the facility.

- *FPL Energy.* Assisted in AERMOD, CALMET, and CALPUFF modeling for a project in Virginia. Gathered and processed data for the project. Helped to create many of the model runs used in the analysis. Created several figures used in the report.

- *Columbus Center, Boston, MA*. Assisted in the microscale analysis of seven intersections around a proposed development over the Massachusetts Turnpike. Used ISC-Prime to estimate impacts from point sources and volume sources from proposed buildings and tunnels. Used CAL3QHCR to estimate impacts from mobile sources. These models were used to evaluate each of the four building alternatives. Provided graphics for the project.

Air Quality Monitoring

- *Massachusetts Broken Stone Company, Berlin, MA*. Participated in an air quality monitoring program for an existing asphalt plant. Assisted in the installation of a meteorological tower. Made routine trips to the facility to maintain and download data from the H_2S monitor.

- *Former Coal Tar Processing Facility, Island End River, Everett, MA*. Participated in an air quality monitoring program for a former industrial facility. Gathered data before and after a pilot study to document existing conditions. Used various types of sampling equipment including SUMMA Canisters and PUF samplers to collect samples during the pilot study.

Meteorological Monitoring

- *Wheelabrator Millbury Municipal Waste Combustor Facility, Millbury, MA*. Routinely collected data from a meteorological tower at a municipal waste facility. Assisted in the maintenance and calibration of the equipment. Provided quarterly reports.

PUBLICATIONS

- "Low frequency sound and infrasound from wind turbines." Noise Control Engineering Journal, Institute of Noise Control Engineering, Volume 59, Number 2, March-April 2011. O'Neal, R.D., Hellweg, Jr., R.D. and R. M. Lampeter.

- "Sound Defense for a Wind Turbine Farm." North American Windpower, Zackin Publications, Volume 4, Number 4, May 2007. O'Neal, R.D., and R.M. Lampeter.

CONFERENCE PAPERS

- "Evaluating and controlling noise from a metal shredder system." INTER-NOISE 2012, New York City, NY, August 19-22, 2012. O'Neal, R.D., Lampeter, R.M., Emil, C.B. and B.A. Gallant.

- "Low frequency sound and infrasound from wind turbines – a status update." NOISE-CON 2010, Baltimore, MD, April 19-21, 2010. O'Neal, R.D., Hellweg, Jr., R.D. and R. M. Lampeter.

- "Nuisance noise and the defense of a wind farm." INTER-NOISE 2009, Ottawa, Canada, August 23-26, 2009. O'Neal, R.D., and R.M. Lampeter.

PRESENTATIONS

- "Sound Levels and the Evolving Regulatory Landscape." AWEA WINDPOWER 2016 Poster Presentation, May 23-26, 2016.
- "How to Address Post-Construction Sound Level Measurement Requirements." AWEA WINDPOWER 2015 Poster Presentation, May 18-21, 2015.
- "Evaluating Shadow Flicker in the Current Regulatory Environment." Massachusetts Wind Working Group, October 30, 2013.
- "Shadow Flicker Regulations and Guidance: New England and Beyond." New England Wind Energy Education Project Webinar, February 10, 2011
- "Low Frequency Sound and Infrasound from Wind Turbines." CanWEA 2010, Montreal, Canada, November 1-3, 2010. O'Neal, R.D., Hellweg, Jr., R.D. and R. M. Lampeter.

PROFESSIONAL ORGANIZATIONS

Institute of Noise Control Engineering (INCE)

PREVIOUS EMPLOYERS

NYC Department of Environmental Protection, June - August 2000.
Meyer Strong and Jones Engineers, P.C., May – August 1999.

Wind Turbine Health Impact Study:

Report of Independent Expert Panel

January 2012

Prepared for:

Massachusetts Department of Environmental Protection

Massachusetts Department of Public Health

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The Panel Charge

The Expert Panel was given the following charge by the Massachusetts Department of Environmental Protection (MassDEP) and Massachusetts Department of Public Health (MDPH):

1. Identify and characterize attributes of concern (e.g., noise, infrasound, vibration, and light flicker) and identify any scientifically documented or potential connection between health impacts associated with wind energy turbines located on land or coastal tidelands that can impact land-based human receptors.
2. Evaluate and discuss information from peer-reviewed scientific studies, other reports, popular media, and public comments received by the MassDEP and/or in response to the *Environmental Monitor Notice* and/or by the MDPH on the nature and type of health complaints commonly reported by individuals who reside near existing wind farms.
3. Assess the magnitude and frequency of any potential impacts and risks to human health associated with the design and operation of wind energy turbines based on existing data.
4. For the attributes of concern, identify documented best practices that could reduce potential human health impacts. Include examples of such best practices (design, operation, maintenance, and management from published articles). The best practices could be used to inform public policy decisions by state, local, or regional governments concerning the siting of turbines.
5. Issue a report within 3 months of the evaluation, summarizing its findings.

To meet its charge, the Panel conducted a literature review and met as a group a total of three times. In addition, calls were also held with Panel members to further clarify points of discussion.

Executive Summary

The Massachusetts Department of Environmental Protection (MassDEP) in collaboration with the Massachusetts Department of Public Health (MDPH) convened a panel of independent experts to identify any documented or potential health impacts of risks that may be associated with exposure to wind turbines, and, specifically, to facilitate discussion of wind turbines and public health based on scientific findings.

While the Commonwealth of Massachusetts has goals for increasing the use of wind energy from the current 40 MW to 2000 MW by the year 2020, MassDEP recognizes there are questions and concerns arising from harnessing wind energy. The scope of the Panel's effort was focused on health impacts of wind turbines *per se*. The panel was *not* charged with considering any possible benefits of avoiding adverse effects of other energy sources such as coal, oil, and natural gas as a result of switching to energy from wind turbines.

Currently, "regulation" of wind turbines is done at the local level through local boards of health and zoning boards. Some members of the public have raised concerns that wind turbines may have health impacts related to noise, infrasound, vibrations, or shadow flickering generated by the turbines. The goal of the Panel's evaluation and report is to provide a review of the science that explores these concerns and provides useful information to MassDEP and MDPH and to local agencies that are often asked to respond to such concerns. The Panel consists of seven individuals with backgrounds in public health, epidemiology, toxicology, neurology and sleep medicine, neuroscience, and mechanical engineering. All of the Panel members are considered independent experts from academic institutions.

In conducting their evaluation, the Panel conducted an extensive literature review of the scientific literature as well as other reports, popular media, and the public comments received by the MassDEP.

ES 1. Panel Charge

1. Identify and characterize attributes of concern (e.g., noise, infrasound, vibration, and light flicker) and identify any scientifically documented or potential connection between health impacts associated with wind turbines located on land or coastal tidelands that can impact land-based human receptors.
2. Evaluate and discuss information from peer reviewed scientific studies, other reports, popular media, and public comments received by the MassDEP and/or in response to the *Environmental Monitor Notice* and/or by the MDPH on the nature and type of health complaints commonly reported by individuals who reside near existing wind farms.
3. Assess the magnitude and frequency of any potential impacts and risks to human health associated with the design and operation of wind energy turbines based on existing data.
4. For the attributes of concern, identify documented best practices that could reduce potential human health impacts. Include examples of such best practices (design, operation, maintenance, and management from published articles). The best practices could be used to inform public policy decisions by state, local, or regional governments concerning the siting of turbines.
5. Issue a report within 3 months of the evaluation, summarizing its findings.

ES 2. Process

To meet its charge, the Panel conducted an extensive literature review and met as a group a total of three times. In addition, calls were also held with Panel members to further clarify points of discussion. An independent facilitator supported the Panel's deliberations. Each Panel member provided written text based on the literature reviews and analyses. Draft versions of the report were reviewed by each Panel member and the Panel reached consensus for the final text and its findings.

ES 3. Report Introduction and Description

Many countries have turned to wind power as a clean energy source because it relies on the wind, which is indefinitely renewable; it is generated "locally," thereby providing a measure of energy independence; and it produces no carbon dioxide emissions when operating. There is interest in pursuing wind energy both on-land and offshore. For this report, however, the focus is on land-based installations and all comments are focused on this technology. Land-based wind turbines currently range from 100 kW to 3 MW (3000 kW). In Massachusetts, the largest turbine is currently 1.8 MW.

The development of modern wind turbines has been an evolutionary design process, applying optimization at many levels. An overview of the characteristics of wind turbines, noise, and vibration is presented in Chapter 2 of the report. Acoustic and seismic measurements of noise and vibration from wind turbines provide a context for comparing measurements from epidemiological studies and for claims purported to be due to emissions from wind turbines. Appendices provide detailed descriptions and equations that allow a more in-depth understanding of wind energy, the structure of the turbines, wind turbine aerodynamics, installation, energy production, shadow flicker, ice throws, wind turbine noise, noise propagation, infrasound, and stall vs. pitch controlled turbines.

Extensive literature searches and reviews were conducted to identify studies that specifically evaluate human population responses to turbines, as well as population and individual responses to the three primary characteristics or attributes of wind turbine operation: noise, vibration, and flicker. An emphasis of the Panel's efforts was to examine the biological plausibility or basis for health effects of turbines (noise, vibration, and flicker). Beyond traditional forms of scientific publications, the Panel also took great care to review other non-peer reviewed materials regarding the potential for health effects including information related to "Wind Turbine Syndrome" and provides a rigorous analysis as to whether there is scientific basis for it. Since the most commonly reported complaint by people living near turbines is sleep disruption, the Panel provides a robust review of the relationship between noise, vibration, and annoyance as well as sleep disturbance from noises and the potential impacts of the resulting sleep deprivation.

In assessing the state of the evidence for health effects of wind turbines, the Panel followed accepted scientific principles and relied on several different types of studies. It considered human studies of the most important or primary value. These were either human epidemiological studies specifically relating to exposure to wind turbines or, where specific exposures resulting from wind turbines could be defined, the panel also considered human experimental data. Animal studies are critical to exploring biological plausibility and understanding potential biological mechanisms of different exposures, and for providing information about possible health effects when experimental research in humans is not ethically or practically possible. As such, this literature was also reviewed with respect to wind turbine exposures. The non-peer reviewed material was considered part of the weight of evidence. In all cases, data quality was considered; at times, some studies were rejected because of lack of rigor or the interpretations were inconsistent with the scientific evidence.

ES 4. Findings

The findings in Chapter 4 are repeated here.

Based on the detailed review of the scientific literature and other available reports and consideration of the strength of scientific evidence, the Panel presents findings relative to three factors associated with the operation of wind turbines: noise and vibration, shadow flicker, and ice throw. The findings that follow address specifics in each of these three areas.

ES 4.1 Noise

ES 4.1.a Production of Noise and Vibration by Wind Turbines

1. Wind turbines can produce unwanted sound (referred to as noise) during operation. The nature of the sound depends on the design of the wind turbine. Propagation of the sound is primarily a function of distance, but it can also be affected by the placement of the turbine, surrounding terrain, and atmospheric conditions.
   a. Upwind and downwind turbines have different sound characteristics, primarily due to the interaction of the blades with the zone of reduced wind speed behind the tower in the case of downwind turbines.
   b. Stall regulated and pitch controlled turbines exhibit differences in their dependence of noise generation on the wind speed
   c. Propagation of sound is affected by refraction of sound due to temperature gradients, reflection from hillsides, and atmospheric absorption. Propagation effects have been shown to lead to different experiences of noise by neighbors.
   d. The audible, amplitude-modulated noise from wind turbines (“whooshing”) is perceived to increase in intensity at night (and sometimes becomes more of a “thumping”) due to multiple effects: i) a stable atmosphere will have larger wind gradients, ii) a stable atmosphere may refract the sound downwards instead of upwards, iii) the ambient noise near the ground is lower both because of the stable atmosphere and because human generated noise is often lower at night.

2. The sound power level of a typical modern utility scale wind turbine is on the order of 103 dB(A), but can be somewhat higher or lower depending on the details of the design and the rated power of the turbine. The perceived sound decreases rapidly with the distance from the wind turbines. Typically, at distances larger than 400 m, sound pressure levels for modern wind turbines are less than 40 dB(A), which is below the level associated with annoyance in the epidemiological studies reviewed.
3. Infrasound refers to vibrations with frequencies below 20 Hz. Infrasound at amplitudes over 100–110 dB can be heard and felt. Research has shown that vibrations below these amplitudes are not felt. The highest infrasound levels that have been measured near turbines and reported in the literature near turbines are under 90 dB at 5 Hz and lower at higher frequencies for locations as close as 100 m.
4. Infrasound from wind turbines is not related to nor does it cause a "continuous whooshing."
5. Pressure waves at any frequency (audible or infrasonic) can cause vibration in another structure or substance. In order for vibration to occur, the amplitude (height) of the wave has to be high enough, and only structures or substances that have the ability to receive the wave (resonant frequency) will vibrate.

ES 4.1.b Health Impacts of Noise and Vibration

1. Most epidemiologic literature on human response to wind turbines relates to self-reported "annoyance," and this response appears to be a function of some combination of the sound itself, the sight of the turbine, and attitude towards the wind turbine project.
   a. There is limited epidemiologic evidence suggesting an association between exposure to wind turbines and annoyance.
   b. There is insufficient epidemiologic evidence to determine whether there is an association between noise from wind turbines and annoyance independent from the effects of seeing a wind turbine and vice versa.

2. There is limited evidence from epidemiologic studies suggesting an association between noise from wind turbines and sleep disruption. In other words, it is possible that noise from some wind turbines can cause sleep disruption.
3. A very loud wind turbine could cause disrupted sleep, particularly in vulnerable populations, at a certain distance, while a very quiet wind turbine would not likely disrupt even the lightest of sleepers at that same distance. But there is not enough evidence to provide particular sound-pressure thresholds at which wind turbines cause sleep disruption. Further study would provide these levels.
4. Whether annoyance from wind turbines leads to sleep issues or stress has not been sufficiently quantified. While not based on evidence of wind turbines, there is evidence that sleep disruption can adversely affect mood, cognitive functioning, and overall sense of health and well-being.
5. There is insufficient evidence that the noise from wind turbines is *directly (i.e., independent from an effect on annoyance or sleep)* causing health problems or disease.
6. Claims that infrasound from wind turbines directly impacts the vestibular system have not been demonstrated scientifically. Available evidence shows that the infrasound levels near wind turbines cannot impact the vestibular system.
   a. The measured levels of infrasound produced by modern upwind wind turbines at distances as close as 68 m are well below that required for non-auditory perception (feeling of vibration in parts of the body, pressure in the chest, etc.).
   b. If infrasound couples into structures, then people inside the structure could feel a vibration. Such structural vibrations have been shown in other applications to lead to feelings of uneasiness and general annoyance. The measurements have shown no evidence of such coupling from modern upwind turbines.
   c. Seismic (ground-carried) measurements recorded near wind turbines and wind turbine farms are unlikely to couple into structures.
   d. A possible coupling mechanism between infrasound and the vestibular system (via the Outer Hair Cells (OHC) in the inner ear) has been proposed but is not yet fully understood or sufficiently explained. Levels of infrasound near wind turbines have been shown to be high enough to be sensed by the OHC. However, evidence does not

exist to demonstrate the influence of wind turbine-generated infrasound on vestibular-mediated effects in the brain.

e. Limited evidence from rodent (rat) laboratory studies identifies short-lived biochemical alterations in cardiac and brain cells in response to short exposures to emissions at 16 Hz and 130 dB. These levels exceed measured infrasound levels from modern turbines by over 35 dB.

7. There is no evidence for a set of health effects, from exposure to wind turbines that could be characterized as a "Wind Turbine Syndrome."
8. The strongest epidemiological study suggests that there is not an association between noise from wind turbines and measures of psychological distress or mental health problems. There were two smaller, weaker, studies: one did note an association, one did not. Therefore, we conclude the weight of the evidence suggests no association between noise from wind turbines and measures of psychological distress or mental health problems**.**
9. None of the limited epidemiological evidence reviewed suggests an association between noise from wind turbines and pain and stiffness, diabetes, high blood pressure, tinnitus, hearing impairment, cardiovascular disease, and headache/migraine.

ES 4.2 Shadow Flicker

ES 4.2.a Production of Shadow Flicker

Shadow flicker results from the passage of the blades of a rotating wind turbine between the sun and the observer.

1. The occurrence of shadow flicker depends on the location of the observer relative to the turbine and the time of day and year.
2. Frequencies of shadow flicker elicited from turbines is proportional to the rotational speed of the rotor times the number of blades and is generally between 0.5 and 1.1 Hz for typical larger turbines.
3. Shadow flicker is only present at distances of less than 1400 m from the turbine.

ES 4.2.b Health Impacts of Shadow Flicker

1. Scientific evidence suggests that shadow flicker does not pose a risk for eliciting seizures as a result of photic stimulation.

2. There is limited scientific evidence of an association between annoyance from prolonged shadow flicker (exceeding 30 minutes per day) and potential transitory cognitive and physical health effects.

ES 4.3 Ice Throw

ES 4.3.a Production of Ice Throw

Ice can fall or be thrown from a wind turbine during or after an event when ice forms or accumulates on the blades.

1. The distance that a piece of ice may travel from the turbine is a function of the wind speed, the operating conditions, and the shape of the ice.
2. In most cases, ice falls within a distance from the turbine equal to the tower height, and in any case, very seldom does the distance exceed twice the total height of the turbine (tower height plus blade length).

ES 4.3.b Health Impacts of Ice Throw

1. There is sufficient evidence that falling ice is physically harmful and measures should be taken to ensure that the public is not likely to encounter such ice.

ES 4.4 Other Considerations

In addition to the specific findings stated above for noise and vibration, shadow flicker and ice throw, the Panel concludes the following:

1. Effective public participation in and direct benefits from wind energy projects (such as receiving electricity from the neighboring wind turbines) have been shown to result in less annoyance in general and better public acceptance overall.

ES 5. Best Practices Regarding Human Health Effects of Wind Turbines

The best practices presented in Chapter 5 are repeated here.

Broadly speaking, the term “best practice” refers to policies, guidelines, or recommendations that have been developed for a specific situation. Implicit in the term is that the practice is based on the best information available at the time of its institution. A best practice may be refined as more information and studies become available. The panel recognizes that in countries which are dependent on wind energy and are protective of public health, best practices have been developed and adopted.

In some cases, the weight of evidence for a specific practice is stronger than it is in other cases. Accordingly, best practice* may be categorized in terms of the evidence available, as follows:

Descriptions of Three Best Practice Categories

Category	**Name**	**Description**
1	Research Validated Best Practice	A program, activity, or strategy that has the highest degree of proven effectiveness supported by objective and comprehensive research and evaluation.
2	Field Tested Best Practice	A program, activity, or strategy that has been shown to work effectively and produce successful outcomes and is supported to some degree by subjective and objective data sources.
3	Promising Practice	A program, activity, or strategy that has worked within one organization and shows promise during its early stages for becoming a best practice with long-term sustainable impact. A promising practice must have some objective basis for claiming effectiveness and must have the potential for replication among other organizations.

**These categories are based on those suggested in "Identifying and Promoting Promising Practices." Federal Register, Vol. 68. No 131. 131. July 2003. www.acf.hhs.gov/programs/ccf/about_ccf/gbk_pdf/pp_gbk.pdf*

ES 5.1 Noise

Evidence regarding wind turbine noise and human health is limited. There is limited evidence of an association between wind turbine noise and both annoyance and sleep disruption, depending on the sound pressure level at the location of concern. However, there are no research-based sound pressure levels that correspond to human responses to noise. A number of countries that have more experience with wind energy and are protective of public health have developed guidelines to minimize the possible adverse effects of noise. These guidelines consider time of day, land use, and ambient wind speed. The table below summarizes the guidelines of Germany (in the categories of industrial, commercial and villages) and Denmark (in the categories of sparsely populated and residential). The sound levels shown in the table are for nighttime and are assumed to be taken immediately outside of the residence or building of concern. In addition, the World Health Organization recommends a maximum nighttime sound pressure level of 40 dB(A) in residential areas. Recommended setbacks corresponding to these values may be calculated by software such as WindPro or similar software. Such calculations are normally to be done as part of feasibility studies. The Panel considers the guidelines shown below to be Promising Practices (Category 3) but to embody some aspects of Field Tested Best Practices (Category 2) as well.

Promising Practices for Nighttime Sound Pressure Levels by Land Use Type

Land Use	**Sound Pressure Level, dB(A) Nighttime Limits**
Industrial	70
Commercial	50
Villages, mixed usage	45
Sparsely populated areas, 8 m/s wind*	44
Sparsely populated areas, 6 m/s wind*	42
Residential areas, 8 m/s wind*	39
Residential areas, 6 m/s wind*	37

**measured at 10 m above ground, outside of residence or location of concern*

The time period over which these noise limits are measured or calculated also makes a difference. For instance, the often-cited World Health Organization recommended nighttime noise cap of 40 dB(A) is averaged over one year (and does not refer specifically to wind turbine noise). Denmark's noise limits in the table above are calculated over a 10-minute period. These limits are in line with the noise levels that the epidemiological studies connect with insignificant reports of annoyance.

The Panel recommends that noise limits such as those presented in the table above be included as part of a statewide policy regarding new wind turbine installations. In addition, suitable ranges and procedures for cases when the noise levels may be greater than those values should also be considered. The considerations should take into account trade-offs between environmental and health impacts of different energy sources, national and state goals for energy independence, potential extent of impacts, etc.

The Panel also recommends that those involved in a wind turbine purchase become familiar with the noise specifications for the turbine and factors that affect noise production and noise control. Stall and pitch regulated turbines have different noise characteristics, especially in high winds. For certain turbines, it is possible to decrease noise at night through suitable control measures (e.g., reducing the rotational speed of the rotor). If noise control measures are to be considered, the wind turbine manufacturer must be able to demonstrate that such control is possible.

The Panel recommends an ongoing program of monitoring and evaluating the sound produced by wind turbines that are installed in the Commonwealth. IEC 61400-11 provides the standard for making noise measurements of wind turbines (International Electrotechnical Commission, 2002). In general, more comprehensive assessment of wind turbine noise in populated areas is recommended. These assessments should be done with reference to the broader ongoing research in wind turbine noise production and its effects, which is taking place internationally. Such assessments would be useful for refining siting guidelines and for developing best practices of a higher category. Closer investigation near homes where outdoor measurements show A and C weighting differences of greater than 15 dB is recommended.

ES 5.2 Shadow Flicker

Based on the scientific evidence and field experience related to shadow flicker, Germany has adopted guidelines that specify the following:

1. Shadow flicker should be calculated based on the astronomical maximum values (i.e., not considering the effect of cloud cover, etc.).
2. Commercial software such as WindPro or similar software may be used for these calculations. Such calculations should be done as part of feasibility studies for new wind turbines.
3. Shadow flicker should not occur more than 30 minutes per day and not more than 30 hours per year at the point of concern (e.g., residences).
4. Shadow flicker can be kept to acceptable levels either by setback or by control of the wind turbine. In the latter case, the wind turbine manufacturer must be able to demonstrate that such control is possible.

The guidelines summarized above may be considered to be a Field Tested Best Practice (Category 2). Additional studies could be performed, specifically regarding the number of hours per year that shadow flicker should be allowed, that would allow them to be placed in Research Validated (Category 1) Best Practices.

ES 5.3 Ice Throw

Ice falling from a wind turbine could pose a danger to human health. It is also clear that the danger is limited to those times when icing occurs and is limited to relatively close proximity to the wind turbine. Accordingly, the following should be considered Category 1 Best Practices.

1. In areas where icing events are possible, warnings should be posted so that no one passes underneath a wind turbine during an icing event and until the ice has been shed.
2. Activities in the vicinity of a wind turbine should be restricted during and immediately after icing events in consideration of the following two limits (in meters).

For a turbine that may not have ice control measures, it may be assumed that ice could fall within the following limit:

$$x_{\max,\,throw} = 1.5(2R + H)$$

Where: R = rotor radius (m), H = hub height (m)

For ice falling from a stationary turbine, the following limit should be used:

$$x_{\max,\,fall} = U(R + H)/15$$

Where: U = maximum likely wind speed (m/s)

The choice of maximum likely wind speed should be the expected one-year return maximum, found in accordance to the International Electrotechnical Commission's design standard for wind turbines, IEC 61400-1.

Danger from falling ice may also be limited by ice control measures. If ice control measures are to be considered, the wind turbine manufacturer must be able to demonstrate that such control is possible.

ES 5.4 Public Participation/Annoyance

There is some evidence of an association between participation, economic or otherwise, in a wind turbine project and the annoyance (or lack thereof) that affected individuals may express. Accordingly, measures taken to directly involve residents who live in close proximity to a wind turbine project may also serve to reduce the level of annoyance. Such measures may be considered to be a Promising Practice (Category 3).

ES 5.5 Regulations/Incentives/Public Education

The evidence indicates that in those parts of the world where there are a significant number of wind turbines in relatively close proximity to where people live, there is a close coupling between the development of guidelines, provision of incentives, and educating the public. The Panel suggests that the public be engaged through such strategies as education, incentives for community-owned wind developments, compensations to those experiencing documented loss of property values, comprehensive setback guidelines, and public education related to renewable energy. These multi-faceted approaches may be considered to be a Promising Practice (Category 3).

Chapter 1

Introduction to the Study

The Massachusetts Department of Environmental Protection (MassDEP), in collaboration with the Massachusetts Department of Public Health (MDPH), convened a panel of independent experts to identify any documented or potential health impacts or risks that may be associated with exposure to wind turbines, and, specifically, to facilitate discussion of wind turbines and public health based on sound science. While the Commonwealth of Massachusetts has goals for increasing the use of wind energy from the current 40 MW to 2000 MW by the year 2020, MassDEP recognizes there are questions and concerns arising from harnessing wind energy. Although fossil fuel non-renewable sources have negative environmental and health impacts, it should be noted that the scope of the Panel's effort was focused on wind turbines and is not meant to be a comparative analysis of the relative merits of wind energy vs. nonrenewable fossil fuel sources such as coal, oil, and natural gas. Currently, "regulation" of wind turbines is done at the local level through local boards of health and zoning boards. Some members of the public have raised concerns that wind turbines may have health impacts related to noise, infrasound, vibrations, or shadow flickering generated by the turbines. The goal of the Panel's evaluation and report is to provide a review of the science that explores these concerns and provides useful information to MassDEP and MDPH and to local agencies who are often asked to respond to such concerns.

The overall context for this study is that the use of wind turbines results in positive effects on public health and environmental health. For example, wind turbines operating in Massachusetts produce electricity in the amount of approximately 2,100–2,900 MWh annually per rated MW, depending on the design of the turbine and the average wind speed at the installation site. Furthermore, the use of wind turbines for electricity production in the New England electrical grid will result in a significant decrease in the consumption of conventional fuels and a corresponding decrease in the production of CO_2 and oxides of nitrogen and sulfur (see Appendix A for details). Reductions in the production of these pollutants will have demonstrable and positive benefits on human and environmental health. However, local impacts of wind turbines, whether anticipated or demonstrated, have resulted in fewer turbines being installed than might otherwise have been expected. To the extent that these impacts can be ameliorated, it should be possible to take advantage of the indigenous wind energy resource more effectively.

The Panel consists of seven individuals with backgrounds in public health, epidemiology, toxicology, neurology and sleep medicine, neuroscience, and mechanical engineering. With the exception of two individuals (Drs. Manwell and Mills), Panel members did not have any direct experience with wind turbines. The Panel did an extensive literature review of the scientific literature (see bibliography) as well as other reports, popular media, and the public comments received by the MassDEP.

Chapter 2

Introduction to Wind Turbines

This chapter provides an introduction to wind turbines so as to provide a context for the discussion that follows. More information on wind turbines may be found in the appendices, particularly in Appendix A.

2.1 Wind Turbine Anatomy and Operation

Wind turbines utilize the wind, which originates from sunlight due to the differential heating of various parts of the earth. This differential heating produces zones of high and low pressure, resulting in air movement. The motion of the air is also affected by the earth's rotation. Many countries have turned to wind power as a clean energy source because it relies on the wind, which is indefinitely renewable; it is generated "locally," thereby providing a measure of energy independence; and it produces no carbon dioxide emissions when operating. There is interest in pursuing wind energy both on-land and offshore. For this report, however, the focus is on land-based installations, and all comments will focus on this technology.

The development of modern wind turbines has been an evolutionary design process, applying optimization at many levels. This section gives a brief overview of the characteristics of wind turbines with some mention of the optimization parameters of interest. Appendix A provides a detailed explanation of wind energy.

The main features of modern wind turbines one notices are the very tall towers, which are no longer a lattice structure but a single cylindrical-like structure and the three upwind, very long, highly contoured turbine blades. The tower design has evolved partly because of biological impact factors as well as for other practical reasons. The early lattice towers were attractive nesting sites for birds. This led to an unnecessary impact of wind turbines on bird populations. The lattice structures also had to be climbed externally by turbine technicians. The tubular towers, which are now more common, are climbed internally. This reduces the health risks for maintenance crews.

The power in the wind available to a wind turbine is related to the cube of the wind speed and the square of the radius of the rotor. Not all the available power in the wind can be captured by a wind turbine, however. Betz (van Kuik, 2007) showed that the maximum power that can be extracted is 16/27 times the available power (see Appendix A). In an attempt to extract the maximum power from the wind, modern turbines have very large rotors and the towers are quite high. In this way the dependence on the radius is “optimized,” and the dependence on the wind speed is “optimized.” The wind speed is higher away from the ground due to boundary layer effects, and as such, the towers are made higher in order to capture the higher speed winds (more information about the wind profiles and variability is found in Appendix A). It is noted here that the rotor radius may increase again in the future, but currently the largest rotors used on land are around 100 m in diameter. This upper limit is currently a function of the radius of curvature of the roads on which the trucks that deliver the turbine blades must drive to the installation sites. Clearance under bridges is also a factor.

The efficiency with which the wind’s power is captured by a particular wind turbine (i.e., how close it comes to the Betz limit) is a function of the blade design, the gearbox, the electrical generator, and the control system. The aerodynamic forces on the rotor blade play a major role. The best design maximizes lift and minimizes drag at every blade section from hub to tip. The twisted and tapered shapes of modern blades attempt to meet this optimal condition. Other factors also must be taken into consideration such as structural strength, ease of manufacturing and transport, type of materials, cost, etc.

Beyond these visual features, the number of blades and speed of the tips play a role in the optimization of the performance through what is called solidity. When setting tip speeds based on number of blades, however, trade-offs exist because of the influence of these parameters on weight, cost, and noise. For instance, higher tip speeds often results in more noise.

The dominance of the 3-bladed upwind systems is both historic and evolutionary. The European manufacturers moved to 3-bladed systems and installed numerous turbines, both in Europe and abroad. Upwind systems are preferable to downwind systems for on-land installations because they are quieter. The downwind configuration has certain useful features but it suffers from the interaction noise created when the blades pass through the wake that forms behind the tower.

The conversion of the kinetic energy of the wind into electrical energy is handled by the rotor nacelle assembly (RNA), which consists of the rotor, the drive train, and various ancillary components. The rotor grouping includes the blades, the hub, and the pitch control components. The drive train includes the shafts, bearings, gearbox (not necessary for direct drive generators), couplings, mechanical brake, and generator. A schematic of the RNA, together with more detail concerning the operation of the various parts, is in Appendix A.

The rotors are controlled so as to generate electricity most effectively and as such must withstand continuously fluctuating forces during normal operation and extreme loads during storms. Accordingly, in general a wind turbine rotor does not operate at its own maximum power coefficient at all wind speeds. Because of this, the power output of a wind turbine is generally described by a relationship, known as a power curve. A typical power curve is shown in the appendix. Below the cut-in speed no power is produced. Between cut-in and rated wind speed the power increases significantly with wind speed. Above the rated speed, the power produced is constant, regardless of the wind speed, and above the cut-out speed the turbine is shut down often with use of the mechanical brake.

Two main types of rotor control systems exist: pitch and stall. Stall controlled turbines have fixed blades and operate at a fixed speed. The aerodynamic design of the blades is such that the power is self-limiting, as long as the generator is connected to the electrical grid. Pitch regulated turbines have blades that can be rotated about their long axis. Such an arrangement allows more precise control. Pitch controlled turbines are also generally quieter than stall controlled turbines, especially at higher wind speeds. Until recently, many turbines used stall control. At present, most large turbines use pitch control. Appendices A and F provide more details on pitch and stall.

The energy production of a wind turbine is usually considered annually. Estimates are usually obtained by calculating the expected energy that will be produced every hour of a representative year (by considering the turbine's power curve and the estimated wind resource) and then summing the energy from all the hours. Sometimes a normalized term known as the capacity factor (CF) is used to characterize the performance. This is the actual energy produced (or estimated to be produced) divided by the amount of energy that would be produced if the turbine were running at its rated output for the entire year. Appendix A gives more detail on these computations.

2.2 Noise from Turbines

Because of the concerns about the noise generated from wind turbines, a short summary of the sources of noise is provided here. A thorough description of the various noise sources from a wind turbine is given in the text by Wagner et al. (1996).

A turbine produces noise mechanically and aerodynamically. Mechanical noise sources include the gearbox, generator, yaw drives, cooling fans, and auxiliary equipment such as hydraulics. Because the emitted sound is associated with the rotation of mechanical and electrical equipment, it is often tonal. For instance, it was found that noise associated with a 1500 kW turbine with a generator running at speeds between 1100 and 1800 rpm contained a tone between 20 and 30 Hz (Betke et al., 2004). The yaw system on the other hand might produce more of a grinding type of noise but only when the yaw mechanism is engaged. The transmission of mechanical noise can be either airborne or structure-borne as the associated vibrations can be transmitted into the hub and tower and then radiated into the surrounding space.

Advances in gearboxes and yaw systems have decreased these noise sources over the years. Direct drive systems will improve this even more. In addition, utility scale wind turbines are usually insulated to prevent mechanical noise from proliferating outside the nacelle or tower (Alberts, 2006)

Aerodynamic sound is generated due to complex fluid-structure interactions occurring on the blades. Wagner et al. (1996) break down the sources of aerodynamic sound as follows in Table 1.

Table 1

Sources of Aerodynamic Sound from a Wind Turbine (Wagner et al., 1996*).*

Noise Type	**Mechanism**	**Characteristic**
Trailing-edge noise	Interaction of boundary layer turbulence with blade trailing edge	Broadband, main source of high frequency noise (770 Hz < f < 2 kHz)
Tip noise	Interaction of tip turbulence with blade tip surface	Broadband
Stall, separation noise	Interaction of turbulence with blade surface	Broadband
Laminar boundary layer noise	Non-linear boundary layer instabilities interacting with the blade surface	Tonal
Blunt trailing edge noise	Vortex shedding at blunt trailing edge	Tonal
Noise from flow over holes, slits, and intrusions	Unsteady shear flows over holes and slits, vortex shedding from intrusions	Tonal
Inflow turbulence noise	Interaction of blade with atmospheric turbulence	Broadband
Steady thickness noise, steady loading noise	Rotation of blades or rotation of lifting surface	Low frequency related to blade passing frequency (outside of audible range)
Unsteady loading noise	Passage of blades through varying velocities, due to pitch change or blade altitude change as it rotates* For downwind turbines passage through tower shadow	Whooshing or beating, amplitude modulation of audible broadband noise. For downwind turbines, impulsive noise at blade passing frequency

**van den Berg 2004.*

Of these mechanisms, the most persistent and often strongest source of aerodynamic sound from modern wind turbines is the trailing edge noise. It is also the amplitude modulation of this noise source due to the presence of atmospheric effects and directional propagation effects that result in the whooshing or beating sound often reported (van den Berg, 2004). As a turbine blade rotates through a changing wind stream, the aerodynamics change, leading to differences in the boundary layer and thus to differences in the trailing edge noise (Oerlemans, 2009). Also, the direction in which the blade is pointing changes as it rotates, leading to differences in the directivity of the noise from the trailing edge. This noise source leads to what some people call the "whooshing" sound.

Most modern turbines use pitch control for a variety of reasons. One of the reasons is that at higher wind speeds, when the control system has the greatest impact, the pitch controlled turbine is quieter than a comparable stall regulated turbine would be. Appendix E shows the difference in the noise from two such systems.

When discussing noise from turbines, it is important to also consider propagation effects and multiple turbine effects. One propagation effect of interest is due to the dependence of the speed of sound on temperature. When there is a large temperature gradient (which may occur during the day due to surface warming or due to topography such as hills and valleys) the path a sound wave travels will be refracted. Normally this means that during a typical day sound is "turned" away from the earth's surface. However, at night the sound propagates at a constant height or even be "turned" down toward the earth's surface, making it more noticeable than it otherwise might be.

The absorption of sound by vegetation and reflection of sound from hillsides are other propagation effects of interest. Several of these effects were shown to be influencing the sound field near a few homes in North Carolina that were impacted by a wind turbine installation (Kelley et al., 1985). A downwind 2-bladed, 2 MW turbine was installed on a mountaintop in North Carolina. It created high amplitude impulsive noise due to the interaction of the blades and the tower wakes. Some homes (10 in 1000) were adversely affected by this high amplitude impulsive noise. It is shown in the report by Kelley et al. (1985) that echoes and focusing due to refraction occurred at the location of the affected homes.

In flat terrain, noise in the audible range will propagate along a flat terrain in a manner such that its amplitude will decay exactly as distance from the source (1/distance). Appendix E provides formulae for approximating the overall sound level at a given distance from a source. In the inaudible range, it has been noted that often the sound behaves as if the propagation was governed by a $1/(\text{distance})^{1/2}$ (Shepherd & Hubbard, 1991).

When one considers the noise from a wind farm in which multiple turbines are located close to each other, an estimate for the overall noise from the farm can be obtained. Appendix E describes the method for obtaining the estimate. All these estimates rely on information regarding the sound power generated by the turbine at the hub height. The power level for several modern turbines is given in Appendix D.

2.2.a Measurement and Reporting of Noise

Turbines produce multiple types of sound as indicated previously, and the sound is characterized in several ways: tonal or broadband, constant amplitude or amplitude modulated, and audible or infrasonic. The first two characterization pairs have been mentioned previously. Audible refers to sound with frequencies from 20 Hz to 20 kHz. The waves in the infrasonic range, less than 20 Hz, may actually be audible if the amplitude of the sound is high enough. Appendix D provides a brief primer on acoustics and the hearing threshold associated with the entire frequency spectrum.

Sound is simply pressure fluctuations and as such, this is what a microphone measures. However, the amplitude of the fluctuations is reported not in units of pressure (such as Pascals) but on a decibel scale. The sound pressure level (SPL) is defined by

$$SPL = 10 \log_{10} [p^2/p^2_{ref}] = 20 \log_{10}(p/p_{ref})$$

the resulting number having the units of decibels (dB). The reference pressure p_{ref} for airborne sound is 20×10^{-6} Pa (i.e., 20 μPa or 20 micro Pascals). Some implications of the decibel scale are noted in Appendix D.

When sound is broadband (contains multiple frequencies), it is useful to use averages that measure approximately the amplitude of the sound and its frequency content. Standard averaging methods such as octave and 1/3-octave band are described in Appendix D. In essence, the entire frequency range is broken into chunks, and the amplitude of the sound at frequencies in each chunk is averaged. An overall sound pressure value can be obtained by averaging all of the bands.

When presenting the sound pressure it is common to also use a filter or weighting. The A-weighting is commonly used in wind turbine measurements. This filter takes into account the threshold of human hearing and gives the same decibel reading at different frequencies that would equate to equal loudness. This means that at low frequencies (where amplitudes have to be incredibly high for the sound to be heard by people) a large negative weight would be applied. C-weighting only filters the levels at frequencies below about 30 Hz and above 4 kHz and filters them only slightly between 0 and 30 Hz. The weight values for both the A and C weightings filters are shown in Appendix D, and an example with actual wind turbine data is presented.

There are many other weighting methods. For instance, the day-night level filter penalizes nighttime noise between the hours of 10 p.m. and 7 a.m. by adding an additional 10 dB to sound produced during these hours.

When analyzing wind turbine and other anthropogenic sound there is a question as to what averaging period should be used. The World Health Organization uses a yearly average. Others argue though that especially for wind turbines, which respond to seasonal variations as well as diurnal variations, much shorter averages should be considered.

2.2.b Infrasound and Low-frequency Noise (IFLN)

The term *infrasound* refers to pressure waves with frequencies less than 20 Hz. In the infrasonic range, the amplitude of the sound must be very high for it to be audible to humans. For instance, the hearing threshold below 20 Hz requires that the amplitude be above 80 dB for it to be heard and at 5 Hz it has to be above 103 dB (O'Neal, 2011; Watanabe & Moeller, 1990). This gives little room between the audible and the pain values for the infrasound range: 165 dB at 2 Hz and 145 dB at 20 Hz cause pain (Leventhal, 2006).

The *low frequency* range is usually characterized as 20–200 Hz (Leventhal, 2006; O'Neal, 2011). This is within the audible range but again the threshold of hearing indicates that fairly high amplitude is required in this frequency range as well. The A-weighting of sound is based upon the threshold of human hearing such that it reports the measured values adjusted by -50 dB at 20 Hz, -10 dB at 200 Hz, and + 1 dB at 1000 Hz. The A-weighting curve is shown in Appendix D.

It is known that low frequency waves propagate with less attenuation than high-frequency waves. Measurements have shown that the amplitude for the airborne infrasonic waves can be cylindrical in nature, decaying at a rate inversely proportional to the square root of the distance from the source. Normally the decay of the amplitude of an acoustic wave is inversely proportional to the distance (Shepherd & Hubbard, 1991).

It is difficult to find reliable and comparable infrasound and low frequency noise (ILFN) measurement data in the peer-reviewed literature. Table 2 provides some examples of such measurements from wind turbines. For each case, the reliability of the infrasonic data is not known (the infrasonic measurement technique is not described in each report), although it is assumed that the low frequency noise was captured accurately. The method for obtaining the sound pressure level is not described for each reported data set, and some may come from averages over many day/time/wind conditions while others may be just from a single day's measurement campaign.

Table 2
Literature-based Measurements of Wind Turbines; dB alone refers to unweighted values

Turbine Rating (kW)	Distance (m)	Frequency	Sound Pressure Level	Reference
500	200	5 20	55 dB(G)[2] 35 dB(G)[2]	Jakobsen, 2005[3]
3200	68	4 20	72 dB(G)[2] 50 dB(G)[2]	Jakobsen, 2005[3]
1500	65	5 20 100	>70 dB(A) 60 dB(A) 35 dB(A)	Leventhal, 2006
2000 (2)	100	5 20 200	95 dB 65 dB 55 dB	van den Berg, 2004[3]
1500	98	1 10 20 100 200	90 dB 70 dB 68 dB 68 dB 60 dB	Jung, 2008[3]
-	450	10 100 200	75 dB 55 dB 40 dB	Palmer, 2010
2300	305	5 20 100	73 dB(A) 55 dB(A) - 95 50 dB(A) - 70	O'Neal, 2011[3]

[1]dB alone refers to un-weighted values.
[2]G weighting reflects human response to infrasound. The curve is defined to have a gain of zero dB at 10 Hz. Between 1 Hz and 20 Hz the slope is approximately 12 dB per octave. The cut-off below 1 Hz has a slope of 24 dB per octave, and above 20 Hz the slope is -24 dB per octave. Humans can hear 95 dB(G).
[3]Indicates peer-reviewed article.

When these recorded levels are taken at face value, one might conclude that the infrasonic regime levels are well below the audible threshold. In contrast, the low frequency regime becomes audible around 30 Hz. Such data have led many researchers to conclude that the infrasound and low frequency noise from wind turbines is not an issue (Leventhal, 2009; O'Neal, 2011; Bowdler, 2009). Others who have sought explanations for complaints from those living near wind turbines have pointed to ILFN as a problem (Pierpont, 2009; Branco & Alves-

Pereira, 2004). Some have declared the low frequency range to be of greatest concern (Kamperman et al., 2008; Jung, 2008).

It is important to make the clear distinction between amplitude-modulated noise from wind turbines and the ILFN from turbines. Amplitude modulation in wind turbines noise has been discussed at length by Oerlemans (2009) and van den Berg (2004). Amplitude modulation is what causes the whooshing sound referred to as swish-swish by van den Berg (that sometimes becomes a thumping sound). The whooshing noise created by modern wind turbines occurs because of variations in the trailing edge noise produced by a rotor blade as it sweeps through its path and the directionality of the noise because of the perceived pitch of the blade at different locations along its 360° rotation. The sound is produced in the audible range, and it is modulated so that it is quiet and then loud and then quiet again at a rate related to the blade passing frequency (rate blades pass the tower) which is often around 1 Hz. Van den Berg (2004) noted that the level of amplitude modulation is often greater at night because the difference between the wind speed at the top and bottom of the rotor disc can be much larger at night when there is a stable atmosphere than during the day when the wind profile is less severe. It is further argued that in a stable atmosphere there is little wind near the ground so wind noise does not mask the turbine noise for a listener near the ground. Finally, atmospheric effects can change the propagation of the sound refracting the noise towards the ground rather than away from the ground. The whooshing that is heard is NOT infrasound and much of its content is not at low frequency. Most of the sound is at higher frequency and as such it will be subject to higher atmospheric attenuation than the low frequency sound. An anecdotal finding that the whooshing sound carries farther when the atmosphere is stable does not imply that it is infrasound or heavy in low frequency content, it simply implies that the refraction of the sound is also different when the atmosphere is stable. It is important to note then that when a complaint is tied to the thumping or whooshing that is being heard, the complaint may not be about ILFN at all even if the complaint mentions low frequency noise. Kamperman et al. (2008) state that, “It is not clear to us whether the complaints about “low frequency” noise are about the audible low frequency part of the “swoosh-boom” sound, the once-per-second amplitude modulation … of the “swoosh-boom” sound, or some combination of the two.”

Chapter 3

Health Effects

3.1 Introduction

Chapter 3 reviews the evidence for human health effects of wind turbines. Extensive literature searches and reviews were conducted to identify studies that specifically evaluate population responses to turbines, as well as population and individual responses to noise, vibration, and flicker. The biological plausibility or basis for health effects of turbines (noise, vibration, and flicker) was examined. Beyond traditional forms of scientific publications, the Panel also reviewed other non-peer reviewed materials including information related to “Wind Turbine Syndrome” and provides a rigorous analysis of its scientific basis. Since the most commonly reported complaint by people living near turbines is sleep disruption, the Panel provides a robust review of the relationship between noise, vibration, annoyance as well as sleep disturbance from noises and the potential impacts of the resulting sleep deprivation.

In assessing the state of the evidence for health effects of wind turbines, the Panel relied on several different types of studies. It considered human studies of primary value. These were either human epidemiological studies specifically relating to exposure to wind turbines or, where specific exposures resulting from wind turbines could be defined, the Panel also considered human experimental data. Animal studies are critical to exploring biological plausibility and understanding potential biological mechanisms of different exposures, and for providing information about possible health effects when experimental research in humans is not ethically or practically possible (National Research Council (NRC), 1991). As such, this literature was also reviewed with respect to wind turbine exposures. In all cases, data quality is considered. At times some studies were rejected because of lack of rigor or the interpretations were inconsistent with the scientific evidence. These are identified in the discussion below.

In the specific case of the possibility of ice being thrown from wind turbine blades, the Panel discusses the physics of such ice throw in order to provide the basis of the extent of the potential for injury from thrown ice (see Chapter 2).

3.2 Human Exposures to Wind Turbines

Epidemiologic study designs differ in their ability to provide evidence of an association (Ellwood, 1998). Typical study designs include randomized trials, cohort studies, and case-control studies and can include elements of prospective follow-up, retrospective assessments, or cross-sectional analysis where exposure and outcome data are essentially concurrent. Each of these designs has strengths and weaknesses and thus can provide varying levels of strength of evidence for causal associations between exposures and outcomes, which can also be affected by analytic choices. Thus, this literature needs to be examined in detail, regardless of study type, to determine strength of evidence for causality.

Review of this literature began with a PubMed search for “wind turbine” or “wind turbines” to identify peer-reviewed literature pertaining to health effects of wind turbines. Titles and abstracts of identified papers were then read to make a first pass determination of whether the paper was a study on health effects of exposure to wind turbines or might possibly contain relevant references to such studies. Because the peer-reviewed literature so identified was relatively limited, we also examined several non-peer reviewed papers, reports, and books that discussed health effects of wind turbines. All of this literature was examined for additional relevant references, but for the purposes of determining strength of evidence, we only considered such publications if they described studies of some sort in sufficient detail to assess the validity of the findings. This process identified four studies that generated peer-reviewed papers on health effects of wind turbines. A few other non-peer reviewed documents described data of sufficient relevance to merit consideration and are discussed below as well.

3.3 Epidemiological Studies of Exposure to Wind Turbines

The four studies that generated peer-reviewed papers on health effects of wind turbines included two from Sweden (E. Pedersen et al., 2007; E. Pedersen & Waye, 2004), one from the Netherlands (E. Pedersen et al., 2009), and one from New Zealand (Shepherd at al., 2011). The primary outcome assessed in the first three of these studies is annoyance. Annoyance *per se* is not a biological disease, but has been defined in different ways. For example, as “a feeling of resentment, displeasure, discomfort, dissatisfaction, or offence which occurs when noise interferes with someone’s thoughts, feelings or daily activities” (Passchier-Vermeer, 1993); or “a mental state characterized by distress and aversion, which if maintained, can lead to a deterioration of health and well-being” (Shepherd et al., 2010). Annoyance is usually assessed with questionnaires, and this is the case for the three studies mentioned above. There is consistent evidence for annoyance in populations exposed for more than one year to sound levels of 37 dB(A), and severe annoyance at about 42 dB(A) (Concha-Barrientos et al., 2004). In each of those studies annoyance was assessed by questionnaire, and the respondent was asked to indicate annoyance to a number of items (including wind turbines) on a five-point scale (do not notice, notice but not annoyed, slightly annoyed, rather annoyed, very annoyed). While annoyance as such is certainly not to be dismissed, in assessing global burden of disease the World Health Organization (WHO) has taken the approach of excluding annoyance as an outcome because it is not a formally defined health outcome *per se* (Concha-Barrientos et al., 2004). Rather, to the extent annoyance may cause other health outcomes, those other outcomes could be considered directly. Nonetheless, because of a paucity of literature on the association between wind turbines and other health outcomes, we consider here the literature on wind turbines and annoyance.

3.3.a Swedish Studies

Both Swedish studies were cross sectional and involved mailed questionnaires to potential participants. For the first Swedish study, 627 households were identified in one of five areas of Sweden chosen to have enough dwellings at varying distances from wind turbines and of comparable geographical, cultural, and topographical structure (E. Pedersen & Waye, 2004). There were 16 wind turbines in the study area and of these, 14 had a power of 600–650 kW, and the other 2 turbines had 500 kW and 150 kW. The towers were between 47 and 50 m in height. Of the turbines, 13 were WindWorld machines, 2 were Enercon, and 1 was a Vestas turbine. Questionnaires were to be filled out by one person per household who was between the ages of 18 and 75. If there was more than one such person, the one whose birthday was closest to May 20th was chosen. It is not clear how the specific 627 households were chosen, and of the 627, only 513 potential participants were identified, although it is not clear why the other households did not have potential participants. Of the 513 potential participants, 351 (68.4%) responded.

The purpose of the questionnaire was masked by querying the participant about living conditions in general, some questions on which were related to wind turbines. However, a later section of the questionnaire focused more specifically on wind turbines, and so the degree to which the respondent was unaware about the focus on wind turbines is unclear. A-weighted sound levels were determined at each respondent’s dwelling, and these levels were grouped into

6 categories (in dB(A): <30, 30–32.5, 32.5–35, 35–37.5, 37.5–40, and >40). Ninety-three percent of respondents could see a wind turbine from their dwelling.

The main results of this study were that there was a significant association between noise level and annoyance. This association was attenuated when adjusted for the respondent's attitude towards the visual impact of the turbines, which itself was a strong predictor of annoyance levels, but the association with noise still persisted. Further adjustment for noise sensitivity and attitude towards wind turbines in general did not change the results. The authors indicated that the reporting of sleep disturbances went up with higher noise categories, but did not report on the significance of this association. Nor did the authors report on associations with other health-related questions that were apparently on the questionnaire (such as headache, undue tiredness, pain and stiffness in the back, neck or shoulders, or feeling tensed/stressed, or irritable).

The 68% response rate in this study is reasonably good, but it is somewhat disconcerting that the response rate appeared to be higher in the two highest noise level categories (76% and 78% vs. 60–69%). It is not implausible that those who were annoyed by the turbines were more inclined to return the questionnaire. In the lowest two sound categories (<32.5 dB(A)) nobody reported being more than slightly annoyed, whereas in the highest two categories 28% (37.5–40 dB(A)) and 44% (>40 dB(A)) reported being more than slightly annoyed (unadjusted percentages). Assuming annoyance would drive returning the questionnaires, this would suggest that the percentages in the highest categories may be somewhat inflated. The limited description of the selection process in this study is a limitation as well, as is the cross sectional nature of the study. Cross-sectional studies lack the ability to determine the temporality of cause and effect; in the case of these kinds of studies, we cannot know whether the annoyance level was present before the wind turbines were operational from a cross sectional study design. Furthermore, despite efforts to blind the respondent to the emphasis on wind turbines, it is not clear to what degree this was successful.

The second Swedish study (E. Pedersen & Persson Waye, 2007) took a similar approach to the first, but in this study the selection procedures were explained in more detail and were clearly rigorous. Specific details on the wind turbines in the area were not provided, but it was noted that areas were sought with wind turbines that had a nominal power of more than 500 kW, although some of the areas also contained turbines with lower power. A later publication by these authors (Pedersen et al., 2009) indicates that the turbines in this study were up to 1.5 MW and up to 65 m high. In the areas chosen, either all households were recruited or a random sample was used. In this study 1,309 questionnaires were sent out and 754 (57.6%) were returned. The response rate by noise category level, however, was not reported. There was a clear association between noise level and hearing turbine noise, with the percentage of those hearing turbine noise steadily increasing across the noise level categories. However, despite a significant unadjusted association between noise levels and annoyance (dichotomized as more than slightly annoyed or not), and after adjusting for attitude towards wind turbines or visual aspects of the turbines (e.g., visual angle on the horizon, an indicator of how prominent the turbines are in the field of view), each of which was strongly associated with annoyance, the association with noise level category was lost. The model from which this conclusion was drawn, however, imposed a linear relation on the association between noise level category and annoyance. But in the crude percentages of people annoyed across noise level categories, it appeared that the relation might not be linear, but rather most prevalent in the highest noise. The percentage of those in the highest noise level category (>40 dB(A)) reporting annoyance (~15%) appeared to be higher than among people in the lower noise categories (<5%).

Given the more rigorous description of the selection process in this study, it has to be considered stronger than the first Swedish study. While 58% is pretty good for a questionnaire response rate, the non-response levels still leave room for bias. The authors do not report the response rate by noise level categories, but if the pattern is similar to the first Swedish study, it could suggest that the percentage annoyed in the highest noise category could be inflated. The cross sectional nature of the study is also a limitation and complicates interpretation of the effects on the noise-annoyance association of adjustment for the other factors. Regarding the loss of the association after adjustment for attitude, if one assumes that the noise levels caused a negative attitude towards wind turbines, then the loss of association between noise and annoyance after adjusting for attitude does not argue against annoyance being caused by increasing turbine noise, but rather that that is the path by which noise causes annoyance (louder noise→negative attitude→annoyance). If, on the other hand, the attitude towards turbines was not caused by the noise, then the results would suggest that noise levels did not cause the annoyance. Visual angle, however, clearly does not cause the noise level; thus, the lack of association between noise and annoyance in analyses adjusted for visual angle more strongly suggest that the turbine noise level is not causing the annoyance, but perhaps the visual intrusion instead. This is similar to the conclusion of an earlier Danish report (T. H. Pedersen & Nielsen, 1994). Either way, however, the data still suggest that there may be an association between turbine noise and annoyance when the noise levels are >40 dB(A).

A more intricate statistical model of the association between turbine noise levels and annoyance that used the data from both Swedish studies was reported separately (Pedersen & Larsman, 2008). The authors used structural equation models (SEMs) to simultaneously account for several aspects of visual attitude towards the turbines and general attitude towards the turbines. These analyses suggested a significant association between noise levels and annoyance even after considering other factors.

3.3.b Dutch Study

The Dutch study aimed to recruit households that reflected general wind turbine exposure conditions over a range of background sound levels. All areas within the Netherlands that were characterized by one of three clearly defined land-use types—built-up area, rural area with a main road, and rural area without a main road—and that had at least two wind turbines of at least 500 kW within 500 meters of each other were selected for the study. Sites dominated by industry or business were excluded. All addresses within these areas were obtained and classified into one of five wind turbine noise categories (<30, 30–35, 35–40, 40–45, and >45 dB(A)) based on characteristics of nearby wind turbines, measurements of sound from those turbines, and the International Standards Organization (ISO) standard model of wind turbine noise propagation. Individual households were randomly selected for recruitment within noise/land type categories, except for the highest noise level for which all households were selected because of the small number exposed at the wind turbine noise levels of the highest category.

As with the Swedish studies, the Dutch study was cross sectional and involved a mailed questionnaire modeled on the one used in the Swedish studies. Of 1,948 mailed surveys, 725 (37%) were returned. There was only minor variation in response rate by turbine noise category, although unlike the Swedish studies, the response rate was slightly lower in the higher noise categories. A random sample of 200 non-responders was sent an abbreviated questionnaire asking only two questions about annoyance from wind turbine noise. There was no difference in the distribution of answers to these questions among these non-responders and those who responded to the full questionnaire.

One of the more dramatic findings of this study was that among people who benefited economically from the turbines (n=100; 14%)—who were much more commonly in the higher noise categories—there was virtually no annoyance (3%) despite the same pattern of noticing the noise as those who did not benefit economically. It is possible that this is because attitude towards turbines drives annoyance, but it was also suggested that those who benefit economically are able to turn off the turbines when they become annoying. However, it is not clear how many of those who benefited economically actually had that level of control over the turbines.

Similarly, there was very little annoyance among people who could not see a wind turbine from their residence even when those people were in higher noise categories (although none were in the highest category). In models that adjusted for visibility of wind turbines and economic benefit, sound level was still a significant predictor of annoyance. However, because of the way in which sound and visibility were modeled in this analysis, the association between higher noise levels and higher annoyance could have been driven entirely by those who could see a wind turbine, while there could still have been no association between wind turbine noise level and annoyance among those who could not see a wind turbine. Thus, this study has to be considered inconclusive with respect to an association between wind turbine sound level and annoyance *independent of* the effect of seeing a wind turbine (and vice versa).

The Dutch study has the limitation of being cross sectional as were the Swedish studies, and the non-response in the Dutch study was much larger than in the Swedish studies. The results of the limited assessment of a subset of non-responders mitigate somewhat against the concerns raised by the low response rate, but not completely.

3.3.c New Zealand Study

The New Zealand study recruited participants from what the authors refer to as two demographically matched neighborhoods (an exposed group living near wind turbines and a control group living far from turbines), although supporting data for this are not presented. The area with the turbines is described as being characterized by hilly terrain, with long ridges running 250–450 m above sea level, on which 66 125 m high wind turbines are positioned. The power of the turbines is not provided. For the exposed group, participants were drawn from those 18 years and older living in 56 houses located within 2 km of a wind turbine, and for the control group participants were drawn from those 18 years and older living in 250 houses located at least 8 km from the wind turbines. It is unclear how many participants per household were recruited, but the final study sample included 39 people in the exposed group and 158 in the control group. Response rates of 34% for the exposed group and 32% for the control group are given. The outcome assessed was response to the abbreviated version of the WHO's quality of life (QOL)-BREF (WHOQOL-BREF)—a health-related QOL questionnaire. These questions were embedded within a larger questionnaire with various facets designed to mask the focus on wind turbines. Although there were no statistically significant demographic differences between the two groups, 43.6% of those in the exposed group had a university education while only 34.2% in the control group did.

The exposed group was found to have significantly worse physical QOL (in particular the sleep and energy level items of this scale) and worse environmental QOL (in particular ratings of how healthy the environment is and satisfaction with the conditions of their living space). The groups did not differ in scores on the social or psychological scales. The mean ratings for an overall QOL item was significantly lower in the exposed group. All of these analyses were adjusted for length of residence, but for no other variables.

As with the other studies discussed, this study has the limitation of being cross sectional. As with the Dutch study, the response rate in the present study is rather low, and unfortunately, there are no data in the New Zealand study on non-participants. This raises concern that self-selection into the study could differ by important factors in some way between the two groups. The difference seen in education level between the groups exacerbates this concern. It is also unclear whether appropriate statistical analysis methods were used given that there may have been multiple respondents from the same household, which is not stated but would have needed to have been accounted for in the analysis. The lack of control for other variables that may be related to reporting of QOL is also a limitation. In this regard it is important to note that a lack of a statistically significant difference in factors between groups does not rule out the possibility of those factors potentially accounting for some of the difference in outcome scores between groups, particularly when the sample size is small like in this study. Whether participants could see wind turbines was not assessed, but it is likely that most if not all in the exposed group could and most if not all in the control group could not, given their locations. Given the findings in the

Swedish and Dutch studies, this means that even if the difference in QOL scores seen are due to wind turbines, it is possible that it is driven by seeing the turbines rather than sound from the turbines. Overall, the level of evidence from this study for a causal association between wind turbines and reported QOL is limited.

3.3.d Additional Non-Peer Reviewed Documents

Papers that appear in the peer-reviewed literature have by definition undergone a level of review external to the study team by not only the editors of the journal, but also two to three (usually) scientists familiar with the field of the study and the methodology used. These hurdles provide an opportunity to identify problems with the paper—from methodology to interpretation of the results—and either provide the opportunity to address problems or reject the paper if the problems are considered fatal to the interpretation of the results. Non-peer reviewed literature is not subject to this external review scrutiny. This does not mean that all peer-reviewed literature is of high quality nor that non-peered reviewed literature is necessarily inferior to peer-reviewed literature, but it does mean that non-peered reviewed literature does not need to undergo any review process to appear. Indeed, at times studies appear in non-peer reviewed outlets precisely because they did not meet the bar of quality necessary to appear in the peer-reviewed literature. Thus, non-peer reviewed literature needs to be scrutinized with this in mind. Four such non-peer-reviewed reports are described below. In addition to those four, a few early reports of annoyance from wind turbines generally found a weak relationship between annoyance and the equivalent A-weighted SPL, although those studies were mainly based on studies of smaller turbines of less than 500 kW (T. H. Pedersen & Nielsen, 1994; Rand & Clarke, 1990; Wolsink et al., 1993).

<u>Project WINDFARMperception: Visual and acoustic impact of wind turbine farms on residents (van den Berg et al., 2008).</u> This report describes the study upon which the Dutch paper summarized above (E. Pedersen et al., 2009) is based. The characteristics of the wind turbines are thus as described above. In addition to the data that appeared in the peer-reviewed literature, this report describes analyses of additional data that was collected. These additional data relate to health effects and turbine noise exposure. The questionnaire assessed stress levels with the General Health Questionnaire (GHQ), a validated scale that has been widely used in such studies and which assesses symptoms felt over the past several weeks. In models adjusted for age, economic benefit from the turbines, and sex, there was no association between sound

levels and stress. In contrast, there was a significant association between sound levels and interrupted sleep (at least once a month), even when further adjusting for background noise levels. This was most obvious at turbine noise levels >45 dB(A), but there appeared to be an increasing trend in occurrence of interrupted sleep with increasing noise categories even across the lower noise categories. This study also asked participants about chronic health conditions including diabetes, high blood pressure, tinnitus, hearing impairment, cardiovascular disease, and migraine. Although no associations were seen between wind turbine noise and these outcomes in adjusted analyses, the chronic nature of these outcomes and the lack of data on timing of onset with respect to when the wind turbines were introduced make interpreting these negative findings difficult.

Report to the commission related to Moturimu wind farm, New Zealand (Phipps, 2007). This report to a commission in New Zealand related to the Moturimu wind farm describes a survey conducted by Robyn Phipps to investigate the visual and acoustical effects experienced by residents living at least 2 km from existing wind farms in the Manawatu and Tararua regions of New Zealand. Most respondents were within 3 km, although a few lived further away, as far as 15 km. The characteristics and number of wind turbines was not provided. Although this work does not appear to have come out in the peer-reviewed literature, reasonable details about the methodology are provided.

Roughly 1,100 surveys were delivered to postal addresses and 614 (56%) were returned. Participants were asked to rate on a scale of 1–5 their agreement with different statements related to their perceptions of the wind turbines. When these questions dealt with visual issues, they were framed both positively and negatively (e.g., “I think the turbines spoil the view,” and “I think the turbines are quite attractive”). This apparently was not the case with other questions (e.g., “Watching the turbines can create an unpleasant physical sensation in my body”).

Overall, 9% of respondents endorsed being “affected” by the flicker of the wind turbines; 15% were sufficiently bothered by the visual and noise effects of the turbines to consider complaining, and 10% actually had complained. While 56% is a relatively good response rate for a mailed survey, the reasons for non-response of nearly half of potential participants must be considered. It is possible that non-respondents did not care enough about the effects of the wind turbines to bother responding, which presumably would lower the overall percentages that were “affected” by the turbines. On the other hand, it is not clear how long the turbines were in operation prior to the survey, and it is conceivable that some more affected people may have moved out of the area before the time of the survey.

A further drawback to the reported survey was that there was not a determination of how the percentage of "affected" respondents related to distance from the turbines, the ability to see the turbines, or noise levels experienced from the turbines. The report cites a lot of literature on noise and health effects, and while such effects have been reported in the literature, they are almost uniformly at sound levels above what is usually found for people living near turbines (and most certainly higher than those usually reported for people living more than 2 km from a turbine). A WHO report provides a good review of this literature (WHO, 2009). The lowest threshold levels for seeing any effect are about 35 dB(A) (maximum per event or L_{Amax}) for some physiological sleep responses (e.g., EEG, or duration of sleep stages), but these thresholds are for levels inside the house near the sleeper, which will be much lower than what is experienced outside the house. The lowest threshold level for complaints of well-being were estimated at 35 dB(A) as a yearly average outside the house at night ($L_{night, outside}$). But for health outcomes the thresholds for any effect are much higher, for example 50 dB(A) ($L_{night, outside}$) for hypertension or myocardial infarction.

"Wind Turbine Syndrome" (Pierpont, 2009): This book describes several people who suffer health symptoms that they attribute to wind turbines. Such descriptions can be informative in describing phenomena and raising suggestions for possible follow-up with more rigorous study designs, but generally are not considered evidence for causality. In this particular case, though, there are elements that go beyond the most basic symptom descriptions and so warrant consideration as a study. But limitations to the design employed make it impossible for this work to contribute any evidence to the question of whether there is a causal association between wind turbine exposure and health effects. Given this, the very term "Wind Turbine Syndrome" is misleading as it implies a causal role for wind turbines in the described health symptoms.

The book describes health symptoms experienced among 38 people from 10 different families who lived near wind turbines and subsequently either moved away from the turbines or spent significant periods of time away. The participants ranged in age from less than 1 to 75 years old, with 13 (34%) younger than 16 years and 17 (45%) younger than 22. The participants were queried about their health symptoms before exposure to turbines (presumably before the turbines were operational), during exposure to turbines, and after moving away. There is an impressive detailed description of the extent and severity of health symptoms experienced by this group, with a core group of symptoms centered around vibratory responses and termed Visceral Vibratory Vestibular Disturbance (VVVD) by Pierpont. While these symptoms for the most part are attributed to exposure to the wind turbines by the participants—either because they appeared once the turbines were operational or because they seemed to diminish after going away from the turbines—the way in which these participants were recruited makes it impossible to draw any conclusions about attributing causality to the turbines.

The most critical problem with respect to inferring causality from Pierpont's findings lies in how the families were identified for participation. To be included in the study, among other criteria, at least one family member had to have severe symptoms *and* reside near a recently erected wind turbine. In epidemiological terms this is selecting participants based on both exposure and outcome, which guarantees a biased (non-causal) association between wind turbines and symptoms. While it could be argued that other family members may not have had severe symptoms—and so would not be selected based on outcome—it is hard to consider other family members as truly independent observations, as their reporting of symptoms, or indeed their experiencing of symptoms, could be influenced by the more severely affected family member. This is particularly so when the symptoms are in the realm of anxiety, sleep disturbance, memory, and concentration; and the severely affected family members are reporting increased irritability, anger, and shouting.

Although not always, several of the participants reported an improvement of symptoms after moving away from the wind turbines. While this is suggestive and should not be discounted as something to explore further, the highly selective nature of the interviewed group as a whole makes the evidence for causality from these data *per se* weak. There are also many factors that change when moving, making it difficult to attribute changes to any specific difference with certainty. Additional factors that contribute to the inability to infer causality from these data include the small sample size, lack of detail on the larger population that could have been considered for inclusion in the study, and lack of detail on precisely how the actual participants were recruited. In addition, while the clinical history was extensive, the symptom data were all self-reported. Another complication is that there are no precise data on distance to turbines, and noise levels or infrasound vibration levels at the participants' homes.

“Adverse health effects of industrial wind turbines: a preliminary report” (Nissenbaum et al., 2011): This report describes a study involving questionnaire assessment of mental and physical health (SF-36), sleep disturbance (Pittsburgh Sleep Quality Index), and sleepiness (Epworth Sleepiness Scale) among residents near one of two wind farms in Maine (Vinalhaven & Mars Hill). The Mars Hill site is a linear arrangement of 28 General Electric 1.5 MW turbines, sited on a ridgeline. The Vinalhaven site is a cluster of three similar turbines, sited on a flat, tree-covered island. All residents within 1.5 km of one of the turbines were identified, and all those older than 18 years and non-demented were considered eligible for the study. A set of households from an area of similar socioeconomic makeup but 3–7 km from wind turbines were also recruited. The recruitment process involved house-to-house visits up to three times to recruit participants. Among those within at most 1.5 km from the nearest turbine, 65 adults were identified and 38 (58%; 22 male, 16 female) participated from 23 unique households. Among those 3-7 km from the nearest turbine, houses were visited until a similar number of participants were recruited. This process successfully recruited 41 adults (18 male, 23 female) from 33 unique households. No information was given on the number of homes or people approached so the participation rate cannot be determined.

Analyses adjusted for age, sex, and site (the two different wind farms) found that those living within 1.5 km of a wind turbine had worse sleep quality and mental health scores and higher ratings of sleepiness than those living 3–7 km from a turbine. Physical health scores did not differ between the groups. Similar associations were found when distance to the nearest turbine was analyzed as a continuous variable.

This study is somewhat limited by its size—much smaller than the Swedish or Dutch studies described above—but nonetheless suggests relevant potential health impacts of living near wind turbines. There are, however, critical details left out of the report that make it difficult to fully assess the strength of this evidence. In particular, critical details of the group living 3–7 km from wind turbines is left out. It is stated that the area is of similar socioeconomic makeup, and while this may be the case, no data to back this up are presented—either on an area level or on an individual participant level. In addition, while the selection process for these participants is described as random, the process of recruiting these participants by going home to home until a certain number of participants are reached is not random. Given this, details of how homes were identified, how many homes/people were approached, and differences between those who did and did not participate are important to know. Without this, attributing any of the observed associations to the wind turbines (either noise from them or the sight of them) is premature.

3.3.e Summary of Epidemiological Data

There is only a limited literature of epidemiological studies on health effects of wind turbines. Furthermore, existing studies are limited by their cross sectional design, self-reported symptoms, limited ability to control for other factors, and to varying degrees of non-response rates. The study that accounted most extensively for other factors that could affect reported symptoms had a very low response rate (E. Pedersen et al., 2009; van den Berg, et al., 2008).

All four peer-reviewed papers discussed above suggested an association between increasing sound levels from wind turbines and increasing annoyance. Such an association was also suggested by two of the non-peer reviewed reports that met at least basic criteria to be considered studies. The only two papers to consider the influence of seeing a wind turbine (each one of the peer-reviewed papers) both found a strong association between seeing a turbine and annoyance. Furthermore, in the studies with available data, the influence of either sound from a turbine or seeing a turbine was reduced—if not eliminated, as was the case for sound in one study—when both of these factors were considered together. However, this precise relation cannot be disentangled from the existing literature because the published analyses do not properly account for both seeing and hearing wind turbines given the relation between these two that the data seem to suggest. Specifically, the possibility that there may be an association between either of those factors and annoyance, but possibly only for those who both see and hear sound from a turbine, and not for those who either do not hear sound from or do not see a turbine. Furthermore, in the one study to consider whether individuals benefit economically from the turbines in question, there appeared to be virtually no annoyance regardless of whether those people could see or hear a turbine. Even if one considers the data just for those who could see a wind turbine and did not benefit economically from the turbines, defining at what noise levels the percentage of those annoyed becomes more dramatic is difficult. Higher percentages of annoyance did appear to be more consistent above 40 dB(A). Roughly 27% were annoyed (at least 4 on a 1–5 point scale of annoyance; 5 being the worst), while roughly 18% were very annoyed (5 on a 1–5 scale). The equivalent levels of annoyed and very annoyed for 35–40 dB(A) were roughly 15% and 6%, respectively. These percentages, however, should be considered upper bounds for a specific relation with noise levels because, with respect to estimating direct effects of noise, they are likely inflated as a result of both selective participation in the studies and the fact that the percentages do not take into account the effect of seeing a turbine.

Thus, in considering simply exposure to wind turbines in general, while all seem to suggest an association with annoyance, because even the peer-reviewed papers have weaknesses, including the cross sectional designs and sometimes quite low response rates, **the Panel concludes that there is limited evidence suggesting an association between exposure to wind turbines and annoyance**. However, only two of the studies considered both seeing and hearing wind turbines, and even in these the possible contributions of seeing and hearing a wind turbine were not properly disentangled. Therefore, **the Panel concludes that there is insufficient evidence to determine whether there is an association between noise from wind turbines and annoyance independent from the effects of seeing a wind turbine and vice versa**. Even these conclusions must be considered in light of the possibility suggested from one of the peer-reviewed studies that there is extremely low annoyance—regardless of seeing or hearing sound from a wind turbine—among people who benefit economically from the turbines.

There was also the suggestion that poorer sleep was related to wind turbine noise levels. While it intuitively makes sense that more noise would lead to more sleep disruption, there is limited data to inform whether this is occurring at the noise levels produced from wind turbines. An association was indicated in the New Zealand study, suggested without presenting details in one of the Swedish studies, and found in two non-peer-reviewed studies. Therefore, **the Panel concludes that there is limited evidence suggesting an association between noise from wind turbines and sleep disruption and that further study would quantify precise sound levels from wind turbines that disrupt sleep**.

The strongest epidemiological study to examine the association between noise and psychological health suggests there is not an association between noise from wind turbines and measures of psychological distress or mental health problems. There were two smaller, weaker, studies: one did note an association, one did not. Therefore, **the Panel concludes the weight of the evidence suggests no association between noise from wind turbines and measures of psychological distress or mental health problems.**

One Swedish study apparently collected data on headache, undue tiredness, pain and stiffness in the back, neck, or shoulders, or feeling tensed/stressed and irritable, but did not report on analyses of these data. The Dutch study found no association between noise from wind turbines and diabetes, high blood pressure, tinnitus, hearing impairment, cardiovascular disease, and migraine, although this was not reported in the peer-reviewed literature. Therefore, **the Panel concludes that none of the limited epidemiological evidence reviewed suggests an association between noise from wind turbines and pain and stiffness, diabetes, high blood pressure, tinnitus, hearing impairment, cardiovascular disease, and headache/migraine.**

These conclusions align with those presented in the peer-reviewed article by Knopper and Ollson (2011). They write "Conclusions of the peer reviewed literature differ in some ways from those in the popular literature. In peer reviewed studies, wind turbine annoyance has been statistically associated with wind turbine noise, but found to be more strongly related to visual impact, attitude to wind turbines and sensitivity to noise. … it is acknowledged that noise from wind turbines can be annoying to some and associated with some reported health effects (e.g., sleep disturbance), especially when found at sound pressure levels greater than 40 db(A)."

3.4 Exposures from Wind Turbines: Noise, Vibration, Shadow Flicker, and Ice Throw

In addition to the human epidemiologic study literature on exposure to wind turbines and health effects described in the section above, the Panel assessed literature that could shed light on specific exposures resulting from wind turbines and possible health effects. The exposures covered here include noise and vibration, shadow flicker, and ice throw. Each of these exposures is addressed separately in light of their documented and potential health effects. When health effects are described in the popular media, these claims are discussed.

3.4.a Potential Health Effects Associated with Noise and Vibration

The epidemiologic studies discussed above point to noise from wind turbines as a source of annoyance. The studies also noted that some respondents note sleep disruption due to the turbine noise. In this section, the characteristics of audible and inaudible noise from turbines are discussed in light of our understanding of their impacts on human health.

It is clear that when sound levels get too high, the sound can cause hearing loss (Concha-Barrientos et al., 2004). These sound levels, however, are outside the range of what one would experience from a wind turbine. There is evidence that levels of audible noise below levels that cause hearing loss can have a variety of health effects or indicators. Detail about the evidence for such health effects have been well summarized in a WHO report that came to several relevant conclusions (WHO, 2009). First, there is sufficient evidence for biological effects of noise during sleep: increase in heart rate, arousals, sleep stage changes and awakening; second, there is limited evidence that noise at night causes hormone level changes and clinical conditions such as cardiovascular illness, depression, and other mental illness. What the WHO report also details is observable noise threshold levels for these potential effects. For such health effects, where data are sufficient to estimate a threshold level, that level is never below 40 dB(A)—as a yearly average—for noise outside (ambient noise) at night—and these estimates take into account sleeping with windows slightly open.

One difficulty with the WHO threshold estimate is that a yearly average can mask the particular quality of turbine noise that leads survey respondents to note annoyance or sleep disruption. For instance, the pulsatile nature of wind turbine noise has been shown to lead to respondents claiming annoyance at a lower averaged sound level than for road noise (E. Pederson, 2004). Yearly averaging of sound eliminates (or smooths) the fluctuations in the sound and ignores differences between day and night levels. Regulations may or may not take this into account.

Health conditions caused by intense vibration are documented in the literature. These are the types of exposures that result from jackhammers, vibrating hand tools, pneumatic tools, etc. In these cases, the vibration is called arm-body or whole-body vibration. Vibration can cause changes in tendons, muscles, bones and joints, and can affect the nervous system. Collectively, these effects are known as Hand-Arm Vibration Syndrome (HAVS). Guidelines and interventions are intended to protect workers from these vibration-induced effects (reviewed by European Agency for Safety and Health at Work, 2008; (NIOSH 1989). OSHA does not have standards concerning vibration exposure. The American Conference of Governmental Industrial Hygienists (ACGIH) has developed Threshold Limit Values (TLVs) for vibration exposure to hand-held tools. The exposure limits are given as frequency-weighted acceleration (NIOSH, 1989).

3.4.a.i Impact of Noise from Wind Turbines on Sleep

The epidemiological studies indicate that noise and/or vibration from wind turbines has been noted as causing sleep disruption. In this section sleep and sleep disruption are discussed. In addition, suggestions are provided for more definitively evaluating the impact of wind turbines on sleep.

All sounds have the potential to disrupt sleep. Since wind turbines produce sounds, they might cause sleep disruption. A very loud wind turbine at close distance would likely disrupt sleep, particularly in vulnerable populations (such as those with insomnia or mood disorders, aging populations, or "light sleepers"), while a relatively quiet wind turbine would not be expected to disrupt even the lightest of sleepers, particularly if it were placed at considerable distance.

There is insufficient evidence to provide very specific information about how likely particular sound-pressure thresholds of wind turbines are at disrupting sleep. Physiologic studies of noises from wind turbines introduced to sleeping people would provide these specific levels. Borrowing existing data (e.g., Basner, 2011) and guidelines (e.g., WHO) about noises at night, beyond wind turbines, might help provide reasonable judgment about noise limits at night. But it would be optimal to have specific data about the particular influence that wind turbines have on sleep.

In this section we introduce broad concepts about sleep, the interaction of sleep and noises, and the potential for wind turbines to cause that disruption.

Sleep

Sleep is a naturally occurring state of altered consciousness and reduced physical activity that interacts with all aspects of our physiology and contributes daily to our health and well-being.

Measurements of sleep in people are typically performed with recordings that include electroencephalography (EEG). This can be performed in a laboratory or home, and for clinical or experimental purposes. Other physiological parameters are also commonly measured, including muscle movements, lung, and heart function.

While the precise amount of sleep that a person requires is not known, and likely varies across different people and different ages, there are numerous consequences of reduced sleep (i.e., sleep deprivation).

Deficiencies of sleep can take numerous forms, including the inability to initiate sleep; the inability to maintain sleep; abnormal composition of sleep itself, such as too little deep sleep (sometimes called slow-wave sleep, or stage N3); or frequent brief disruptions of sleep, called arousals. Sources of sleep deprivation can be voluntary (desirable or undesirable) or involuntary. Voluntary sources include staying awake late at night or awakening early. These can be for work or school, or while engaging in some personal activities during normal sleep times. Sleep deprivation can also be caused by myriad involuntary and undesired problems (including those internal to the body such as pain, anxiety, mood disorders) and frequent need to urinate, or by numerous sleep disorders (including insomnia, sleep apnea, circadian disorders, parasomnias, sleep-related movement disorders, etc), or simply by the lightening of sleep depth in normal aging. Finally, sleep deprivation can be caused by numerous external factors, such as noises or other sensory information in the sleeper's environment.

Sleep is conventionally categorized into rapid eye movement (REM) and non-REM sleep. Within the non-REM sleep are several stages of sleep ranging from light sleep to deep sleep. Beyond these traditional sleep categories, the EEG signal can be analyzed in a more detailed and sophisticated way, including looking at the frequency composition of the signals. This is important in sleep, as we now know that certain signatures in the brain waves (i.e., EEG) disclose information about who is vulnerable to noise-induced sleep disruption, and what moments within sleep are most vulnerable (Dang-Vu et al., 2010; McKinney et al., 2011).

Insomnia can be characterized by a person having difficulty falling asleep or staying asleep that is not better explained by another condition (such as pain or another sleep disorder) (see ICSD, 2nd Edition for details of the diagnostic criteria for insomnia). Approximately 25% of the general population experience occasional sleep deprivation or insomnia. Sleep deprivation is defined by reduced quantity or quality of sleep, and it can result in excessive daytime sleepiness as well as problems including those associated with mood and cognitive function (Roth et al., 2001; Rogers, 2007; Walker, 2008). As might be expected, the severity of the sleep deprivation has an impact on the level of cognitive functioning, and real-life consequences can include driving accidents, impulsive behaviors, errors in attention, and mood problems (Rogers, 2007; Killgore, 2010). Loss of sleep appears to be cumulative, meaning it adds up night after night. This can result in subtle impairments in reaction times, decision-making ability, attentional vigilance, and integration of information that is sometimes only apparent to the sleep-deprived individual after an accident or error occurs, and sometimes not perceived by the sleep-deprived person at all (Rogers, 2007; van Dongen 2003).

Sleep and Wind Turbines

Given the effects of sleep deprivation on health and well-being, including problems with mood and cognition, it is possible that cognitive and mood complaints and other medical or psychological issues associated with sleep loss can stem from living in immediate proximity to wind turbines, if the turbines disrupt sleep. Existing data, however, on the relationship between wind turbines and sleep are inadequate. Numerous factors determine whether a sound disrupts sleep. Broadly speaking, they are derived from factors about the sleeper and factors about the sound.

Case reports of subjective complaints about sleep, particularly those not critically and objectively appraised in the normal scientific manner, are the lowest level of evidence, not simply because they lack any objective measurements, but also because they lack the level of scrutiny considered satisfactory for making even crude claims about cause and effect. For instance, consider the case of a person who sleeps poorly at home (near a wind turbine), and sleeps better when on vacation (away from a wind turbine). One might conclude from this case that wind turbines cause sleep disruption for this person, and even generalize that information to other people. But there are numerous factors that might make it more likely that a person can sleep well on vacation, having nothing to do with the wind turbine. Furthermore, given the enormous prevalence of sleep disorders, such as insomnia, and the potentially larger prevalence of disorders that impinge on sleep, such as depression, it is crucial that these factors be taken into consideration when weighing the evidence pointing to a causal effect of wind turbines on sleep disruption for the general population. It is also important to obtain objective measurements of sleep, in addition to subjective complaints.

Subjective reports of sleeping well or sleeping poorly can be misleading or even inaccurate. People can underestimate or overestimate the quality of their sleep. Future studies should examine the acoustic properties of wind turbines when assessing the elements that might disrupt sleep. There are unique properties of the noises wind turbines make, and there are some acoustic properties in common with other noises (such as trucks or trains or airplanes). It is important to make these distinctions when assessing the effects of wind turbines on noise, by using data from other noises. Without this physiologic, objective information, the effects of wind turbines on sleep might be over- or underestimated.

It should be noted that not all sounds impair the ability to fall asleep or maintain sleep. To the contrary, people commonly use sound-masking techniques by introducing sounds in the environment that hinder the perception of undesirable noises. Colloquially, this is sometimes called “white noise,” and there are certain key acoustic properties to these kinds of sounds that make them more effective than other sounds. Different noises can affect people differently. The emotional valence that is ascribed by an individual to a particular sound can have a major influence on the ability to initiate or maintain sleep. Certain aspects of sounds are particularly alerting and therefore would be more likely to disrupt sleep at lower sound pressure levels. But among those that are not, there is a wide range of responses to these sounds, depending partly on the emotional valence ascribed to them. A noise, for instance, that is associated with a distressing object, is more likely to impede sleep onset.

Finally, characteristics of sleep physiology change across a given night of sleep—and across the life cycle of a person—and are different for different people, including the effects of noise on sleep (e.g., Dang-Vu et al., 2010; McKinney et al., 2011). And some people might initially have difficulty with noises at night, but habituate to them with repeated exposure (Basner, 2011).

In summary, **sleep is a complex biological state, important for health and well-being across a wide range of physiologic functions. To date, no study has adequately examined the influence of wind turbines on sleep.**

Future directions: The precise effects of noise-induced sleep disruption from wind turbines may benefit from further study that examines sound-pressure levels near the sleeper, while simultaneously measuring sleep physiology to determine responses of sleep to a variety of levels of noise produced by wind turbines. The purpose would be to understand the precise sound-pressure levels that are least likely to disturb sleep. It would also be helpful to examine whether sleepers might habituate to these noises, making the impact of a given sound less and less over time. Finally, it would be helpful to study these effects in susceptible populations, including those with insomnia or mood disorders or in aging populations, in addition to the general population.

Summary of Sleep Data

In summary, sleep is a complex biological state, important for health and well-being across a wide range of physiologic functions. **To date, no study has adequately examined the influence of wind turbines and their effects on sleep.**

3.4.b Shadow Flicker Considerations and Potential Health Effects

Shadow flicker is caused when changes in light intensity occur from rotating wind turbine blades that cast shadows (see Appendix B for more details on the physics of the phenomenon.) These shadows move on the ground and on buildings and structures and vary in terms of frequency rate and intensity. Shadow flicker is reported to be less of a problem in the United States than in Northern Europe due to higher latitudes and lower sun angles in Europe. Nonetheless, it can still be a considerable nuisance to individuals exposed to shadow flicker for considerable amounts of time per day or year in the United States as well. Shadow flicker can vary significantly by wind speed and duration, geographic location of the sunlight, and the distance from the turbine blades to any relevant structures or buildings. In general, shadow flicker branches out from the wind turbine in a declining butterfly wing characteristic geographic area with higher amounts of flicker being closer to the turbine and less flicker in the outer parts of the geographic area (New England Wind Energy Education Project (NEWEEP), 2011; Smedley et al., 2010). Shadow flicker is present up until approximately 1400 m, but the strongest flicker is up to 400 m from the turbine when it occurs (NEWEEP, 2011). In addition, shadow flicker usually occurs in the morning and evening close to sunrise and sunset when shadows are the longest. Furthermore, shadow flicker can fluctuate in different seasons of the year depending on the geographic location of the turbine such that some sites will only report flicker during the winter months while others will report it during summer months. Other factors that determine shadow flicker rates and intensity include objects in the landscape (i.e., trees and other existing shadows) and weather patterns. For instance, there is no shadow flicker on cloudy days without sun as compared with sunny days. Also, shadow flicker speed (shadows passing per second) increases with the rotor speed (NRC, 2007). In addition, when several turbines are located relatively close to one another there can be combined flicker from the different blades of the different turbines and conversely, if situated on different geographic areas around structures, shadow flicker can occur at different times of the day at the same site from the different turbines so pre-planning of siting location is very important (Harding et al., 2008). General consensus in Germany resulted in the guidance of 30 hours per year and 30 minutes per day (based on astronomical, clear sky calculations) as acceptable limits for shadow flicker from wind turbines (NRC, 2007). This is similar to the Denmark guidance of 10 hours per year based on actual conditions.

3.4.b.i Potential Health Effects of Flicker

Because some individuals are predisposed to have seizures when exposed to certain types of flashing lights, there has been concern that wind turbines had the potential to cause seizures in these vulnerable individuals. In fact, seizures caused by visual or photic stimuli are typically observed in people with certain types of epilepsy (Guerrini & Genton, 2004), particularly generalized epilepsy. While it is not precisely known how many people have photosensitivity that causes seizures, it appears to be approximately 5% of people with epilepsy, amounting to about 100,000 people in the United States. And many of these people will already be treated with antiepileptic medications thus reducing this risk further.

Fortunately, not all flashing light will elicit a seizure, even in untreated people with known photosensitivity. There are several key factors that likely need to simultaneously occur in order for the stimulus to induce a seizure, even among the fraction of people with photosensitive seizures. The frequency of the stimulus is important as is the stimulus area and pattern (See below) (http://www.epilepsyfoundation.org/aboutepilepsy/seizures/photosensitivity/gerba.cfm).

Frequencies above 10 Hz are more likely to cause epileptic seizures in vulnerable individuals, and seizures caused by photic stimulation are generally produced at frequencies ranging from greater than 5 Hz. However, shadow flicker frequencies from wind turbines are related to the rotor frequency and this usually results in 0.3–1.0 Hz, which is outside of the range of seizure thresholds according to the National Resource Council and the Epilepsy Foundation (NRC, 2007). In fact, studies performed by Harding et al. (2008) initially concluded that because light flicker can affect the entire retina, and even if the eyes are closed that intermittent light can get in the retina, suggested that 4 km would be a safe distance to avoid seizure risk based on shadow flicker (Harding et al., 2008). However, a follow-up analysis considering different meteorological conditions and shadow flicker rates concluded that there appeared to be no risk for seizures unless a vulnerable individual was closer than 1.2 times the total turbine height on land and 2.8 times the total turbine height in the water, which could potentially result in frequencies of greater than 5 Hz (Smedley et al., 2010).

Although some individuals have complained of additional health complaints including migraines, nausea, dizziness, or disorientation from shadow flicker, only one government-sponsored study from Germany (Pohl et al., 1999) was identified for review. This German study was performed by the Institute of Psychology, Christian-Albrechts-University Kiel on behalf of the Federal Ministry of Economics and Technology (BMWi) and supported by the Office of Biology, Energy, and Environment of the Federal Ministry for Education and Research (BMBF), and on behalf of the State Environmental Agency of Schleswig. The purpose of this government-sponsored study was to determine whether periodic shadow with a duration of more than 30 minutes created significant stress-related health effects. The shadows were created by a projection system, which simulated the flicker from actual wind turbines.

Two groups of different aged individuals were studied. The first group consisted of 32 students (average age 23 years). The second group included 25 professionals (average age 47 years). Both men and women were included. The subjects were each randomly assigned to one of two experimental groups, so there was a control group and an experimental group. The experimental group was exposed to 60 minutes of simulated flicker. For the control group lighting conditions were the same as in the experimental group, but without periodic shadow. The main part of the study consisted of a series of six test and measurement phases, two before the light was turned on, three each at intervals of 20 minutes while the simulated shadow flickering was taking place, and one more after the flicker light was turned off. Among the variables measured were general performance indicators of stress (arithmetic, visual search tasks) and those of mental and physical well-being, cognitive processing, and stress in the autonomic nervous system (heart rate, blood pressure, skin conductance, and finger temperature). Systematic effects due to the simulated flicker could be detected in comparable ways in both exposure groups studied. Both physical and cognitive effects were found in this exposure scenario for shadow flicker.

It appears clear that shadow flicker can be a significant annoyance or nuisance to some individuals, particularly if they are wind project non-participants (people who do not benefit economically or receive electricity from the turbine) whose land abuts the property where the turbine is located. In addition, flashing (a phenomenon closely related to shadow flicker, but due to the reflection of sunlight – see Appendix B) can be a problem if turbines are sited too close to highways or other roadways. This could cause dangerous conditions for drivers. Accordingly, turbine siting near highways should be planned so as to reduce flashing as much as possible to protect drivers. However, use of low reflective turbine blades is commonly employed to reduce this potential flashing problem. Provisions to avoid many of these potential health and annoyance problems appear to be employed as current practice in many pre-planning sites with the use of computer programs such as WindPro. These programs can accurately determine shadow flicker rates based on input of accurate analysis area, planned turbine location, the turbine design (height, length, hub height, rotor diameter, and blade width), and residence or roadway locations. Many of these computer programs can then create maps indicating the location and incidence of shadow flicker. Such programs may also provide estimates of daily minutes and hours per year of expected shadow flicker that can then be used for wind turbine planning and siting or for mitigation efforts. Several states require these analyses to be performed before any new turbine projects can be implemented.

3.4.b.ii Summary of Impacts of Flicker

Collectively, although shadow flicker can be a considerable nuisance particularly to wind turbine project non-participants, the evidence suggests that there is no risk of seizure from shadow flicker caused by wind turbines. In addition, there is limited evidence primarily from a German government-sponsored study (Pohl et al., 1999) that prolonged shadow flicker (more than 30 minutes) can result in transient stress-related effects on cognition (concentration, attention) and autonomic nervous system functioning (heart rate, blood pressure). There was insufficient documentation to evaluate other than anecdotal reports of additional health effects including migraines or nausea, dizziness or disorientation. There are documented mitigation methods for addressing shadow flicker from wind turbines and these methods are presented in Appendix B.

3.4.c Ice Throw and its Potential Health Effects

Under certain weather conditions ice may form on the surface of wind turbine blades. Normally, wind turbines intended for use in locations where ice may form are designed to shut down when there is a significant amount of ice on the blades. The means to prevent operation when ice is present may include ice sensor and vibration sensors. Ice sensors are used on most wind turbines in cold climates. Vibration sensors are used on nearly all wind turbines. They would cause the turbine to shut down, for example, if ice buildup on the blades resulted in an imbalance of the rotor and hence detectable vibrations in the structure.

Ice built up on blades normally falls off while the turbine is stationary. If that occurs during high winds, the ice could be blown by the wind some distance from the tower. In addition, it is conceivable that ice could be thrown from a moving wind turbine blade under some circumstances, although that would most likely occur only during startup (while the rotational speed is still relatively low) or as a result of the failure of the control system. It is therefore worth considering the maximum plausible distance that a piece of ice could land from the turbine under two “worst case” circumstances: 1) ice falls from a stopped turbine during very high winds, and 2) ice is suddenly released from a blade when the rotor is rotating at its normal operating speed.

Ice is a physical hazard, that depending on the mass, velocity, and the angle of throw can result in a wide range of effects to humans: alarm and surprise to abrasions, organ damage, concussions, and perhaps death. Avoidance of ice throw is critical. More detail on ice throw and options for mitigation are presented in Appendix C.

3.5 Effects of Noise and Vibration in Animal Models

Domestic animals such as cats and dogs can serve as sentinels of problematic environmental conditions. The Panel searched for literature that might point to non-laboratory animal studies or well-documented cases of animals impacted by wind turbines. Anecdotal reports in the press of goat deaths (UK), premature births and adverse effects in cows (Japan, US) provide circumstantial evidence, but lack specifics regarding background rates of illness or extent of impact.

Laboratory-based animal models are often used to predict and to develop mechanistic explanations of the causes of disease by external factors, such as noise or chemicals in humans. In the absence of robust epidemiological data, animal models can provide clues to complex biological responses. However, the limitations of relying on animal models are well documented, particularly for endpoints that involve the brain. The benefits of using an animal model include ease of experimental manipulation such as multiple exposures, typically well-controlled experimental conditions, and genetically identical groups of animals.

Evaluation of biological plausibility for the multitude of reported health effects of wind turbines requires a suitable animal model documented with data that demonstrate cause and effect. Review of this literature began with a PubMed and ToxNet search for “wind turbine” or “wind turbines”; or “infrasound” or “low frequency noise”; and “animal” or “mammal” to identify peer-reviewed studies in which laboratory animals were exposed to noise or vibration intended to mimic that of wind turbines. Titles and abstracts of identified papers were read to make a first pass determination of whether the paper was a study on effects in mammals or might contain relevant references to other relevant studies. The searches yielded several studies, many of which were not peer-reviewed, were not whole-animal mammalian or were not experimental, but were reviews in which animal studies were mentioned or experiments conducted in dissected cochlea. The literature review yielded eight peer-reviewed studies, all relying on the laboratory rat as the model. The studies fall into two groups—those conducted in the 1970's and early 1980's and those conducted in 2007–2010. The most recent studies are conducted in China and are funded by the National Natural Science Foundation of China. Table AG.1 (in Appendix G) provides a summary of the studies.

There is no general agreement about the specific biological activity of infrasound on rodents, although at high doses it appears to negatively affect the cardiovascular, brain, and respiratory systems (Sienkiewicz, 2007). Early studies lacked the ability to document the doses of infrasound given the rats, did not report general pathologies associated with the exposures and lacked suitable controls. Since then, researchers have focused on the brain and cardiac systems as sensitive targets of infrasound. Experimental conditions in these studies lack a documented rationale for the selection and the use of infrasound of 5-15 Hz at 130 dB. While this appears to be standard practice, the relevance of these frequencies and pressures is unclear—both to the rat and more importantly to the human. The exposures are acute—short-term, high dose. Researchers do not document rat behaviors (including startle responses), pathologies, frank toxicities, and outcomes due to these exposures. Therefore, interpretation of all of the animal model data for infrasound outcomes must be with the lens of any high-dose, short-term exposure in toxicology, specifically questioning whether the observations are readily translatable to low-dose, chronic exposures.

Pei et al., (2007 and 2009) examine changes in cardiac ultrastructure and function in adult male Sprague-Dawley rats exposed to 5 Hz at 130 dB for 2 hours for 1, 7, or 14 successive days. Cardiomyocytes were enzymatically isolated from the adult left ventricular hearts after sacrifice. Whole cell patch-clamp techniques were employed to measure whole cell L-Type Ca^{2+} currents. The objective of these studies was to determine whether there was a cumulative effect of insult as measured by influx of calcium into cardiomyocytes. After infrasound exposure, rats in the 7– and 14–day exposure groups demonstrated statistically significant changes in intracellular Ca^{2+} homeostasis in cardiomyocytes as demonstrated by electrochemical stimulation of the cells, molecular identification of specific heart-protein levels, and calcium transport measurements.

Several studies examine the effects of infrasound on behavioral performance in rats. The first of these studies was conducted under primitive acoustic conditions compared with those of today (Petounis et al., 1977). In this study the researchers examined the behavior of adult female rats (undisclosed strain) exposed to increasing infrasound (2 Hz, 104 dB; 7 Hz, 122 dB; and 16

Hz, 124 dB) for increasing time (5-minute increments for up to 120 minutes). Decreased activity levels (sleeping more) and exploratory behavior were documented as dose and duration of exposure increased. The authors fail to mention that frank toxicity including pain is associated with these behaviors, raising the question of relevance of high dose exposures. In response to this and similar studies that identify increase in sleep, increase in avoidance behaviors and suppression of locomotor activity, Spyraki et al., (1977) hypothesized that these responses are mediated by norepinephrine levels in the brain and as such, exposed adult male Wistar rats to increasing doses of infrasound for one hour. Using homogenized brain tissue, norepinephrine concentrations were measured using fluorometric methods. Researchers demonstrated a dose-dependent decrease in norepinephrine levels in brain tissue from infrasound-treated rats, beginning at a dose of 7 Hz and 122 dB for one hour. No observations of frank toxicity were recorded. Liu et al., (2010) hypothesized that since infrasound could affect the brain, it potentially could increase cell proliferation (neurogenesis) in the dentate gyrus of the rat hippocampus, specifically a region that continues to generate new neurons in the adult male Sprague-Dawley rat. Using a slightly longer exposure period of 2 hours/day for 7 days at 16 Hz and 130 dB, the data suggest that infrasound exposure inhibits cell proliferation in the dentate gyrus, yet has no affect on early migration and differentiation. This study lacks suitable positive and negative controls that allow these conclusions to be drawn.

Several unpublished or non-peer reviewed studies reported behavioral responses as relevant endpoints of infrasound exposure. These data are not discussed, yet are the basis for several recent studies. In one more recent peer-reviewed behavioral rat study, adult male Wistar rats were classified as “superior endurance” and those as “inferior endurance” using the Rota-rod Treadmill (Yamamura et al., 1990). A range of frequencies and pressures were used to expose the rats for 60—150 minutes. Comparison of the pre-exposure endurance time on the Rota-Rod Treadmill with endurance after exposure to infrasound showed that the endurance time of the superior group after exposure to 16 Hz, 105 dB was not reduced. The endurance of the inferior group was reduced by exposure to 16 Hz, 105 dB after 10 minutes, to 16 Hz, 95 dB after 70 minutes, and to 16 Hz, 85 dB after 150 minutes. Of most relevance is the identification of a subset of rats that may be more responsive to infrasound due to their genetic makeup. There has been no follow-up regarding intra-strain susceptibility since this study.

More recent studies have focused on the mechanisms by which infrasound may disrupt normal brain function. As stated above, the infrasound exposures are acute—short-term, high dose. At the very least, researchers should document rat behaviors, pathologies, frank toxicities, and outcomes due to these high dose exposures in addition to measuring specific subcellular effects.

Some of the biological stress literature suggests that microglial activation can occur with heightened stress, but it appears to be short-lived and transitory affecting the autonomic nervous system and neuroendocrine system, resulting in multiple reported effects. To investigate the effect of infrasound on hippocampus-dependent learning and memory, Yuan et al. (2009) measure cognitive abilities and activation of molecular signaling pathways in order to determine the role of the neuronal signaling transduction pathway, BDNF-TRkB, in infrasound-induced impairment of memory and learning in the rat. Adult male Sprague-Dawley rats were exposed to infrasound of 16 Hz and 130 dB for 2 hours daily for 14 days. The acoustic conditions appeared to be well monitored and documented. The Morris water maze was used to determine spatial learning and retention, and molecular techniques were used to measure cell proliferation and concentrations of signaling pathway proteins. Using these semi-quantitative methods, rats exposed to infrasound demonstrated impaired hippocampal-dependent spatial learning acquisition and retention performance in the maze scheme compared with unexposed control rats, demonstrable downregulation of the BDNF-TRkB pathway, and decreased BrdU-labeled cell proliferation in the dentatel gyrus.

In another study, Du et al. (2010) hypothesize that microglial cells may be responsible for infrasound-induced stress. To test this hypothesis, 60 adult male Sprague-Dawley rats were exposed in an infrasonic chamber to 16 Hz at 130 dB for 2 hours. Brains were removed and sectioned and the hypothalamic paraventricular nucleus (PVN) examined. Primary microglial cells were isolated from whole brains of neonatal rats and grown in culture before they were exposed to infrasound under the same conditions as the whole animals. Molecular methods were used to identify the presence and levels of proteins indicative of biological stress (corticotrophin-releasing hormone (CRH) and corticotrophin-releasing hormone receptor (CRH type 1 receptor) in areas of the brain that control the stress response. Specifically, studies were done to determine whether microglial cells are involved in infrasound-response, changes in microglial activation, and CRH-R1 expression in vivo in the PVN and in vitro at time points after the two-hour infrasound exposure. The data show that the exposures resulted in microglial activation, beginning at 0.5 hours post exposure, and up-regulation of CRH-R1 expression. The magnitude of the response increased significantly from the control to 6 hours post exposure, returning to control levels, generally by 24 hours post-exposure. This study is well controlled, and while it does rely on a specific antagonist for dissecting the relative involvement of the neurons and the microglial cells, the data suggest that infrasound as administered in this study to rats can activate microglial cells, suggesting a possible mechanism for infrasound-induced ”stress” or nuisance at a physical level (i.e., proinflammatory cytokines causing sickness response behaviors).

In summary, there are no studies in which laboratory animals are subjected to exposures that mimic wind turbines. There is insufficient evidence from laboratory animal studies of effects of low frequency noise on the respiratory system. There is limited evidence that rats are a robust model for human infrasound exposure and effects. The reader is referred to Appendix G for specific study conditions. In any case, the infrasound levels and exposure conditions to which the rodents are exposed are adequate to cause pain to the rodents. When exposed to these levels of infrasound, there is some evidence of reversible molecular effects including short-lived biochemical alterations in cardiac and brain cells, suggesting a possible mechanism for high-dose, infrasound-induced effects in rats.

3.6 Health Impact Claims Associated with Noise and Vibration Exposure

The popular media contain a large number of articles that claim the noise and vibration from wind turbines adversely affect human health. In this section the Panel examines the physical and biological basis for these assertions. Additionally, the scientific articles from which these assertions are made are examined in light of the methods used and their limitations.

Pierpont (2009) has been cited as offering evidence of the physical effects of ILFN, referring to “Wind Turbine Syndrome” and its impact on the vestibular system—by disturbed sensory input to eyes, inner ears, and stretch and pressure receptors in a variety of body locations. The basis for the syndrome relies on data from research carried out for reasons (e.g., space missions) other than assessment of wind turbines on health. Such research can be valuable to understanding new conditions, however, when the presentation of data is incomplete, it can lead to inaccurate conclusions. A few such cases are mentioned here:

Pierpont (2009) notes that von Dirke and Parker (1994) show that the abdominal area resonates between 4 and 6 Hz and that wind turbines can produce infrasound within this range (due to the blade rotation rate). However, the von Dirke paper states that our bodies have evolved to be tolerant of the 4–6 Hz abdominal motion range: this range coincides with jogging and running. The paper also reveals that motion sickness (which was the focus of the study) only occurred when the vibrations to which people were subjected were between 0.01 and 0.5 Hz. The study exposed people to vibration from positive to negative 1 G forces. Subjects were also rotated around various axes to achieve the vibration levels and frequencies of interest in the study. Interpretation of these data may allow one to conclude that while the abdominal area has a resonance in a region at which there is infrasound being emitted by wind turbines, there will be no impact. Further, the infrasound emitted by wind turbines in the range of frequencies at which subjects did note motion sickness is orders of magnitude less than the level that induced motion sickness (see Table 2). So while a connection is made, the evidence at this point is not sufficient to draw a conclusion that a person's abdominal area or stretch point can be excited by turbine infrasound. If it were, this might lead to symptoms of motion sickness.

Pierpont (2009) points to a study by Todd et al. (2008) as potential proof that the inner ear may be playing a role in creating the symptoms of "Wind Turbine Syndrome." Todd et al. (2008) show that the vestibular system shows a best frequency response around 100 Hz. This is a fact, but again it is unclear how it relates to low frequency noise from wind turbines. The best frequency response was assessed by moving subjects' heads (knocking the side of the head) in a very specific direction because the portion of the inner ear that is being discussed acts as a gravitational sensor or an accelerometer; therefore, it responds to motion. A physical mechanism by which the audible sound produced by a wind turbine at 100 Hz would couple to the human body in a way to create the necessary motion to which this portion of the inner ear would respond is unknown.

More recently, Salt and Hullar (2010) have looked for something physical about the ear that could be responding to infrasonic frequencies. They describe how the outer (OHC) and inner (IHC) hair cells of the cochlea respond to different types of stimuli: the IHC responding to velocity and OHC responding to displacement. They discuss how the OHC respond to lower frequencies than the IHC, and how the OHC acts as an amplifier for the IHC. They state that it is known that low frequencies present in a sound signal can mask the higher frequencies—presumably because the OHC is not amplifying the higher frequency correctly when the OHC is responding to low frequency disturbances. However, they emphatically state that "although vestibular hair cells are maximally sensitive to low frequencies they typically do not respond to airborne infrasound. Rather, they normally respond to mechanical inputs resulting from head movements and positional changes with their output controlling muscle reflexes to maintain posture and eye position." It is completely unknown how the very few neural paths from the OHC to the brain respond, if they do at all (95% of the connections are between the IHC and the brain). So at this moment, inner ear experts have not found a method for airborne infrasound to impact the inner ear. The potential exists such that the OHC respond to infrasound, but that the functional role of the connection between the OHC and the brain remains unknown. Further, the modulation of the sound received at the IHC itself has not been shown to cause nausea, headaches, or dizziness.

In the discussion of amplitude-modulated noise, it was already noted that wind turbines produce audible sound in the low frequency regime (20–200Hz). It has been shown that the sound levels in this range from some turbines are above the levels for which subjects in a Korean study have complained of psychological effects (Jung & Cheung, 2008). O'Neal (2011) also shows that the sound pressure level for frequencies between 30 and 200 Hz from two modern wind turbines at roughly 310 m are above the threshold of hearing but below the criterion for creating window rattle or other perceptible vibrations. The issue of vibration is discussed more in the next section. It is noted that the amplitude-modulated noise is most likely at the heart of annoyance complaints. In addition, amplitude-modulated noise may be a source of sleep disturbance noted by survey respondents. However, direct health impacts have not been demonstrated.

3.6.a Vibration

Vibroacoustics disease (VAD) has been identified as a potential health impact of wind turbines in the Pierpont book. Most of the literature around VAD is attributed to Branco and Alves-Pereira. Related citations attributed to Takahashi (2001), Hedge and Rasmussen (1982) though are also provided. These studies all required very clear coupling to large vibration sources such as jackhammers and heavy equipment. The latter references focus on high levels of low frequency vibrations and noise. In particular, Rasmussen studied the response of people to vibrating floors and chairs. The vibration displacements in the study were on the order of 0.01 cm (or 1000 times larger than the motion found 100 m from a wind farm in a seismic study (Styles et al., 2005). Takahashi used loud speakers placed 2 m from subjects' bodies, only testing audible frequencies 20–50 Hz, using pressure levels on the order of 100–110 dB (roughly 30 dB higher than any sound measured from a wind turbine in this frequency range) to induce vibrations at various points on the body. The Hedge source is not a study but a bulleted list of points that seem to go along with a lecture in an ergonomics class for which no citations are provided. Branco's work is slightly different in that she considered very long-term exposures to moderately intense vibration inputs. While there may be possible connection to wind turbines, at present, the connection is not substantiated given the very low levels of vibration and airborne ILFN that have been measured from wind turbines.

While vibroacoustic disease may not be substantiated, vibration levels that lead to annoyance or feelings of uneasiness may be more plausible. Evidence for these responses is discussed below.

Pierpont refers to a paper by Findeis and Peters (2004). This reference describes a situation in Germany where complaints of disturbing sound and vibration were investigated through the measurement of the vibration and acoustics within the dwelling, noting that people complained about vibrations that were not audible. The one figure provided in the text shows that people were disturbed by what was determined to be structure-borne sound that was radiated by walls and floors at levels equivalent to 65 dB at 10 Hz and 40 dB at 100 Hz. The 10 Hz level is just below audible. The level reported at 100 Hz, however, is just above the hearing threshold. The authors concluded that the disturbances were due to a component of the HVAC system that coupled directly to the building.

The Findeis and Peters (2004), report is reminiscent of papers related to investigations of "haunted" spaces (Tandy, 1998, 1999). In these studies room frequencies around 18 Hz were found. The studies hypothesized that apparitions were the result of eye vibrations (the eye is sensitive to 18 Hz) induced by the room vibration field. In one of these studies, a ceiling fan was found to be the source of the vibration. In the other, the source was not identified.

When the source was identified in the previously mentioned studies, there appears to be an obvious physical coupling mechanism. In other situations it has been estimated that airborne disturbances have influenced structures. A NASA report from 1982 gives a figure that estimates the necessary sound pressure level at various frequencies to force vibrations in windows, walls, and floors of typical buildings (Stephens, 1982). The figure on page 14 of that report shows infrasound levels of 70–80 dB can induce wall and floor vibrations. On page 39 the report also shows some floor vibration levels that were associated with a wind turbine. On the graph these were the lowest levels of vibration when compared to vibrations from aircraft noise and sonic booms. Another figure on page 43 shows vibrations and perception across the infrasonic frequency range. Again, wind turbine data are shown, and they are below the perception line.

A second technical report (Kelley, 1985) from that timeframe describes disturbances from the MOD-1 wind turbine in Boone, North Carolina. This was a downwind turbine mounted on a truss tower. Out of 1000 homes within about 2 km, 10 homes experienced room vibrations under certain wind conditions. A careful measurement campaign showed that indeed these few homes had room vibrations related to the impulsive noise unique to downwind turbines. The report contains several findings including the following: 1) the disturbances inside the homes were linked to the impulsive sound generated by the turbine (due to tower wake/blade interaction) and not seismic waves, 2) the impulsive signal was feeding energy into the vibrational modes of the rooms, floors, and walls where the floor/wall modes were the only modes in the infrasonic range, 3) people felt the disturbance more than they heard it, 4) peak vibration values were measured in the frequency range 10–20 Hz (floor/wall resonances) and it was deduced that the wall facing the turbine was being excited, 5) the fact that only 10 homes out of 1000 (scattered in various directions around the turbine) were affected was shown to be related to complicated sound propagation paths, and 6) while the shape of the impulse itself was given much attention and was shown to be a driving force in the coupling to the structural vibrations, comments were made in the report to the effect that nonimpulsive signals with energy at the right frequency could couple into the structure. The report describes a situation in Oregon where resonances in the flow through an exhaust stack of a gas-run turbine plant had an associated slow modulation of the sound leading to annoyance near the plant. Again it was found that structural modes in nearby homes were being excited but this time by an acoustic field that was not impulsive in nature. This is an important point because modern wind turbines do not create impulsive noise with strong content around 20 Hz like the downwind turbine in North Carolina. Instead, they generate amplitude-modulated sound around 1 kHz as well as broadband infrasound (van den Berg, 2004). The broadband infrasound that also existed for the North Carolina turbine was not shown to be responsible for the disturbances. As well, the amplitude-modulated noise that existed was not shown to be responsible for the disturbances. So, while there are comparisons made to the gas turbine power plant and to the HVAC system component where the impulsiveness of the sound was not the same, direct comment on the effect of modern turbines on the vibration of homes is not possible.

A recent paper by Bolin et al. (2011), surveys much of the low frequency literature pertinent to modern wind turbines and notes that all measurements of indoor and outdoor levels of sound simultaneously do not show the same amplification and ringing of frequencies associated with structural resonances similar to what was found in North Carolina. Instead the sound inside is normally less than the sound outside the structure. Bolin et al. (2011) note that measurements indicate that the indoor ILFN from wind turbines typically comply with national guidelines (such as the Danish guideline for 44 dB(A) outside a dwelling). However, this does not preclude a situation where levels would be found to be higher than the standards. They propose that further investigations of an individual dwelling should be conducted if the measured difference between C-weighted and A-weighted sound pressure level of outdoor exposure is greater than 15 dB. A similar criterion is noted in the non-peer reviewed report by Kamperman et al. (2008).

Related to room vibration is window rattle. This topic is described in the NASA reports, discussed above (Stephens, 1982) and discussed in the articles by Jung and Cheung (2008) and O'Neal (2011). In these articles it has been noted that window rattle is often induced by vibrations between 5 and 9 Hz, and measurements from wind turbines show that there can be enough energy in this range to induce window rattle. Whether the window rattle then generates its own sound field inside a room at an amplitude great enough to disturb the human body is unknown.

Seismic transmission of vibration at the North Carolina site was considered. In that study the seismic waves were ruled out as too low of amplitude to induce the room vibrations that were generated. Related are two sets of measurements that were taken near wind farms to assess the potential impact of seismic activity on extremely sensitive seismic measurement stations (Styles, 2005, Schofield, 2010). One study considered both waves traveling in the ground and the coupling of airborne infrasound to the ground, showing that the dominant source of seismic motion is the Rayleigh waves in the ground transmitted directly by the tower, and that the airborne infrasound is not playing a role in creating measurable seismic motion. The two reports indicate that at 100 meters from a wind turbine farm (>6 turbines) the maximum motion that is induced is 120 nanometers (at about 1 Hz). A nanometer is 10^{-9} m. So this is 1.2×10^{-7} m of ground displacement. Extremely sensitive measuring devices have been used to detect this slight motion. To put the motion in perspective, the diameter of a human hair is on the order of 10^{-6} m. These findings indicate that seismic motion induced from one or two turbines is so small that it would be difficult to induce any physical or structural response.

Hessler and Hessler, (2010) reviewed various state noise limits and discussed them in connection with wind turbines. The article contains a few comments related to low frequency noise. It is stated that, "a link between health complaints and turbine noise has only been asserted based on what is essentially anecdotal evidence without any valid epidemiological studies or scientific proof of any kind." The article states that if a metric for low frequency noise is needed, then a limit of 65 dB(C) could be used. This proposed criterion is not flexible for use in different environments such as rural vs. city. In this sense, Bolin et als' suggestion of checking for a difference between C-weighted and A-weighted sound pressure level of outdoor exposure greater than 15 dB is more appropriate. This value of 15 dB, was based on past complaints associated with combustion turbines. The Bolin article, however, also cautions that obtaining accurate low frequency measurements for wind turbines is difficult because of the presence of wind. Even sophisticated windscreens cannot eliminate the ambient low frequency wind noise.

Leventhal (2006) notes that when hearing and deaf subjects are tested simultaneously, the subjects' chests would resonate with sounds in the range of 50–80 Hz. However, the amplitude of the sound had to be 40–50 dB higher than the human hearing threshold for the deaf subjects to report the chest vibration. This leads one to conclude that chest resonance in isolation should not be associated with inaudible sound. If a room is vibrating due to a structural resonance, such levels may be obtained. Again, this effect has never been measured associated with a modern wind turbine.

The stimulation of house resonances and self-reported ill-effects due to a modern wind turbine appear in a report by independent consultants that describes pressure measurements taken inside and outside of a home in Falmouth Massachusetts in the spring of 2011 (Ambrose & Rand, 2011). The measurements were taken at roughly 500 meters from a single 1.65 MW stall-regulated turbine when the wind speeds were relatively high: 20-30 m/s at hub height. The authors noted feeling ill when the dB(A) levels indoors were between 18 and 24 (with a corresponding dB(G) level of 51-64). They report that they felt effects both inside and outside but preferred to be outside where the dB(A) levels ranged from 41-46 (with corresponding dB(G) levels from 54-65.) This is curious because weighted measurements account for human response and the weighted values were higher outside. However, the actual dB(L) levels were higher inside.

The authors present some data indicating that the G-weighted value of the pressure signal is often greater than 60 dB(G), the averaged threshold value proposed by Salt and Hullar (2011) for OHC activation. However, the method used to obtain the data is not presented, and the time scale over which the data are presented (< 0.015 seconds or 66 Hz) is too short to properly capture the low frequency content.

The data analysis differed from the common standard of practice in an attempt to highlight weaknesses in the standard measurement approach associated with the capture of amplitude modulation and ILFN. This departure from the standard is a useful step in defining a measurement technique such as that called for in a report by HGC Engineering (HGC, 2010), that notes policy making entities should "consider adopting or endorsing a proven measurement procedure that could be used to quantify noise at infrasonic frequencies."

The measurements by Ambrose and Rand (2011) show a difference in A and C weighted outdoor sound levels of around 15 dB at the high wind speeds (which is Bolin et. al.'s recommended value for triggering further interior investigations). The simultaneous indoor and outdoor measurements indicate that at very low frequencies (2-6 Hz) the indoor pressure levels are greater than those outdoors. It is useful to note that the structural forcing at the blade-passage-frequency, the time delay and the subsequent ringing that was present in the Boone homes (Kelley, 1985) is not demonstrated by Ambrose and Rand (2011). This indicates that the structural coupling is not forced by the amplitude modulation and is due to a much subtler process. Importantly, while there is an amplification at these lower frequencies, the indoor levels (unweighted) are still far lower than any levels that have ever been shown to cause a physical response (including the activation of the OHC) in humans.

The measurements did reveal a 22.9 Hz tone that was amplitude modulated at approximately the blade passage frequency. The source of the tone was not identified, and no indication as to whether the tone varied with wind speed was provided, a useful step to help determine whether the tone is aerodynamically generated. The level of this tone is shown to be higher than the OHC activation threshold. The 22.9 Hz tone did not couple to the structure and showed the normal attenuation from outside to inside the structure. In order to determine if the results that show potential tonal activation of the OHC are generalizable, it is necessary to identify the source of this tone which could be unique to stall-regulated turbines or even unique to this specific brand of turbine.

Finally, the measurements shown in the report are atypical within the wind turbine measurement literature and the data analysis is not fully described. Also, the report offers no plausible coupling mechanism of the sound waves to the body beyond that proposed by Salt and Hullar (2011). Because of this, the results are suggestive but require corroboration of the measurements and scientifically based mechanisms for human health impact.

3.6.b Summary of Claimed Health Impacts

In this section, the potential health impacts due to noise and vibration from wind turbines was discussed. Both the infrasonic and low frequency noise ranges were considered. Assertions that infrasound and low frequency noise from turbines affect the vestibular system either through airborne coupling to humans are not empirically supported. In the multitude of citations given in the popular media as to methods in which the vestibular system is influenced, all refer to situations in which there is direct vibration coupling to the body or when the wave amplitudes are orders of magnitudes greater than those produced by wind turbines. Recent research has found one potential path in the auditory system, the OHC, in which infrasound might be sensed. There is no evidence, however, that when the OHC sense infrasound, it then leads to any of the symptoms reported by complainants. That the infrasound and low frequency noise couple to humans through the forcing of structural vibration is plausible but has not been demonstrated for modern wind turbines. In addition, should it be shown that such a coupling occurs, research indicates that the coupling would be transient and highly dependent on wind conditions and localized to very few homes surrounding a turbine.

Seismic activity near a turbine due to vibrations transmitted down the tower has been measured, and the levels are too low to produce vibrations in humans.

The audible noise from wind turbines, in particular the amplitude modulated trailing edge noise, does exist, changes level based on atmospheric conditions, can change character from swish to thump-based on atmospheric effects, and can be perceived from home to home differently based on propagation effects. This audible sound has been noted by complainants as a source of annoyance and a cause for sleep disruption. Some authors have proposed nighttime noise regulations and regulations based on shorter time averages (vs. annual averages) as a means to reduce annoyance from this noise source. Some have conjectured that the low frequency content of the amplitude-modulated noise is responsible for the annoyance. They have proposed that the difference between the measured outdoor A- and C- weighted sound pressure levels could be used to identify situations in which the low frequency content is playing a larger role. Further, they note that this difference might be used as part of a regulation as a means to reduce annoyance.

Chapter 4

Findings

Based on the detailed review of the scientific literature and other available reports and consideration of the strength of scientific evidence, the Panel presents findings relative to three factors associated with the operation of wind turbines: noise and vibration, shadow flicker, and ice throw. The findings that follow address specifics in each of these three areas.

4.1 Noise

4.1.a Production of Noise and Vibration by Wind Turbines

1. Wind turbines can produce unwanted sound (referred to as noise) during operation. The nature of the sound depends on the design of the wind turbine. Propagation of the sound is primarily a function of distance, but it can also be affected by the placement of the turbine, surrounding terrain, and atmospheric conditions.
    a. Upwind and downwind turbines have different sound characteristics, primarily due to the interaction of the blades with the zone of reduced wind speed behind the tower in the case of downwind turbines.
    b. Stall regulated and pitch controlled turbines exhibit differences in their dependence of noise generation on the wind speed
    c. Propagation of sound is affected by refraction of sound due to temperature gradients, reflection from hillsides, and atmospheric absorption. Propagation effects have been shown to lead to different experiences of noise by neighbors.
    d. The audible, amplitude-modulated noise from wind turbines ("whooshing") is perceived to increase in intensity at night (and sometimes becomes more of a "thumping") due to multiple effects: i) a stable atmosphere will have larger wind gradients, ii) a stable atmosphere may refract the sound downwards instead of upwards, iii) the ambient noise near the ground is lower both because of the stable atmosphere and because human generated noise is often lower at night.
2. The sound power level of a typical modern utility scale wind turbine is on the order of 103 dB(A), but can be somewhat higher or lower depending on the details of the design and the rated power of the turbine. The perceived sound decreases rapidly with the distance from the wind turbines. Typically, at distances larger than 400 m, sound

pressure levels for modern wind turbines are less than 40 dB(A), which is below the level associated with annoyance in the epidemiological studies reviewed.

3. Infrasound refers to vibrations with frequencies below 20 Hz. Infrasound at amplitudes over 100–110 dB can be heard and felt. Research has shown that vibrations below these amplitudes are not felt. The highest infrasound levels that have been measured near turbines and reported in the literature near turbines are under 90 dB at 5 Hz and lower at higher frequencies for locations as close as 100 m.
4. Infrasound from wind turbines is not related to nor does it cause a “continuous whooshing.”
5. Pressure waves at any frequency (audible or infrasonic) can cause vibration in another structure or substance. In order for vibration to occur, the amplitude (height) of the wave has to be high enough, and only structures or substances that have the ability to receive the wave (resonant frequency) will vibrate.

4.1.b Health Impacts of Noise and Vibration

1. Most epidemiologic literature on human response to wind turbines relates to self-reported “annoyance,” and this response appears to be a function of some combination of the sound itself, the sight of the turbine, and attitude towards the wind turbine project.
   a. There is limited epidemiologic evidence suggesting an association between exposure to wind turbines and annoyance.
   b. There is insufficient epidemiologic evidence to determine whether there is an association between noise from wind turbines and annoyance independent from the effects of seeing a wind turbine and vice versa.
2. There is limited evidence from epidemiologic studies suggesting an association between noise from wind turbines and sleep disruption. In other words, it is possible that noise from some wind turbines can cause sleep disruption.
3. A very loud wind turbine could cause disrupted sleep, particularly in vulnerable populations, at a certain distance, while a very quiet wind turbine would not likely disrupt even the lightest of sleepers at that same distance. But there is not enough evidence to

provide particular sound-pressure thresholds at which wind turbines cause sleep disruption. Further study would provide these levels.

4. Whether annoyance from wind turbines leads to sleep issues or stress has not been sufficiently quantified. While not based on evidence of wind turbines, there is evidence that sleep disruption can adversely affect mood, cognitive functioning, and overall sense of health and well-being.
5. There is insufficient evidence that the noise from wind turbines is *directly (i.e., independent from an effect on annoyance or sleep)* causing health problems or disease.
6. Claims that infrasound from wind turbines directly impacts the vestibular system have not been demonstrated scientifically. Available evidence shows that the infrasound levels near wind turbines cannot impact the vestibular system.
    a. The measured levels of infrasound produced by modern upwind wind turbines at distances as close as 68 m are well below that required for non-auditory perception (feeling of vibration in parts of the body, pressure in the chest, etc.).
    b. If infrasound couples into structures, then people inside the structure could feel a vibration. Such structural vibrations have been shown in other applications to lead to feelings of uneasiness and general annoyance. The measurements have shown no evidence of such coupling from modern upwind turbines.
    c. Seismic (ground-carried) measurements recorded near wind turbines and wind turbine farms are unlikely to couple into structures.
    d. A possible coupling mechanism between infrasound and the vestibular system (via the Outer Hair Cells (OHC) in the inner ear) has been proposed but is not yet fully understood or sufficiently explained. Levels of infrasound near wind turbines have been shown to be high enough to be sensed by the OHC. However, evidence does not exist to demonstrate the influence of wind turbine-generated infrasound on vestibular-mediated effects in the brain.
    e. Limited evidence from rodent (rat) laboratory studies identifies short-lived biochemical alterations in cardiac and brain cells in response to short exposures to emissions at 16 Hz and 130 dB. These levels exceed measured infrasound levels from modern turbines by over 35 dB.

7. There is no evidence for a set of health effects, from exposure to wind turbines, that could be characterized as a "Wind Turbine Syndrome."
8. The strongest epidemiological study suggests that there is not an association between noise from wind turbines and measures of psychological distress or mental health problems. There were two smaller, weaker, studies: one did note an association, one did not. Therefore, we conclude the weight of the evidence suggests no association between noise from wind turbines and measures of psychological distress or mental health problems**.**
9. None of the limited epidemiological evidence reviewed suggests an association between noise from wind turbines and pain and stiffness, diabetes, high blood pressure, tinnitus, hearing impairment, cardiovascular disease, and headache/migraine.

4.2 Shadow Flicker

4.2.a Production of Shadow Flicker

Shadow flicker results from the passage of the blades of a rotating wind turbine between the sun and the observer.

1. The occurrence of shadow flicker depends on the location of the observer relative to the turbine and the time of day and year.
2. Frequencies of shadow flicker elicited from turbines is proportional to the rotational speed of the rotor times the number of blades and is generally between 0.5 and 1.1 Hz for typical larger turbines.
3. Shadow flicker is only present at distances of less than 1400 m from the turbine.

4.2.b Health Impacts of Shadow Flicker

1. Scientific evidence suggests that shadow flicker does not pose a risk for eliciting seizures as a result of photic stimulation.
2. There is limited scientific evidence of an association between annoyance from prolonged shadow flicker (exceeding 30 minutes per day) and potential transitory cognitive and physical health effects.

4.3 Ice Throw

4.3.a Production of Ice Throw

Ice can fall or be thrown from a wind turbine during or after an event when ice forms or accumulates on the blades.

1. The distance that a piece of ice may travel from the turbine is a function of the wind speed, the operating conditions, and the shape of the ice.
2. In most cases, ice falls within a distance from the turbine equal to the tower height, and in any case, very seldom does the distance exceed twice the total height of the turbine (tower height plus blade length).

4.3.b Health Impacts of Ice Throw

1. There is sufficient evidence that falling ice is physically harmful and measures should be taken to ensure that the public is not likely to encounter such ice.

4.4 Other Considerations

In addition to the specific findings stated above for noise and vibration, shadow flicker and ice throw, the Panel concludes the following:

1. Effective public participation in and direct benefits from wind energy projects (such as receiving electricity from the neighboring wind turbines) have been shown to result in less annoyance in general and better public acceptance overall.

Chapter 5

Best Practices Regarding Human Health Effects Of Wind Turbines

Broadly speaking, the term “best practice” refers to policies, guidelines, or recommendations that have been developed for a specific situation. Implicit in the term is that the practice is based on the best information available at the time of its institution. A best practice may be refined as more information and studies become available. The panel recognizes that in countries which are dependent on wind energy and are protective of public health, best practices have been developed and adopted.

In some cases, the weight of evidence for a specific practice is stronger than it is in other cases. Accordingly, best practice* may be categorized in terms of the evidence available, as shown in Table 3:

Table 3

Descriptions of Three Best Practice Categories

Category	Name	Description
1	Research Validated Best Practice	A program, activity, or strategy that has the highest degree of proven effectiveness supported by objective and comprehensive research and evaluation.
2	Field Tested Best Practice	A program, activity, or strategy that has been shown to work effectively and produce successful outcomes and is supported to some degree by subjective and objective data sources.
3	Promising Practice	A program, activity, or strategy that has worked within one organization and shows promise during its early stages for becoming a best practice with long-term sustainable impact. A promising practice must have some objective basis for claiming effectiveness and must have the potential for replication among other organizations.

**These categories are based on those suggested in "Identifying and Promoting Promising Practices." Federal Register, Vol. 68. No 131. 131. July 2003.*
www.acf.hhs.gov/programs/ccf/about_ccf/gbk_pdf/pp_gbk.pdf

5.1 Noise

Evidence regarding wind turbine noise and human health is limited. There is limited evidence of an association between wind turbine noise and both annoyance and sleep disruption, depending on the sound pressure level at the location of concern. However, there are no research-based sound pressure levels that correspond to human responses to noise. A number of countries that have more experience with wind energy and are protective of public health have developed guidelines to minimize the possible adverse effects of noise. These guidelines consider time of day, land use, and ambient wind speed. Table 4 summarizes the guidelines of Germany (in the categories of industrial, commercial and villages) and Denmark (in the categories of sparsely populated and residential). The sound levels shown in the table are for nighttime and are assumed to be taken immediately outside of the residence or building of concern. In addition, the World Health Organization recommends a maximum nighttime sound pressure level of 40 dB(A) in residential areas. Recommended setbacks corresponding to these values may be calculated by software such as WindPro or similar software. Such calculations are normally to be done as part of feasibility studies. The Panel considers the guidelines shown below to be Promising Practices (Category 3) but to embody some aspects of Field Tested Best Practices (Category 2) as well.

Table 4

Promising Practices for Nighttime Sound Pressure Levels by Land Use Type

Land Use	**Sound Pressure Level, dB(A) Nighttime Limits**
Industrial	70
Commercial	50
Villages, mixed usage	45
Sparsely populated areas, 8 m/s wind*	44
Sparsely populated areas, 6 m/s wind*	42
Residential areas, 8 m/s wind*	39
Residential areas, 6 m/s wind*	37

**measured at 10 m above ground, outside of residence or location of concern*

The time period over which these noise limits are measured or calculated also makes a difference. For instance, the often-cited World Health Organization recommended nighttime noise cap of 40 dB(A) is averaged over one year (and does not refer specifically to wind turbine noise). Denmark's noise limits in the table above are calculated over a 10-minute period. These limits are in line with the noise levels that the epidemiological studies connect with insignificant reports of annoyance.

The Panel recommends that noise limits such as those presented in the table above be included as part of a statewide policy regarding new wind turbine installations. In addition, suitable ranges and procedures for cases when the noise levels may be greater than those values should also be considered. The considerations should take into account trade-offs between environmental and health impacts of different energy sources, national and state goals for energy independence, potential extent of impacts, etc.

The Panel also recommends that those involved in a wind turbine purchase become familiar with the noise specifications for the turbine and factors that affect noise production and noise control. Stall and pitch regulated turbines have different noise characteristics, especially in high winds. For certain turbines, it is possible to decrease noise at night through suitable control measures (e.g., reducing the rotational speed of the rotor). If noise control measures are to be considered, the wind turbine manufacturer must be able to demonstrate that such control is possible.

The Panel recommends an ongoing program of monitoring and evaluating the sound produced by wind turbines that are installed in the Commonwealth. IEC 61400-11 provides the standard for making noise measurements of wind turbines (International Electrotechnical Commission, 2002). In general, more comprehensive assessment of wind turbine noise in populated areas is recommended. These assessments should be done with reference to the broader ongoing research in wind turbine noise production and its effects, which is taking place internationally. Such assessments would be useful for refining siting guidelines and for developing best practices of a higher category. Closer investigation near homes where outdoor measurements show A and C weighting differences of greater than 15 dB is recommended.

5.2 Shadow Flicker

Based on the scientific evidence and field experience related to shadow flicker, Germany has adopted guidelines that specify the following:

1. Shadow flicker should be calculated based on the astronomical maximum values (i.e., not considering the effect of cloud cover, etc.).
2. Commercial software such as WindPro or similar software may be used for these calculations. Such calculations should be done as part of feasibility studies for new wind turbines.
3. Shadow flicker should not occur more than 30 minutes per day and not more than 30 hours per year at the point of concern (e.g., residences).
4. Shadow flicker can be kept to acceptable levels either by setback or by control of the wind turbine. In the latter case, the wind turbine manufacturer must be able to demonstrate that such control is possible.

The guidelines summarized above may be considered to be a Field Tested Best Practice (Category 2). Additional studies could be performed, specifically regarding the number of hours per year that shadow flicker should be allowed, that would allow them to be placed in Research Validated (Category 1) Best Practices.

5.3 Ice Throw

Ice falling from a wind turbine could pose a danger to human health. It is also clear that the danger is limited to those times when icing occurs and is limited to relatively close proximity to the wind turbine. Accordingly, the following should be considered Category 1 Best Practices.

1. In areas where icing events are possible, warnings should be posted so that no one passes underneath a wind turbine during an icing event and until the ice has been shed.
2. Activities in the vicinity of a wind turbine should be restricted during and immediately after icing events in consideration of the following two limits (in meters).

For a turbine that may not have ice control measures, it may be assumed that ice could fall within the following limit:

$$x_{\max,\,throw} = 1.5(2R + H)$$

Where: R = rotor radius (m), H = hub height (m)

For ice falling from a stationary turbine, the following limit should be used:

$$x_{\max,\,fall} = U(R + H)/15$$

Where: U = maximum likely wind speed (m/s)

The choice of maximum likely wind speed should be the expected one-year return maximum, found in accordance to the International Electrotechnical Commission's design standard for wind turbines, IEC 61400-1.

Danger from falling ice may also be limited by ice control measures. If ice control measures are to be considered, the wind turbine manufacturer must be able to demonstrate that such control is possible.

5.4 Public Participation/Annoyance

There is some evidence of an association between participation, economic or otherwise, in a wind turbine project and the annoyance (or lack thereof) that affected individuals may express. Accordingly, measures taken to directly involve residents who live in close proximity to a wind turbine project may also serve to reduce the level of annoyance. Such measures may be considered to be a Promising Practice (Category 3).

5.5 Regulations/Incentives/Public Education

The evidence indicates that in those parts of the world where there are a significant number of wind turbines in relatively close proximity to where people live, there is a close coupling between the development of guidelines, provision of incentives, and educating the public. The Panel suggests that the public be engaged through such strategies as education, incentives for community-owned wind developments, compensations to those experiencing documented loss of property values, comprehensive setback guidelines, and public education related to renewable energy. These multi-faceted approaches may be considered to be a Promising Practice (Category 3).

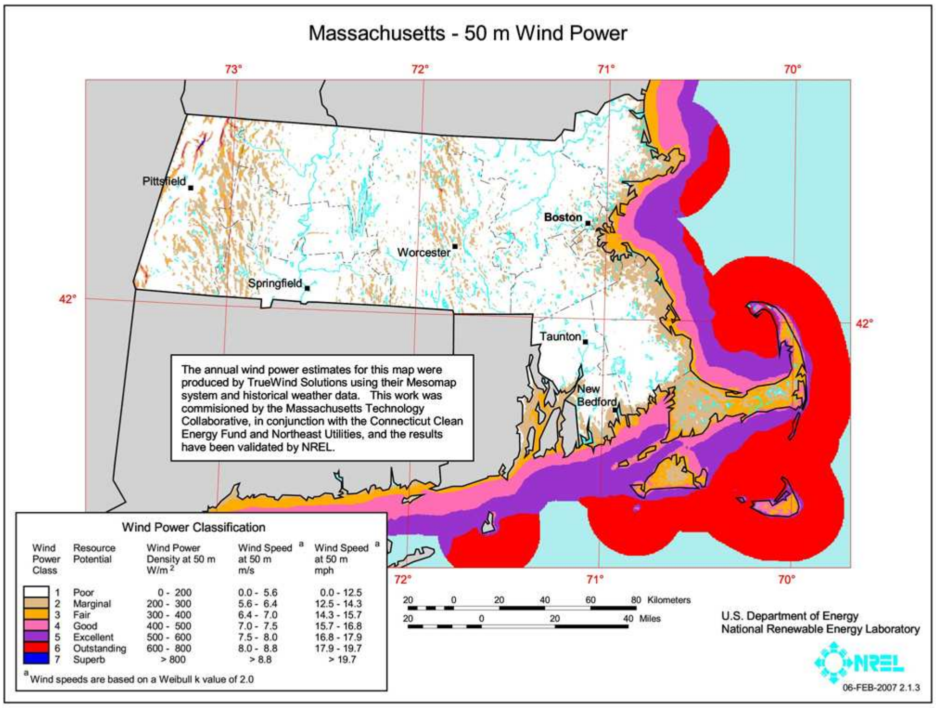
Appendix A:

Wind Turbines - Introduction to Wind Energy

Although wind energy for bulk supply of electricity is a relatively new technology, the historical precedents for it go back a long way. They are descendents of mechanical windmills that first appeared in Persia as early as the 7th century (Vowles, 1932) and then re-appeared in northern Europe in the Middle Ages. They were considerably developed during the 18th and 19th centuries, and then formed the basis for the first electricity generating wind turbine in the late 19th century. Development continued sporadically through the mid 20th century, with modern turbines beginning to emerge in the 1970's. It was the introduction of other technologies, such as electronics, computers, control theory, composite materials, and computer-based simulation capability that led to the successful development of the large scale, autonomously operating wind turbines that have become so widely deployed over the past twenty years.

The wind is the most important external factor in wind energy. It can be thought of as the "fuel" of the wind turbine, even though it is not consumed in the process. The wind determines the amount of energy that is produced, and is therefore referred to as the resource. The wind resource can vary significantly, depending on the location and the nature of the surface. In the United States, the Great Plains have a relatively energetic wind resource. In Massachusetts, winds tend to be relatively low inland, except for mountaintops and ridges. The winds tend to be higher close to the coast and then increase offshore. Average offshore wind speeds generally increase with distance from shore as well. The wind resource of Massachusetts is illustrated in

Figure AA.1: Map of the Massachusetts Wind Resource (From National Renewable Energy Laboratory, *http://www.windpoweringamerica.gov/images/windmaps/ma_50m_800.jpg*)



This section summarizes the basic characteristics of the wind in so far as they relate to wind turbine power production. Much more detail on this topic is provided in (Manwell et al., 2009). The wind will also affect the design of the wind turbines, and for this purpose it is referred to as an "external design condition." This aspect of the wind is discussed in more detail in a later section.

AA.1 Origin of the Wind

The wind originates from sunlight due to the differential heating of various parts of the earth. This differential heating produces zones of high and low pressure, resulting in air movement. The motion of the air is also affected by earth's rotation. Considerations regarding the wind insofar as it relates to wind turbine operation include the following: (i) the winds aloft (geostrophic wind), (ii) atmospheric boundary layer meteorology, (iii) the variation of wind speed with height, (iv) surface roughness, and (v) turbulence.

The geostrophic wind is the wind in the upper atmosphere, which results from the combined effects of the pressure gradient and the earth's rotation (via the Coriolis force). The gradient wind can be thought of as an extension of the geostrophic wind, the difference in this case being that centrifugal effects are included. These result from curved isobars (lines of constant pressure) in the atmosphere. It is these upper atmosphere winds that are the source of most of the energy that eventually impinges on wind turbines. The energy in the upper atmosphere is transferred down closer to the surface via a variety of mechanisms, most notably turbulence, which is generated mechanically (via surface roughness) and thermally (via the rising of warm air and falling of cooler air).

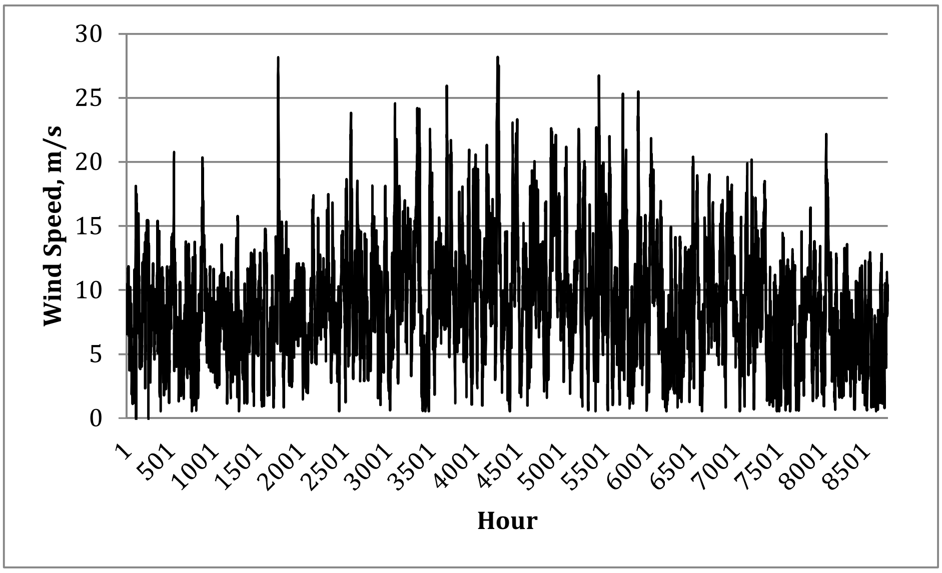
Although driven by higher altitude winds, the wind near the surface is affected by the surrounding topography (such as mountains and ridges) and surface conditions (such as tree cover or presence of buildings).

AA.2 Variability of the Wind

One of the singular characteristics of the wind is its variability, both temporal and spatial. The temporal variability includes: (i) short term (gusts and turbulence), (ii) moderately short term (e.g., hr to hr means), (iii) diurnal (variations over a day), (iv) seasonal, and (v) inter-annual (year to year). The wind may vary spatially as well, both from one location to another or with height above ground.

Figure AA.2 illustrates the variability of the hourly average wind speeds for one year at one location.

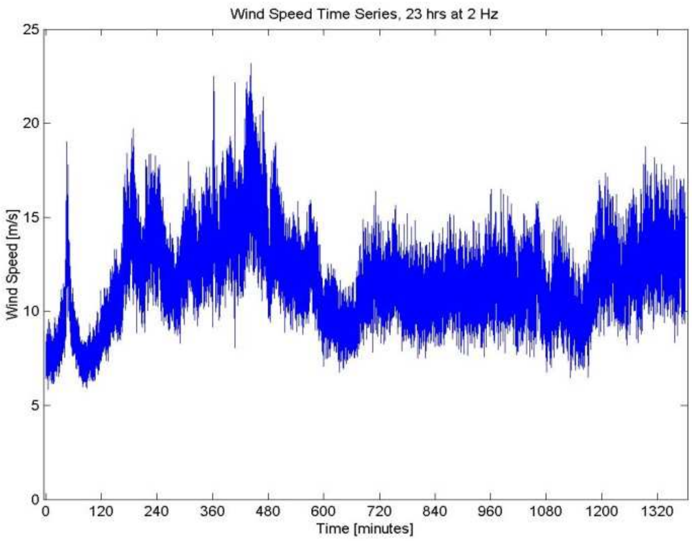
Figure AA.2: Typical hourly wind speeds over a year



As can be seen, the hourly average wind speed in this example varies significantly over the year, ranging from zero to nearly 30 m/s.

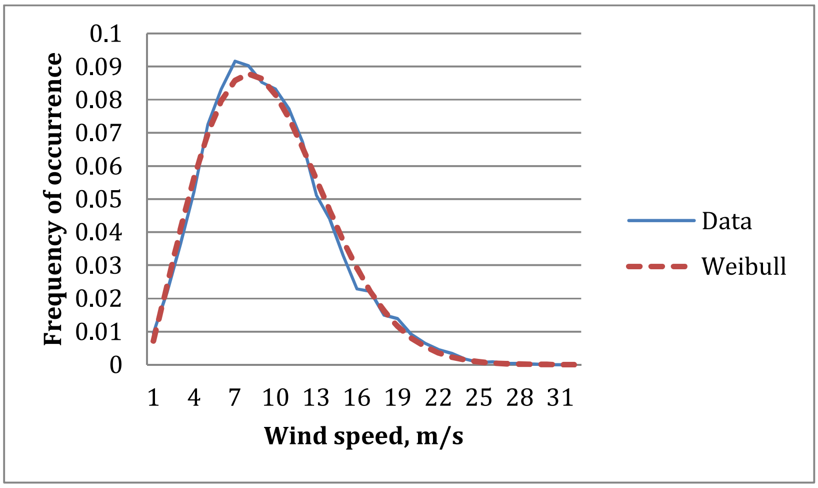
Figure AA.3 illustrates wind speed at another location recorded twice per second over a 23-hour period. There is significant variability here as well. Much of this variability in this figure is associated with short-term fluctuations, or turbulence. Turbulence has some effect on power generation, but it has a more significant effect on the design of wind turbines, due to the material fatigue that it tends to engender. Turbulence is discussed in more detail in a later section.

Figure AA.3: Typical wind data, sampled at 2 Hz for a 23-hr period



In spite of the variability in the wind time series, summary characteristics have much less variability. For example, the annual mean wind speed at a given location is generally within +/-10% of the long-term mean at that site. Furthermore, the distribution of wind speeds, that is to say the frequency of occurrence of winds in various wind speed ranges, also tends to be similar from year. The general shape of such distributions is also similar from one location to another, even if the means are different. In fact, statistical models such as the Weibull distribution can be used to model the occurrences of various wind speeds in most locations on the earth. For example, the number of occurrences of wind speed in various ranges from the data set illustrated in Figure AA.2 are shown in Figure AA.4, together with the those occurrences as modeled by the Weibull distribution.

Figure AA.4: Typical frequency of occurrence of wind speeds, based on data and statistical model



The Weibull distribution's probability density function is given by:

$$p(U) = \left(\frac{k}{c}\right)\left(\frac{U}{c}\right)^{k-1} \exp\left[-\left(\frac{U}{c}\right)^{k}\right] \qquad (1)$$

Where c = Weibull scale factor (m/s) and k = Weibull shape factor (dimensionless)

For the purposes of modeling the occurrences of wind speeds, the scale and shape factors may be approximated as follows:

$$k \approx \left(\frac{\sigma_U}{\overline{U}}\right)^{-1.086} \qquad (2)$$

$$c \approx \overline{U}\left(0.568 + 0.433 / k\right)^{-(1/k)} \qquad (3)$$

Where $\overline{U}$ is the long-term mean wind speed (m/s, based on 10 min or hourly averages) and σ_U is the standard deviation of the wind speed, based on the same 10 min or hourly averages.

AA.3 Power in the Wind

The power available in the wind can be predicted from the fundamental principles of fluid mechanics. First of all, the energy per unit mass of a particle of air is given simply by ½ times the square of the velocity, U (m/s). The mass flow rate of the air (kg/s) through a given area A (m^2) perpendicular to the direction of the wind is $\dot{m} = \rho A U$, where ρ is the density of the air (kg/m^3). The power in the wind per unit area, P/A, (W/m^2) is then:

$$P / A = (\dot{m} / A)\frac{1}{2}U^2 = \frac{1}{2}\rho U^3 \qquad (4)$$

AA.4 Wind Shear

Wind shear is the variation of wind speed with height. Wind shear has relevance to power generation, to turbine design, and to noise generation. The variation of wind speed with height is typically modeled with a power law as follows:

$$U_2 = U_1 [h_2 / h_1]^\alpha \qquad (5)$$

Where U_1 = speed at reference height h_1, U_2 is the wind speed to be estimated at height h_2 and α is the power law exponent. Values of the exponent typically range from a 0.1 for smooth surfaces to 0.4 for very rough surfaces (such as forests or built-up areas.)

Wind shear can also be affected by the stability of the atmosphere. Equations have been developed that allow the incorporation of stability parameters in the analysis, but these too are outside the scope of this overview.

AA.5 Wind and Wind Turbine Structural Issues

As discussed previously, the wind is of particular interest in wind turbine applications, since it is the source of the energy. It is also the source of significant structural loads that the turbine must be able to withstand. Some of these loads occur when the turbine is operating; others occur when it is stopped. Extreme winds, for example, are likely to affect a turbine when it is stopped. High winds with sudden directional change during operation can also induce high loads. Turbulence during normal operation results in fatigue. The following is a summary of the key aspects of the wind that affect the design of wind turbines. More details may be found in (Manwell et al., 2009).

AA.5.a Turbulence

Turbulence in the wind can have significant effect on the structure of a wind turbine as well as its operation, and so it must be considered in the design process. The term "turbulence" refers to the short-term variations in the speed and direction of the wind. It manifests itself as apparently random fluctuations superimposed upon a relatively steady mean flow. Turbulence is not actually random, however. It has some very distinct characteristics, at least in a statistical sense.

Turbulence is characterized by a number of measures. These include: (i) turbulence intensity, (ii) turbulence probability density functions (pdf), (iii) autocorrelations, (iv) integral time scales and length scales, and (v) power spectral density functions. Discussion of the physics of turbulence is outside the scope of this overview.

AA.5.b Gusts

A gust is discrete increase and then decrease in wind speed, possibly associated with a change in wind direction, which can be of significance to the design of a wind turbine. Gusts are typically associated with turbulence.

AA.5.c Extreme Winds

Extreme winds need to be considered for the design of a wind turbine. Extreme winds are normally associated with storms. They occur relatively rarely, but often enough that the possibility of their occurring cannot be ignored. Statistical models, such as the Gumbel distribution (Gumbel, 1958), are used to predict the likelihood of such winds occurring at least once every 50 or 100 years. Such intervals are called return periods.

AA.5.d Soils

Soils are also important for the design and installation of a wind turbine. In particular, the nature of the soil will affect the design of the wind turbine foundations. Discussion of soils is outside the scope of this overview.

AA.6 Wind Turbine Aerodynamics

The heart of the wind turbine is the rotor. This is a device that extracts the kinetic energy from the wind and converts it into a mechanical form. Below is a summary of wind turbine rotor aerodynamics. More details may be found in (Manwell et al., 2009).

A wind turbine rotor is comprised of blades that are attached to a hub. The hub is in turn attached to a shaft (the main shaft) which transfers the energy through the remainder of the drive train to the generator where is it converted to electricity. The maximum power that a rotor can extract from the wind is first of all limited by the power in the wind, which passes through an area defined by the passage of the rotor. At the present time, most wind turbines utilize a rotor with a horizontal axis. That is, the axis of rotation is (nominally) parallel to the earth's surface. Accordingly, the area that is swept out by the rotor is circular. Assuming a rotor radius of *R* (m), the maximum power *P* (W) available in the wind is:

$$P = \frac{1}{2}\rho\pi R^2 U^3 \tag{6}$$

Early in the 20th century, it was shown by Betz (among others, see [4]) that the maximum power that could be extracted was less than the power in the wind; in fact, it was 16/27 times that value. Betz' work led to the definition of a power coefficient, C_p, which expresses the ratio of the actual power extracted by a rotor to the power in the wind. When considering efficiencies of other components in the drive train, as expressed by the η, the total power out a wind turbine, P_{WT}, would be given by:

$$P_{WT} = C_p \eta \frac{1}{2}\rho\pi R^2 U^3 \tag{7}$$

The maximum value of the power coefficient, known as the Betz limit, is thus 16/27.

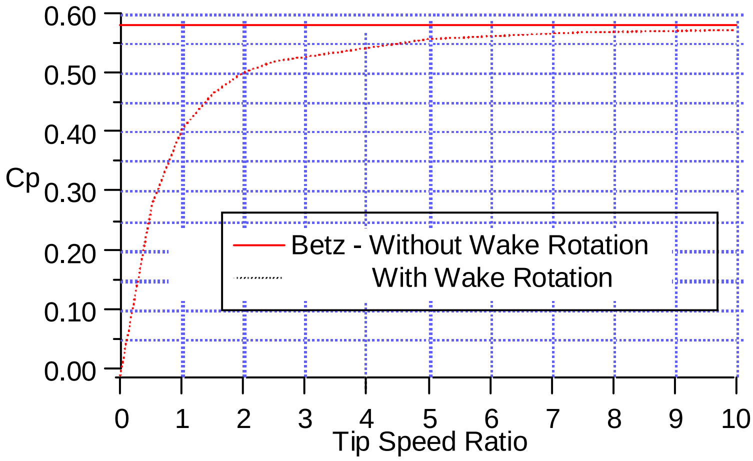
Betz' original analysis was based on the fundamental principles of fluid mechanics including linear momentum theory. It also included the following assumptions: (i) homogenous, incompressible, steady state fluid flow; (ii) no frictional drag; (iii) a rotor with an infinite number of (very small) blades; (iv) uniform thrust over the rotor area; (v) a non-rotating wake; and (vi) the static pressure far upstream and far downstream of the rotor that is equal to the undisturbed ambient static pressure.

A real rotor operating on a horizontal axis will result in a rotating wake. Some of the energy in the wind will go into that rotation and will not be available for conversion into mechanical power. The result is that the maximum power coefficient will actually be less than the Betz limit. The derivation of the maximum power coefficient for the rotating wake case use a number of terms: (i) the rotational speed of turbine rotor, Ω, in radians/sec; (ii) tip speed ratio, $\lambda = \Omega R/U$; (iii) local speed ratio, $\lambda_r = \lambda\, r/R$; (iv) rotational speed of wake, ω; (v) an axial induction factor, *a*, which relates the free stream wind speed to the wind speed at the rotor and the wind speed in the far wake ($U_{rotor} = (1-a)U_{free\ stream}$ and $U_{wake} = (1-2a)U_{free\ stream}$); and (vi) an angular induction factor, *a'* = *ω/2 Ω*. According to this analysis, the maximum possible power coefficient is given by:

$$C_{P,\max} = \frac{8}{\lambda^2}\int_0^{\lambda} a'(1-a)\lambda_r^3 d\lambda_r \tag{8}$$

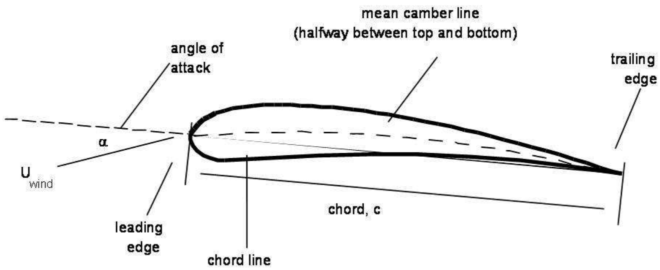
The maximum power coefficient for a rotor with a rotating wake and the Betz limit are illustrated in Figure AA.5.

Figure AA.5: Maximum theoretical power coefficients for rotating and non-rotating wakes



Neither of the analyses summarized above gives any indication as to what the blades of the rotor actually look like. For this purpose, a method called blade element momentum (BEM) theory was developed. This approach assumes that the blades incorporate an airfoil cross section. Figure AA.6 shows a typical airfoil, including some of the nomenclature.

Figure AA.6: Airfoil nomenclature



The BEM method equates the forces on the blades associated with air flowing over the airfoil with forces associated with the change in momentum of the air passing through the rotor. The starting point for this analysis is the assessment of the lift force on an airfoil. Lift is a force perpendicular to the flow. It is given by

$$\tilde{F}_L = C_L \frac{1}{2} \rho c U^2 \qquad (9)$$

Where:

$\tilde{F}_L$ = force per unit length, N/m

C_L = lift coefficient, -

c = chord length (distance from leading edge to trailing edge of airfoil, m)

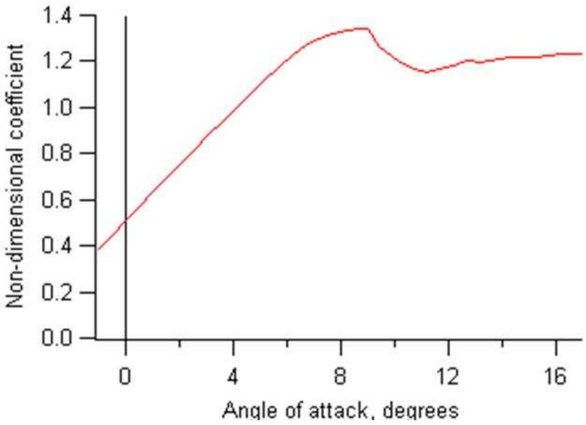
Thin airfoil theory predicts that for a very thin, ideal airfoil the lift coefficient is given by

$$C_L = 2\pi \sin\alpha \qquad (11)$$

where α is the angle of attack, which is the angle between the flow and the chord line of the airfoil.

The lift coefficient for real airfoils typically includes a constant term but the slope, at least for low angles of attack, is similar to that for an ideal airfoil. For greater angles of attack (above 10–15 degrees) the lift coefficient begins to decrease, eventually approaching zero. This is known as stall. A typical lift coefficient vs. angle of attack curve is illustrated in Figure AA.7.

Figure AA.7: Typical airfoil lift vs. angle of attack



There is always some drag force associated with fluid flow. This is a force is in line with the flow. Drag force (per unit length) is given by:

$$\tilde{F}_D = C_D \frac{1}{2} \rho c U^2 \qquad (12)$$

Where C_D = drag coefficient

When designing blades for a wind turbine, it is generally desired to minimize the drag to lift ratio at the design point. This generally results in a lift coefficient in the vicinity of 1.0 and a drag coefficient of approximately 0.006, although these values can differ depending on the airfoil.

Blade element momentum theory, as noted above, relates the blade shape to its performance. The following approach is used. The blade is divided into elements and the rotor is divided into annuli. Two simultaneous equations are developed: one expresses the lift and drag coefficient (and thus forces) on the blade elements as a function of airfoil data and the wind's angle of attack. The other expresses forces on the annuli as a function of the wind through the rotor, rotor characteristics, and changes in momentum. Some of the key assumptions are: (i) the forces on blade elements are determined solely by lift/drag characteristics of the airfoil, (ii) there is no flow along the blade, (iii) lift and drag force are perpendicular and parallel respectively to a "relative wind," and (iv) forces are resolved into components perpendicular to the rotor ("thrust") and tangential to it ("torque").

Using BEM theory, it may be shown for an ideal rotor that the angle of relative wind, φ, as a function of tip speed ratio and radial position on the blade is given by:

$$\varphi = \left(\tfrac{2}{3}\right)\tan^{-1}\left(1/\lambda_r\right) \tag{13}$$

Similarly, the chord length is given by:

$$c = \frac{8\pi r}{BC_L}\left(1 - \cos\varphi\right) \tag{14}$$

Where B = the number of blades

There are some useful observations to be drawn out of the above equations. First of all, in the ideal case the blade will be twisted. In fact, the twist angle will differ from the angle of relative wind by the angle of attack and a reference pitch angle θ_p as follows:

$$\theta_T = \varphi - \alpha - \theta_p \tag{15}$$

It may also be noted that the twist angle will at first increase slowly when moving from the tip inward and then increase more rapidly. Second, the chord of the blade will also increase upon moving from the tip inward, at first slowly and then more rapidly. In the ideal case then, a wind turbine blade is both significantly twisted and tapered. Real blades, however, are designed with a less than optimal shape for a variety of practical reasons.

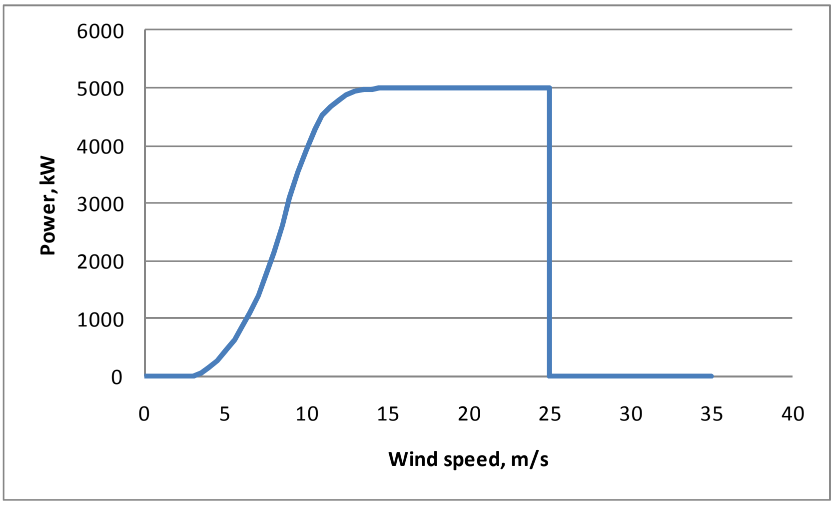
Another important observation has to do with the total area of the blades in comparison to the swept area. The ratio of the projected blade area is known as the solidity, σ. For a given angle of attack, the solidity will decrease with increasing tip speed ratio. For example, assuming a lift coefficient C_L of 1.0, the solidity of an optimum rotor designed to operate at a tip speed ratio of 2.0 is 0.43 whereas an optimum rotor designed to operate at a tip speed ratio of 6.0 would have a solidity of 0.088. It is therefore apparent that in order to keep blade material (and thus cost) to a minimum, it is desirable to design for a tip speed ratio as high as possible.

There are other considerations in selecting a design tip speed ratio for a turbine other than the solidity, however. On the one hand, higher tip speed ratios will result in gearboxes with a lower speed up ratio for a given turbine. On the other hand, the effect of drag and surface roughness of the blade surface may become more significant for a higher tip speed ratio rotor. This effect could result in decreased performance. Another concern is material strength. The total forces on the rotor are nearly the same on the rotor regardless of the solidity. Thus the stresses would be higher. A final consideration is noise. Higher tip speed ratios generally result in more noise produced by the blades.

There are numerous other considerations regarding the design of a wind turbine rotor, including tip losses, type of airfoil to be used, ease of manufacturing and transport, type of control used, selection of materials, etc. These are all outside the scope of this overview, however.

Real wind turbine rotors are designed taking into account many factors, including but not only their aerodynamic performance. In addition, the rotor must be controlled so as to generate electricity most effectively and so as to withstand continuously fluctuating forces during normal operation and extreme loads during storms. Accordingly, a wind turbine rotor does not in general operate at its own maximum power coefficient at all wind speeds. Because of this, the power output of a wind turbine is generally described by curve, known as a power curve, rather than an equation such as the one for P_{WT} which given earlier. Figure AA.8 illustrates a typical power curve. As shown there, below the cut-in speed (3 m/s in the example) no power is produced. Between cut-in and rated wind speed (14.5 m/s in this example), the power increases significantly with wind speed. Above the rated speed, the power produced is constant, regardless of the wind speed, and above the cut-out speed (25 m/s in the example), the turbine is shut down.

Figure AA.8: Typical wind turbine power curve



AA.7 Wind Turbine Mechanics and Dynamics

Earlier we discussed the aerodynamic aspects of a wind turbine, and how that related to its design, performance, and appearance. The next major consideration has to do with the turbine's survivability. This topic includes its ability to withstand the forces to which the turbine will be subjected, deflections of various components, and vibrations that may result during operations.

Issues that need to be considered include: (i) ultimate strength, (ii) relative motion of components, (iii) vibrations, (iv) loads, (v) responses, (vi) stresses, (vii) unsteady motion, resulting in fatigue, and (viii) material properties.

The types of loads that a turbine may be subjected to are as follows: static (non-rotating), steady (rotating), cyclic, transient, impulsive, stochastic, or resonance-induced. Sources of loads may include aerodynamics, gravity, dynamic interactions, or mechanical control. To understand the various loads that a wind turbine may experience, the reader may wish to review the fundamentals of statics (no motion), dynamics (motion), Newton's second law, the various rotational relations (kinematics), strength of materials (including Hooke's law and finding stresses from moments and geometry), gyroscopic forces/moments, and vibrations. Among other topics, the cantilevered beam is particularly important, since rotor blades as well as towers have similar characteristics.

Wind turbines are frequently both the source of and are subject to vibrations. Although the topic can become quite complicated, it is worthwhile to recall that the natural frequency of simple oscillating mass, *m*, and spring, with spring constant, *k*, and is given by:

$$\omega = \sqrt{k/m} \qquad (16)$$

Similarly, rotational natural frequency about an axis of rotation is given by:

$$\omega = \sqrt{k_\theta / J} \qquad (17)$$

Where k_θ is the rotational spring constant and J is the mass moment of inertia

A continuous body, such as a wind turbine blade, will actually have an infinite number of natural frequencies (although only the first few are important), and associated with each natural frequency will be a mode shape that characterizes it deflection. The vibration of a uniform cantilevered beam can be described relatively simply through the use of Euler’s equation (see Manwell et al., 2009). Non-uniform elements require more complex methods for their analysis.

AA.7.a Rotor Motions

There is a variety of motions that occur in the rotor that can be significant to the design or operation of the turbine. These include those in the flapwise, edgewise, and torsional directions.

Flapwise motions are those that are perpendicular to plane of the rotor, and are considered positive in the direction of the thrust. Flapwise forces are the source of the highest aerodynamic bending moments, and accordingly the most significant stresses.

Lead-lag, or edgewise, motions are in plane of rotor and are considered positive when in the direction of the torque. Fluctuating motions in this direction are reflected in the power.

Torsion refers to the twisting of blade about its long axis. Torsional moments in the blades must be accounted for in the design of pitch control mechanisms.

The most important rotor load is the thrust. This is the total force on the rotor in the direction of the wind (flapwise). It is associated with the conversion of the kinetic energy of the wind to mechanical energy. The thrust, T, (N) is given by:

$$T = C_T \frac{1}{2} \rho \pi R^2 U^2 \tag{18}$$

Where C_T is the thrust coefficient. For the ideal rotor in which the axial induction factor, a, is equal to 1/3 (corresponding to the Betz limit), it is easy to show that the thrust coefficient is equal to 8/9. For the same rotor, the thrust coefficient may be as high as 1.0, but this would not occur at $C_p = C_{p,Betz}$.

This thrust gives rise to flapwise bending moments at the root of the blade. For example, for the ideal rotor when a = 1/3, and assuming a very small hub, it may be shown that the flapwise bending moment M_β at the root of the blade would be given by:

$$M_\beta = \frac{T}{B} \frac{2}{3} R \tag{19}$$

Where B = number of blades

From the bending moment, it is straightforward to find the maximum bending stress in the blade. For example, suppose that a blade is 2t m thick at the root, has a symmetrical airfoil, and that the thrust force is perpendicular to the chord line. Then the bending stress would be:

$$\sigma_{\beta,\max} = \frac{M_\beta t}{I_b} \tag{20}$$

(Note that for a real blade, the asymmetry and the angles would complicate the calculation, but the principle is the same.)

Another important load is torque, Q (Nm). Torque is given by:

$$Q = C_Q \frac{1}{2} \rho \pi R^2 U^2 \qquad (21)$$

Where C_Q = the torque coefficient, which also equal to C_p/λ.

Note that torque is also given by:

$$Q = P / \Omega \qquad (22)$$

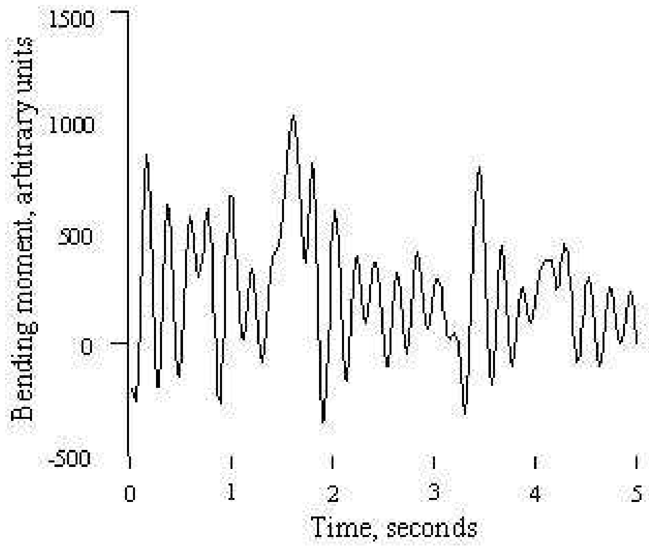
Where P = power (W)

The dynamics of a wind turbine rotor are quite complicated and do not lend themselves to simple illustrations. There is one approach, however, due to Stoddard (Eggleston and Stoddard, 1987) and summarized by (Manwell et al., 2009) which is relatively tractable, but will not be discussed here. In general, the dynamic response of wind turbine rotors must be simulated by numerical models, such as the FAST code (Jonkman, 2005) developed by the National Renewable Energy Laboratory.

AA.7.b Fatigue

Fatigue is an important phenomenon in all wind turbines. The term refers to the degradation of materials due to fluctuating stresses. Such stresses occur constantly in wind turbines due to the inherent variability of the wind, the rotation of the rotor and the yawing of the rotor nacelle assembly (RNA) to follow the wind as its direction changes. Fatigue results in shortened life of many materials and must be accounted for in the design. Figure AA.9 illustrates a typical time history of bending moment that would give rise to fluctuating stresses of similar appearance.

Figure AA.9: Typical wind turbine blade bending moment



The ability of a material to withstand stress fluctuations of various magnitudes is typically illustrated in an S-N curve. In such curves the stress level is shown on the *y* axis and is plotted against the number of cycles to failure. As is apparent from the figure above, stress fluctuations of a variety of magnitudes are likely. The effect of a number of cycles of different ranges is accounted for by the damage due to each cycle using “Miner’s Rule.” In this case, an amount of damage, *d*, due to *n* cycles, where the stress is such that *N* cycles will result in damage is found as follows:

$$d = n / N \tag{23}$$

Miner’s Rule states that the sum of all the damage, *D*, from cycles of all magnitudes must be less than 1.0, or failure is to be expected imminently:

$$D = \sum n_i / N_i \leq 1 \tag{24}$$

Miner’s Rule works best when the cycling is relatively simple. When cycles of varying amplitude follow each other, an algorithm called "rainflow" cycle counting” (Downing and Socie, 1982) is used.

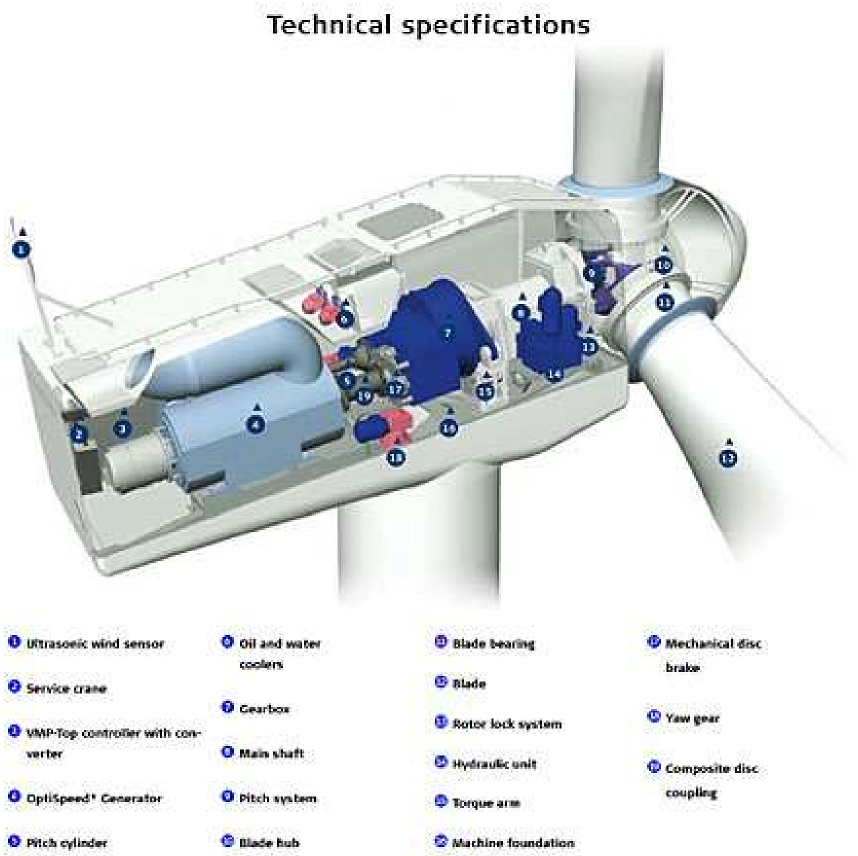
AA.8 Components of Wind Turbines

Wind turbines consist of two main subsystems, the rotor nacelle assembly and the support structure, and each of these is comprised of many components. The following provides some more description of these subsystems. More details, particularly on the rotor nacelle assembly may be found in (Manwell et al., 2009).

AA.8.a Rotor Nacelle Assembly

The rotor nacelle assembly (RNA) includes the majority of the components associated with the conversion of the kinetic energy of the wind into electrical energy. There are two major component groupings in the RNA as well as a number of ancillary components. The main groupings are the rotor and the drive train. The rotor includes the blades, the hub, and pitch control components. The drive train includes shafts, bearings, gearbox (if any), couplings, mechanical brake, and generator. Other components include the bedplate, yaw bearing and yaw drive, oil cooling system, climate control, other electrical components, and parts of the control system. An example of a typical rotor nacelle assembly is illustrated in Figure AA.10.

Figure AA.10: Typical Rotor Nacelle Assembly



(From Vestas http://re.emsd.gov.hk/english/wind/large/large_to.html)

AA.8.b Rotor

The primary components of the rotor are the blades. At the present time, most wind turbines have three blades, and they are oriented so as to operate upwind of the tower. It is to be expected that in the future some wind turbines, particularly those intended for use offshore, will have two blades and will be oriented downwind of the tower, however. For a variety of reasons (including that downwind turbines tend to be noisier) it is less likely that they will be used on land, particularly in populated areas.

The general shape of the blades is chosen in accordance with the principles discussed previously. The other major factor is the required strength of the blades. For this reason, it is often the case that thicker airfoils are used nearer the root than are used closer to the tip. Blades for most modern wind turbines are constructed of composites. The laminates are primarily fiberglass with some carbon fiber for additional strength. The binders are polyester or epoxy.

At the root of the blades the composite material is attached to a steel root, which can then be subsequently bolted to the hub. Most utility scale wind turbines at present include blade pitch control, so there is a mechanism present at the interface of the hub and the blades that will both secure the blades and facilitate their rotation about their long axis.

The hub of the wind turbine rotor is constructed from steel. It is designed so as to attach to the main shaft of the drive train as well as to connect with the blades.

AA.8.c Drive train

The drive train consists of a number of components, including shafts, couplings, a gearbox (usually), a generator, and a brake.

AA.8.d Shafts

The main shaft of the drive train is designed to transmit the torque from the rotor to the gearbox (if there is one) or directly to the generator if there is no gearbox. This shaft may also be required to carry some or all of the weight of the rotor. The applied torque will vary with the amount of power being produced, but in general it is given by the power divided by the rotational speed. As discussed previously, a primary consideration in the aerodynamic design of a wind turbine rotor is the tip speed ratio. A typical design tip speed ratio is 7. Consider a wind turbine with a diameter of 80 m, designed for most efficient operation at a wind speed 12 m/s. The rotational speed of the rotor and thus the main shaft under these conditions would be 20 rpm.

AA.8.e Gearbox

Wind turbines are intended to generate electricity, but most conventional generators are designed to turn at higher speeds than do wind turbine rotors (see below). Therefore, a gearbox is commonly used to increase the speed of the shaft that drives the generator relative to that of the main shaft. Gearboxes consist of a housing, gears, bearings, multiple shafts, seals, and lubricants. Gearboxes for wind turbines are typically either of the parallel shaft or planetary type. Frequently a gearbox incorporates multiple stages, since the maximum allowed ratio per stage is usually well under 10:1. There are trade-offs in the selection of gearbox. Parallel shaft gearboxes are generally less expensive than planetary ones but they are also heavier. Gearboxes are generally quite efficient. Thus the power out is very nearly equal to the power in. The torque in the shafts is then equal to the power divided by the speed of the shaft.

AA.8.f Brake

Nearly all wind turbines incorporate a mechanical brake somewhere on the drive train. This brake is normally designed to stop the rotor under all foreseeable conditions, although in some cases it might only serve as a parking brake for the rotor. Mechanical brakes on utility scale wind turbines are mostly of the caliper/disc type although other types are possible. Brakes may be placed on either the low speed or the high speed side of the gearbox. The advantage of placing it on the high speed side is that less braking torque is required to stop the rotor. On the other hand, the braking torque must then pass through the gearbox, possibly leading to premature failure of the gearbox. In either case, the brake must be designed to absorb all of the rotational energy in the rotor, which is converted into heat as the rotor stops.

AA.8.g Generator

Electrical generators operate via the rotation of a coil of wire in a magnetic field. The magnetic field is created by one or more pairs of magnetic poles situated opposite each other across the axis of rotation. The magnetic field may be created either by electromagnets (as in conventional synchronous generators), by induction in the rotor (as in induction generators,) or with permanent magnets. In alternating current systems the number of pairs of poles and the grid frequency determine the nominal operating speed of the generator. For example, in a 60 Hz AC system, such as the United States, a generator with two pairs of poles would have a nominal operating speed of 1800 rpm. In most AC generators, the field rotates and while the current is generated in a stationary armature (the stator).

The majority of utility scale wind turbines today use wound rotor induction generators (WRIG). This type of generator can function over a relatively wide range of speeds (on the order of 2:1). Wound rotor induction generators are employed together with a power electronic converter in the rotor circuit. In such an arrangement approximately 2/3 of the power is produced on the stator in the usual way. The other third of the power is produced on the rotor and converted to AC of the correct frequency by the power electronic converter. In this configuration the WRIG is often referred to as a doubly fed induction generator (DFIG).

A number of wind turbines use permanent magnet generators. Such generators often have multiple pole pairs as well. This can allow the generator to have the same nominal speed as the wind turbine rotor so the main shaft can be connected directly to the generator without the use of a gearbox. Most permanent magnet generators are designed to operate together with power electronic converters. These converters facilitate variable speed operation of the turbine, while ensuring that the electricity that is produced is of constant frequency and compatible with the electrical grid to which the turbine is connected.

AA.8.h Bedplate

The bedplate is a steel frame to which components of the drive train and other components of the RNA are attached. It ensures that all the components are properly aligned.

AA.8.i Yaw System

Most wind turbines today include a yaw system. This system facilitates orienting the RNA into the wind as the wind direction changes. First of all, there is a slewing bearing that connects the top of the tower to the RNA, allowing the latter to rotate with respect to the former. Also attached to the top of the tower, and often to the outside perimeter of the slewing bearing, is a large diameter bull gear. A yaw motor connected to a smaller gear is attached to the bedplate. When the yaw motor is energized, the small gear engages the bull gear, causing the RNA to move relative to the tower. A yaw controller ensures that the motion is in the proper direction and that it continues until the RNA is aligned with the wind. A yaw brake holds the RNA fixed in position until the yaw controller commands a new orientation.

AA.8.j Control System

A wind turbine will have a control system that ensures the proper operation of the turbine at all times. The control system has two main functions: supervisory control and dynamic control. The supervisory control continuously monitors the external conditions and the operating parameters of the turbine, and starts it up or shuts it down as necessary. The dynamic control system ensures smooth operation of various controllable components, such the pitch of the blades or the electrical torque of the generator. The control system may also be integrated with or at least be in communication with a condition monitoring system that watches over the condition of various key components.

AA.8.k Support Structure

The support structure of a wind turbine is any part of the turbine that is below the main bearing. The support structure for land-based wind turbines may be conceptually divided into two main parts: the tower and the foundation. The tower of a wind turbine is normally constructed of tapered steel tubes. The tubes are bolted together on site to form a single structure of the desired height. The foundation of a wind turbine is the part of the support structure, which is in contact with the ground. Foundations are typically constructed of reinforced concrete. When turbines are installed on rock, the foundations may be attached to the rock with rods, which are grouted into predrilled holes.

AA.8.l Materials for Wind Turbines

The primary types of materials used in the various components of wind turbines are steel, copper, composites, and concrete.

AA.9 Installation

Installation of wind turbines may be a significant undertaking. It involves the following:

- Complete assessment of site conditions
- Detailed preparing for the installation
- Constructing the foundation
- Delivering the components to the site
- Assembling the components into sub-assemblies
- Lifting the sub-assemblies into place with a crane
- Installing the electrical equipment
- Final testing

More details may be found in (Manwell et al., 2009).

AA.10 Energy Production

The purpose of wind turbines is to produce energy. Energy production is usually considered annually. The amount of energy that a wind turbine will produce in a year, E_y, is a function of the wind resource at the site where it is installed and the power curve of the wind turbine. Estimates are usually done by calculating the expected energy that will be produced every hour of a representative year and then summing the energy from all of those hours as shown below:

$$E_y = \sum_{i=1}^{8760} P_{WT}(U_i)\Delta t \tag{25}$$

Where U_i is the wind speed in the i^{th} hour of the year, $P_{WT}(U_i)$ is the average power (based on the power curve) during the i^{th} hour and Δt is the length of the time period of interest (here, one hr). The units of energy are Wh, but the amount of energy production is frequently expressed in either kWh or MWh for the sake of convenience.

It is sometimes cumbersome to characterize the performance of a wind turbine by its actual energy production. Accordingly, a normalized term known as the capacity factor, *CF*, is used. This is the given by the actual energy that is produced (or estimated to be produced) divided by the amount of energy that would be produced if the turbine were running at is rated output, P_R, for the entire year. It is found from the following equation:

$$CF = \frac{E_y}{8760 P_R} \tag{26}$$

AA.11 Unsteady Aspects of Wind Turbine Operation

There are a number of unsteady aspects of wind turbine operation that are significant to the discussion of public reaction to wind turbines. These in particular include the variations in the wind field that can change the nature of the sound emitted from the rotor during operation. These unsteady effects include the following:

1. Wind shear – Wind shear refers to the variation of wind speed across some spatial dimension. Wind shear is most commonly thought of as a vertical phenomenon, that is to say, the increase of wind speed with height. Wind shear can also occur laterally across the rotor under some circumstances. Vertical wind shear is often modeled by a power law as discussed earlier. There are some situations, however, in which such a model is not applicable. One example has to with highly stable atmosphere, such that the wind near the ground is relatively light, but at the height of the rotor the wind is high enough that turbine may be operating. Under such conditions there may be sound emanating from the rotor, but relatively little wind induced sound near the ground to mask that from the rotor. Wind shear may also result in a cyclically varying aspect to the sound produced by the blades as they rotate. This occurs due to the changing magnitude and direction of the relative wind as the blades pass through zones of different wind speed.
2. Tower shadow or blockage – The wind flow near the tower is inevitably somewhat different from where there is no tower. The effect is much more pronounced on wind turbines with downwind rotors, but it still occurs with up-wind rotors. This tower effect can result in a distinct change in sound once per revolution of each blade.

3. Turbulence – Turbulence refers to changes in magnitude and direction of the wind at varying time scales and length scales. The presence of turbulence can affect the nature of the sound.
4. Changes in wind direction – Wind turbines are designed to yaw in response to changes in wind direction. The yawing process takes a finite amount of time and during that time the wind impinging on the rotor will do so at a different direction than it will when the yawing process is complete. Sound produced during the yawing process may have a somewhat different character than after it is complete.
5. Stall – Under some conditions part or all of the airfoils on the blades may be in stall. That is, the angle of relative wind is high enough that the airfoil begins to lose lift. Additional turbulence may also be generated. Again, the nature of the sound produced by the rotor may be different than during an unstalled state. It may also be noted that some turbines intentionally take advantage of stall to limit power in high winds. Under such conditions there may also be a change in sound in comparison to normal operation.

AA.11.a Periodicity of Unsteady Aspects of Wind Turbine Operation

Due to the rotation of the rotor and the nature of the wind, there tend to be certain features of the turbine's operation that are periodic in nature. The most dominant of these have frequencies associated with the rotational speed of the rotor and the blade passage frequency, which is simply the rotational speed times the number of blades. For example, the dominant frequencies in a 3-blade wind turbine rotating at 20 rpm would be 0.33 Hz and 1 Hz. Other significant frequencies may be the first few harmonics of the rotational frequency and blade passage frequency.

AA.12 Wind Turbines and Avoided Pollutants

Wind turbines have a positive impact on human health via avoiding emission of pollutants that would result if the electricity that they generate were produced instead by other generators. While the average emissions of various pollutants per MWh produced from conventional generators is relatively easy to estimate, it is harder to estimate the actual impact of wind turbine generation. This is because the electricity distributed by the electrical grid is produced by different types of generators, and the operation of these generators will be affected differently as a result of the supply of part of the total electrical demand by the wind turbines.

In general, electricity in any large utility network comes from three types of generators: base load, intermediate load, and peaking plants. The fuel or energy source supplying these generators is likely to be coal, fuel oil, natural gas, uranium (nuclear plants), or water (hydroelectric plants). Base load plants are typically coal fired or nuclear plants. Intermediate load plants often use fuel oil or natural gas. Peaking plants are normally natural gas or hydroelectric. There are a considerable number of plants that may be operating at any given time. Which plants are actually operating is determined by the system operator in accordance with what the near term forecasted load is expected to be and the estimated (bid) cost per MWh from all the plant operators in the system. For thermal plants the bid cost is close to that projected fuel cost/MWh. This in turn is found from heat rate of the fuel (kg/MWh) for the plant in question times the unit cost of the fuel ($/kg). Less efficient plants or those with higher unit fuel costs tend to have relatively high bid costs. (Note on the other hand, that wind turbines would have bid costs of zero, since they do not use fuel.)

If a large number of wind turbines are operating such that they are contributing a significant amount of electricity to the total load, the mix of generators may well be different than it would be if the turbines were not present. If only a small number of wind turbines are present, then the mix of generators may not change. However, certain of the plants would be curtailed so as to produce less energy and thus consume less fuel. The emissions of pollutants from all the operating plants could be calculated and so could the projected emissions that would have resulted if the wind turbines were not present. The difference in amount of pollutants produced could then be assigned to the wind turbine as the avoided emissions.

To do such an analysis properly involves estimating the actual impact of wind turbine generation on the mix of generators and the operating level of those generators for every hour of the year. This is a non-trivial exercise, but it has been done for an offshore wind farm that was proposed for the town of Hull, MA. That project was to have included four 3.6 MW turbines, for a total capacity of 14.4 MW. The pollutants considered in the study were CO_2, NO_X, and SO_X. The results of that study are described in detail in (Rached, 2008). The results of that study are summarized in Table AA.1. The results in the table are normalized for a 1 MW (rated) wind turbine and use the medium estimated wind speed for the site. (Note under the assumptions of Rached's study, a one MW (rated) wind turbine in the medium wind speed scenario at the site would generate 2,580 MWh/yr).

Table AA.1:

Avoided emissions of pollutants for 14.4 MW wind project (based on Rached, 2008)

CO_2 (kg/MWyr)	SO_X (kg/MWyr)	NO_X (kg/MWyr)
1,970,000	3,480	1,490

A simpler but less accurate way to estimate the avoided emissions is to use the marginal rates for pollutants as specified by the Massachusetts Greenhouse Gas policy (MEPA, 2007). Applying this method Rached calculated avoided emissions per MW (rated) for the three pollutants for one year of 1,320,000 kg CO_2, 2,080 kg of SO_2, and 701 kg of NO_x.

In the analysis summarized above the majority of the avoidance of pollutant production would be due to reduced consumption of natural gas. If a larger fraction of Massachusetts' energy were to be produced by wind energy, there could be significant reductions of the consumption of fuel oil and coal as well. This should result in larger amounts of avoided pollution per unit of wind turbine production

Appendix B

Wind Turbines – Shadow Flicker

AB.1 Shadow Flicker and Flashing

Shadow flicker occurs when the moving blades of a wind turbine rotor cast moving shadows that cause a flickering effect. This flicker could annoy people living close to the turbine. Similarly, it is possible for sunlight to be reflected from gloss-surfaced turbine blades and cause a "flashing" effect. This phenomenon will occur during a limited amount of time in a year, depending on the altitude of the sun, α_S; the height of the turbine, H, the radius of the rotor, R, and the height, direction and distance to the viewing point. At any given time the maximum distance from a turbine that a flickering shadow will extend is given by:

$$x_{shadow,\max} = \left(H + R - h_{view}\right) / \tan\left(\alpha_s\right) \qquad (27)$$

Where h_{view} is the height of the viewing point.

The solar altitude depends on the latitude, the day of the year, and the time as given in the following equations (Duffie and Beckman, 2006)

$$\alpha_s = 90° - \cos^{-1}\left[\cos(\delta)\cos(\phi)\cos(\omega) + \sin(\delta)\sin(\phi)\right] \qquad (28)$$

Where δ = declination of the earth's axis, ø = latitude and ω = the hour angle

The declination is found from the following equation:

$$\delta = 23.45\sin(360(284 + n)/365) \qquad (29)$$

Where n = day of the year

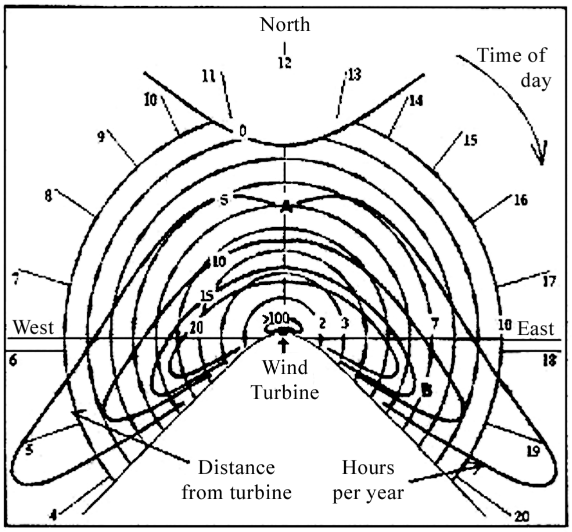
The hour angle is found from the hours from noon (solar time, negative before noon, positive after noon), divided by 15 to convert to degrees.

Another relevant angle is the solar azimuth. This indicates the angle of the sun with respect to certain reference direction (usually north) at a particular time. For example, the sun is always in the south at solar noon, so its azimuth is 180° at that time. The solar azimuth is important since it determines the angle of the wind turbine's shadow with respect to the tower. See Duffie and Beckman (2006) for details on calculating the solar azimuth.

For example, consider a location that has a latitude of 43°. Assume that the day is March 1 (day 60) and the time is 3:00 in the afternoon. Also assume that the turbine has a tower height of 80 m and a radius of 30 m and that the viewing height is 2 m. The declination is -8.3°, the solar altitude is 24.4°, and the solar azimuth is 50.2° W of S. The maximum extent of the shadow is 238 m from the turbine. The angle of the shadow is 50.2° E of N.

Sites are typically characterized by charts such the one illustrated in Figure AB.1 for a location in Denmark (EWEA, 2004). The chart gives the number of hours per year of flicker shadow as a function of direction and distance (measured in units of hub height). In the example shown, two viewing points are considered. One of them (A) is directly to the north of turbine at a distance of 6 times the hub height. The other (B) is located to the south east at a distance of 7 times the hub height. The figure shows that the first viewing point will experience shadow flicker from the turbine for 5 hours per year. The second point will experience flicker for about 12 hours per year.

Figure AB.1: Diagram of shadow flicker calculation (EWEA, 2004)



A, B are viewing points
Note that the equations above assume a clear sky and the absence of rain, clouds, etc.

AB.2 Mitigation Possibilities

Most modern wind turbines allow for real-time control of turbine operation by computer in order to shut down during high shadow flicker times, if necessary. In addition, computer programs can allow for pre-planning of siting location ahead of time to know what a project specific impact will be in terms of shadow flicker when planning a wind turbine project (as discussed in the previous paragraph). This planning can be site-specific in order to avoid potential problems with specific sites based on geographical location or weather patterns.

In terms of safe distances to reduce shadow flicker, these are often project-specific because it depends on whether there are residences or roadways present and what the geographic layout is. This could be particularly important in areas with more forestry and existing shadow, which could reduce nuisance from turbine produced shadow flicker or whether it is an otherwise open land area such as farmland that would be more susceptible to the annoyance of shadow flicker. A general estimate for modeling a shadow flicker risk zone includes 10 times the rotor diameter such that a 90-meter diameter would be equivalent to a 900-meter impact area. However, only certain portions of this zone are actually likely to experience shadow flicker for a significant amount of time. Other modeling considerations include when at least 20% of the sun is covered by the blade and whether to include the blade width in estimates as well. In terms of distance, 2,000 meters is the WindPro computer program default distance (NEWEEP, 2011) for calculations of wind turbine produced shadow flicker. Finally, due to atmospheric effects, 1400 m is the maximum distance from a turbine within which shadow flicker is likely to be significant.

In terms of existing regulations regarding shadow flicker rates, there are no current shadow flicker regulations in Massachusetts (or many other New England states, but there are statewide and local guidelines that have been implemented. These guidelines were provided by the Department of Energy Resources in March 2009 and state that, "wind turbines shall be sited in a manner that minimizes shadowing or flicker impacts" and, "the applicant has the burden of proving that this effect does not have significant adverse impact on neighboring or adjacent uses." Local Massachusetts regulations include the Worcester, MA zoning ordinance, which requires, "The facility owner and operator shall make reasonable efforts to minimize shadow flicker to any occupied building on a non-participating landowner's property." Also, a shadow flicker assessment report is required as is a plan showing the "area of estimated wind turbine shadow flicker." Similarly, the Newburyport, MA regulations require that wind turbines do not result in significant shadow or flicker impacts and an analysis is required for planned projects (NEWEEP, 2011).

The Maine model wind energy facility ordinance states that wind turbines should, "avoid unreasonable adverse shadow flicker effect at any occupied building located on a non-participating landowner's property." They do not state any specific limit to shadow flicker other than these guidelines. However, the New Hampshire Model Small Wind Energy Systems Ordinance states that wind turbines, "shall be sited in a manner that does not result in significant shadow flicker impacts…significant shadow flicker is defined as more than 30 hours per year on abutting occupied buildings." Similar to Maine, several states in the US have adopted the German model of 30 hours per year of allowed shadow flicker that was primarily based on the government-sponsored study summarized above. However, other states or localities including Hutchinson, Minnesota have enacted stricter guidelines including no shadow flicker to be allowed at an existing residential structure, and up to 30 hours per year of shadow flicker allowed on roadways or residentially zoned properties and a computer analysis is required for project approval (NEWEEP, 2011).

In addition, computer programs such as WindPro are also recommended by most states and localities for use in all new planned installations to reduce this potential nuisance of shadow flicker on residential properties or potential health hazards to drivers on busy highways or roadways.

Appendix C

Wind Turbines – Ice Throw

AC.1 Ice Falling or Thrown from Wind Turbines

Under certain weather conditions ice may form on the surface of wind turbine blades. Normally, wind turbines intended for use in locations where ice may form are designed to shut down when there is a significant amount of ice on the blades. The means to prevent operation when ice is present may include ice sensor and vibration sensors. Ice sensors are used on most wind turbines in cold climates. Vibration sensors are used on nearly all wind turbines. They would cause the turbine to shut down, for example, if ice buildup on the blades resulted in an imbalance of the rotor and hence detectable vibrations in the structure.

Ice built up on blades normally falls off while the turbine is stationary. If that occurs during high winds, the ice could be blown by the wind some distance from the tower. In addition, it is conceivable that ice could be thrown from a moving wind turbine blade under some circumstances, although that would most likely occur only during startup (while the rotational speed is still relatively low) or as a result of the failure of the control system. It is therefore worth considering what the maximum plausible distance that a piece of ice could land from the turbine under two "worst case" circumstances: 1) ice falls from a stopped turbine during very high winds, and 2) ice is suddenly released from a blade when the rotor is rotating at its normal operating speed.

In both cases, the distance that the ice may travel is governed by Newton's laws and the principles of fluid mechanics. Calculations are quite simple when the effect of the air (and the wind) is ignored. For example, in that case if a piece of ice falls from a turbine, it will land directly below where it is released. The situation is a little more complex, but still readily solvable if the piece of ice is moving when it is released. For example, suppose that the ice is initially on the tip of a blade, and the blade is pointing vertically upward. Once the ice is released it will continue moving horizontally at the speed it had when it was still attached to the blade. But it will also begin to fall towards the ground, so the piece of ice will have two components of velocity until the ice hits the ground. The time t_g (s) it takes for the ice to reach the ground (assuming a horizontal surface) is $t_g = \sqrt{2h/g}$ where h = height (m) at which the ice is released and g = acceleration of gravity (9.81 m/s^2). The distance x (m) that the ice would travel is $x = t_g \Omega R$ where Ω is the rotational speed of the rotor (rad/s) and R is the length of the blade (m).

Such an analysis is overly simplified, however. It would underestimate the distance that the ice would travel if it fell from a stationary turbine in a high wind, and it would overestimate the distance that the ice would travel if it were suddenly released from a moving blade. It is necessary to consider the effect of the air and the force that it will impart upon the falling ice. For motion in the vertical (z) direction the equation of motion is the following:

$$F_z = ma_z \tag{30}$$

where F_z is the net force (N), m is the mass (kg), and a_z is the acceleration (m/s^2). The force includes two main components. One is the weight, W (N). It is due to gravity and acts in the negative z direction. The other one is due to the drag of the air and it acts opposite to the direction of the velocity. It is found from:

$$F_D = \frac{1}{2} C_D \rho A V_z^2 \tag{31}$$

where ρ is the density of air (1.225 kg/m^2 under standard conditions), A is the projected area (m^2) of the piece of ice, C_D is the drag coefficient of the ice and V_z is the velocity of the ice (m/s) in the z direction.

Acceleration is the derivative of the velocity, so we can rewrite the equation of motion for the vertical direction as follows:

$$\frac{dV_z}{dt} = \left(-W - sign(V_z) \frac{1}{2} C_D \rho A V_z^2 \right) / m \tag{32}$$

Where *sign* (…) indicates the direction of motion along the z axis. For the general case, the piece of ice may leave the blade with initial speed ΩR at an arbitrary angle θ with respect to the horizontal. Accordingly, there will be two components of the velocity, one in the z direction (as before) V_z, the other in the x direction, V_x. This assumes that the x axis is horizontal, is also in the plane of the rotor, and is positive in the direction of the tip of the blade at its apogee.

These velocities are initially:

$$V_{z,0} = \Omega R \sin(\theta) \tag{33}$$

$$V_{x,0} = \Omega R \cos(\theta) \tag{34}$$

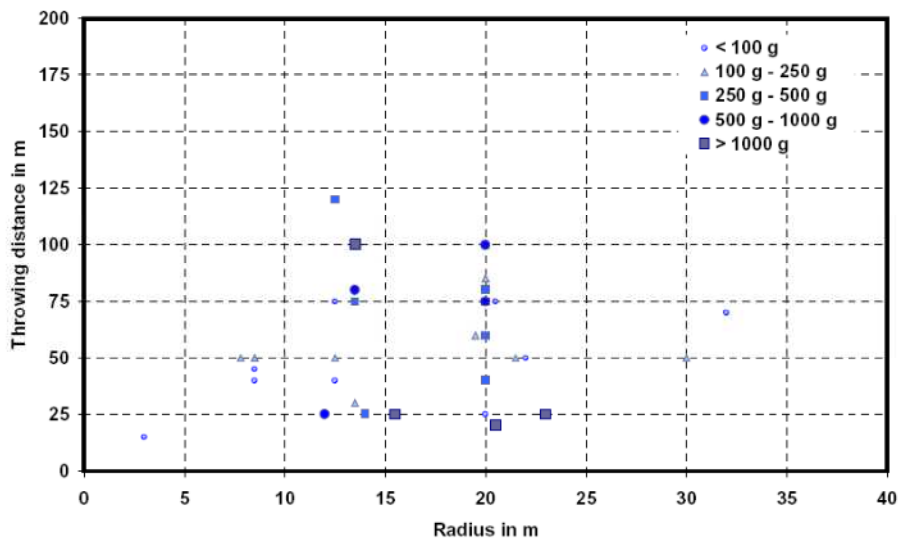
The equation of motion for the *x* direction is:

$$\frac{dV_x}{dt} = \left(-sign(V_z)\frac{1}{2}C_D \rho A V_x^2\right)/m \tag{35}$$

The above equations are a bit difficult to solve analytically, but they can be solved numerically fairly easily. Similar equations may also be developed for the case of a particle of ice falling from a stationary turbine.

Some data from actual ice throw has been compiled by Seifert et al. (2003). Figure AC.1, taken from that report is shown below.

Figure AC.1: Observed throwing distance of ice (from Seifert et al., 2003)



As may be seen in the figure, the maximum distance that ice was observed to fall from a turbine with a diameter of 20 m during operation was approximately 100 m. Based on the observed data, Seifert et al. suggest the following simplified formula for the maximum throwing distance:

$$x_{\max,throw} = 1.5\left(2R + H\right) \tag{36}$$

Where $x_{max,throw}$ = maximum throwing distance (m), R = rotor diameter (m) and H = hub height (m).

By way of illustration, Equation 36 was used to predict the maximum throwing distance of a piece of ice from a turbine with a rotor radius of 20 m installed on a tower 50 m high. That distance was 135 m. The theoretical equations given previously were also used to calculate throwing distance. The following assumptions were made: spherically shaped piece of ice, drag coefficient of 1.2, air density of 1.225 kg/m^3, ice density of 700 kg/m^3, rotor speed of 40 rpm (corresponding to a tip speed ratio of 7 at a wind speed of 12 m/s), angle of release of 45°, and instantaneous release of the ice. The equations predict a maximum throwing distance of 226 m or somewhat less than twice that predicted from the empirical equation. The difference is deemed to be reasonable, especially considering the idealized shape of the particle. Real pieces of ice would actually be highly non-spherical in shape and experience considerably more drag. It may also be noted that it was reported in Cattin et al. (2007) that ice did not fall as far from a wind turbine in the Swiss Alps as would be predicted from Equation 36. In that case the maximum observed distance from a turbine with radius of 20 m and a tower height of 50 m was 92 m. As noted above, Equation 36 predicts 135 m.

Seifert et al. also considered data regarding ice thrown from stationary turbines. Based on the available data they proposed a simple equation for predicted ice fall. That equation is

$$x_{\max,\,fall} = U\left(R + H\right)/15 \tag{37}$$

Where U = wind speed at hub height in m/s, $x_{max,fall}$ = maximum falling distance (m), R = rotor radius (m), H = hub height (m).

Using Equation 37, the predicted maximum distance for a turbine with a radius of 20 m, a tower height of 50 m, and a wind speed of 20 m/s is 120 m. By way of comparison, the fall distance was predicted from the theoretical equations given above for the same situation. The results are highly dependent on the size of the piece of ice and hence the surface to volume ratio. To take one example, a piece of ice that was assumed to be spherical and to have a weight of 10 g would land 110 m from the tower. In the examples discussed by Seifert et al., all the pieces of ice landed less than 100 m from the tower.

AC.2 Summary of Ice Throw Discussion

As noted above, there are two plausible scenarios in which ice may fall from a wind turbine and may land at some distance from the tower. In the first scenario, ice that falls from a stationary turbine is blown some distance from the tower. In the second scenario, ice is thrown from the blade of an operating turbine during a failure of the control system. In the first case, ice may land 100 m or more from the tower in high winds, depending on the wind speed, the height from which the ice falls, and the dimensions of the ice. In the second case, the ice could land even further from the turbine. Just how far would depend on the actual speed of the rotor when the ice was shed, the height of the tower, the length of the blade, the angular position of the blade when the ice was released, and the size and shape of the ice. In general, it appears that ice is unlikely to land farther from the turbine than its maximum vertical extent (tower height plus the radius.)

Appendix D

Wind Turbine – Noise Introduction

Noise is defined simply as unwanted sound. Sound is defined as the sensation produced by stimulation of the organs of hearing by vibrations transmitted through the air or other medium. In air, the transmission is due to a repeating cycle of compressed and expanded air. The frequency of the sound is the number of times per second, Hertz (Hz), that the cycle repeats. Sound at a single frequency is called a tone while sound that is a combination of many frequencies is called broadband.

The human ear is capable of responding over a frequency range from approximately 20 Hz to 20 kHz (Hz: Hertz = 1 cycle/second; Middle C on a piano is a frequency of 262 Hz).

AD.1 Sound Pressure Level

Sound is characterized by both its frequency and its amplitude. Sound pressure is measured in micro Pascals (μPa). Because sound pressure can vary over a wide range of magnitudes a logarithmic scale is used to convert micro Pascals to decibels. Thus sound pressure level (SPL) is defined by $SPL = 10 \log_{10} [p^2/p^2_{ref}] = 20 \log_{10}(p/p_{ref})$ with the resulting number having the units of decibels (dB). The reference pressure p_{ref} for airborne sound is 20×10^{-6} Pa (i.e., 20μPa or 20 micro Pascals). This means that SPL of 0 dB corresponds to a sound wave with amplitude 20μPa. 140 dB is considered the threshold of pain and corresponds to 20,000,000 μPa. Doubling the amplitude of the sound wave increases the SPL by 6 dB.

Therefore, a 40μPa amplitude sound wave would have an SPL of about 6 dB.

When it is stated that there is a large frequency range over which humans can hear, it is also noted that the ear does not hear each frequency similarly. In fact, there is a frequency-dependent threshold of hearing (lower limit) and threshold of pain (higher limit). Experiments have been performed to determine these thresholds. The threshold of hearing curves show that one can hear a tone at 3 kHz (3000 Hz) with an SPL < 0 dB while at 100 Hz one does not hear the tone until its SPL is about 30 dB. Curves showing the thresholds can be easily found in textbooks and online (one online example is at

http://www.santafevisions.com/csf/html/lectures/007_hearing_II.htm). Experiments have also been conducted to determine equal loudness level contours. These contours indicate when two tones of dissimilar frequencies appear to be equally loud.

Some characteristics of human response to sound include:

- Changes in sound level <1 dB cannot be perceived
- Doubling the magnitude of the acoustic pressure leads to a 6 dB increase in SPL
- A 5 dB SPL change will result in a noticeable community response
- A 10 dB SPL change is subjectively heard as an approximate doubling in loudness

AD.2 Frequency Bands

Most sounds in our environment contain multiple frequencies and are variable in that successive identical experiments cannot result in the exact same plot or tabulation of pressure vs. time. Therefore, it is common to use averages that measure approximately the amplitude of the sound and its frequency content. Common averaging methods rely on the principle of octaves, such as 1/10, 1/3, and single octave bands. This means that the entire frequency range is broken into chunks such that the relation between the starting and ending frequencies of each chunk, f_1 and f_2 respectfully, are related by $f_2 = 2^{1/N}f_1$ where N = 1 for a single octave band and 3 for a 1/3 octave band. Because the bands can be constructed based on any starting frequency, a standardized set of bands have been specified. They are usually described by the center frequency of each band. The standard octave-bands are given in Table AD.1 (measured in Hz):

Table AD.1:

Octave bands. Values given in Hz.

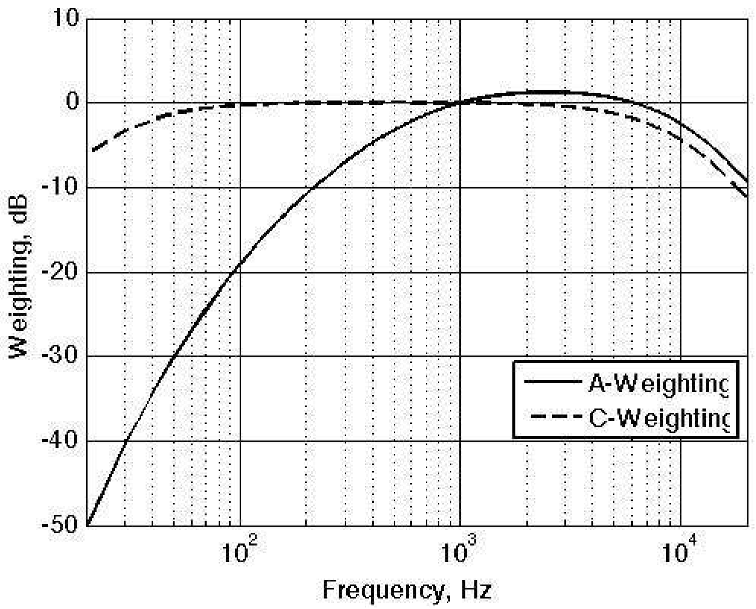
Center Frequency	Lower Band limit	Upper Band Limit
16	11	22
31.5	22	44
63	44	88
125	88	177
250	177	355
500	355	710
1000	710	1420
2000	1420	2840
4000	2840	5680
8000	5680	11360
16000	11360	22720

A similar set of bands can be written for the 1/3 octaves. For each octave band there are 3-1/3 octave bands. Many text and online resources specify the 1/3 octave bands such as (http://www.engineeringtoolbox.com/octave-bands-frequency-limits-d_1602.html). The 1/10 octave band is a narrow-band filter and is used when the sound contains important tones.

AD.3 Weightings

Noise data are often presented as 1/3 octave band measurements. Again, this means that the sound in each frequency band has been averaged over that frequency range. Noise levels are also often reported as weighted values. The most common weighting is A weighting. It was originally intended to be such that sounds of different frequencies giving the same decibel reading with A weighting would be equally loud. The weighting of the octave band centered at 31.5 Hz requires one to subtract 39.4 dB from the actual SPL. The octave bands with centers from 1000 to 8000 where human hearing is most sensitive are corrected by only about +/- 1 dB. When considered together with the threshold of hearing, it is clear that the A-weighting is most applicable for sounds of small amplitude. C-weighting on the other hand subtracts only a few dB from the very highest and very lowest frequency bands. It is therefore more applicable for higher levels of sound. The figure below shows these two weightings. When weighted, the sound pressure level is reported as dBA or dBC respectively.

Figure AD.1: Weighting values for reporting sound pressure levels



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Noise levels change several times per day. To account for these differences other environmental noise measures are often used as shown in Table AD1.

Table AD 2:

A set of visual examples for these measures can be found at (*http://www.epd.gov.hk/epd/noise_education/web/ENG_EPD_HTML/m2/types_3.html*)

Indicator	**Meaning**
L_{max}	The maximum A-weighted sound level measured
L_{10}, L_{50}, L_{90}	The A-weighted sound level that is exceeded n%, of the time, where n is 10, 50, and 90 respectively. During the measurement period L_{90} is generally taken as the background sound level.
L_{eq}	Equivalent sound level. The average A-weighted sound pressure level, which gives the same total energy as the varying sound level during the measurement period of time.
Ldn	Day-night level. The average A-weighted sound level during a 24-hour day after addition of 10 dB to levels measured in the night between 10 p.m. and 7 a.m.

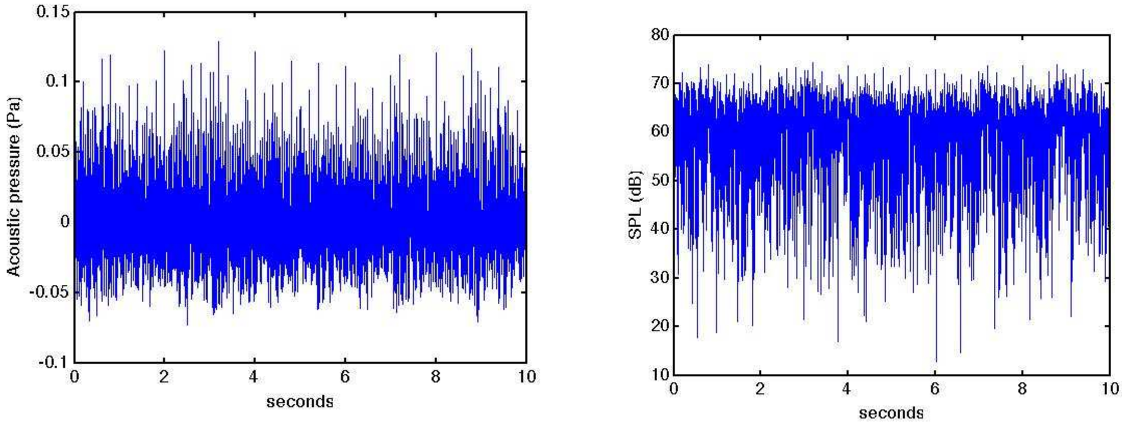
AD.4 Sound Power

Sound intensity and sound power are also often reported. Sound intensity is a measure of the energy transported per unit area and time in a certain direction. It can be shown that the intensity (I) perpendicular to the direction of sound propagation is related to the amplitude of the pressure wave squared, the density of the air (ρ), and the speed of sound (c), $I \sim p^2/\rho c$. The sound power, P, is the total intensity passing through a surface around a sound source. Intensity has units of Watts per square meter (W/m^2) and Power is measured in Watts (W). Both of these quantities are normally reported in dB where the intensity level is calculated as $L_I = 10 \log_{10} (|I|/I_{ref})$ and the power level is calculated as $L_W = 10 \log_{10}(P/P_{ref})$. The reference intensity level is related to the threshold of hearing at 1000 Hz such that $I_{ref} = 10^{-12}$ W/m^2. The reference power value is $P_{ref} = 10^{-12}$ W (1 picowatt). Here a doubling of the power leads to a 3 dB increase in the sound power level (PWL).

AD.5 Example Data Analysis

This is an example of the type of analysis done on sound measurements from a wind turbine. First, the actual signal might look something like what is shown in Figure AD.2.

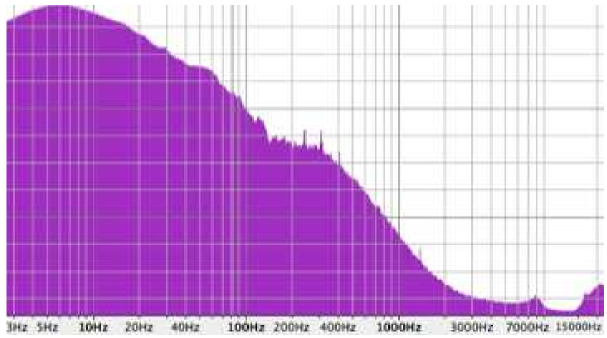
Figure AD.2: Pressure signal from a wind turbine



. *(From(van den Berg, 2011), related to Rheine wind turbine farm). Left in Pascals, right as SPL in dB.*

In Figure AD.2, just the acoustic pressure is shown, which means that atmospheric pressure, which is about 103,000 Pa, has been subtracted and the fluctuations then appear around 0 Pa. These data can easily be presented as SPL by transforming the pressure from Pa to dB. In order to analyze the pressure signal for low frequency content, a much longer time signal must be obtained. The frequency content of a long time signal is analyzed by performing a Fourier Transform. A typical transform of data from a wind turbine is shown in Figure AD.3.

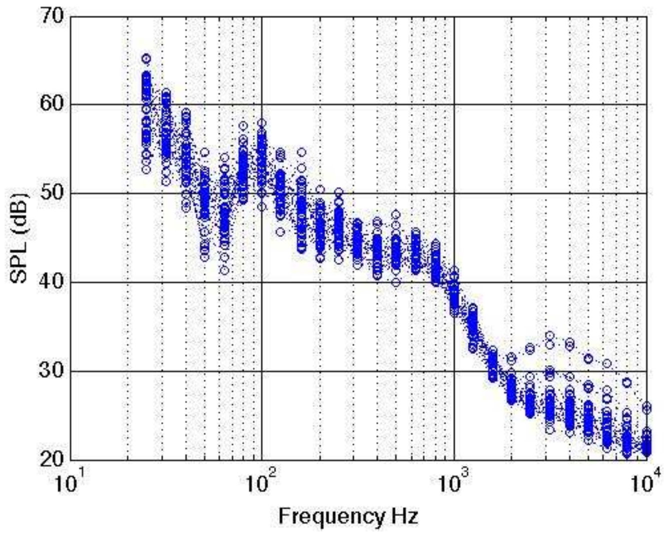
Figure AD.3: Frequency content of typical wind turbine measurement. (from Palmer ASA paper.)



(This figure does not correspond to the Rheine data for which the writer is not able to produce the full frequency domain plot.)

In order to better assess the broadband nature of wind turbine sound, the results are presented in 1/3-octave band form. The averages that are taken in each 1/3-octave band can be done on fast or slow time intervals. For instance, the data in Figure 3 could be averaged on 1/3-octave bands to come up with the overall SPL in the bands. Or, as a measurement is being taken, the instrumentation can provide 1/3-octave band averages on short time scales. For the Rheine data a fast average on 0.05 seconds was recorded. A few of the 1/3-octave band results are shown in Figure AD.4.

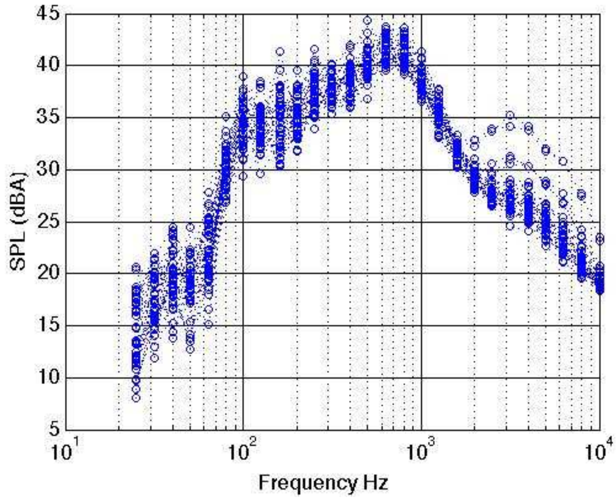
Figure AD.4: Fast averages for 1/3-octave band analysis.



Shown results for 0–0.05, 5–0.05, 10–10.05, …, 200–200.05 seconds.

From these a final overall spectrum emerges.   If these were presented as A-weighted spectrum, then Figure AD.5 is what is presented.

Figure AD.5: Fast averages for 1/3-octave band A-weighted analysis.



Shown results for 0–0.05, 5–0.05, 10–10.05, …, 200–200.05 seconds.

AD.6 Wind Turbine Noise from Some Turbines

What is known about aerodynamically generated noise from wind turbines is that it nominally increases with increasing wind speed until the max power is obtained, and it increases with increasing rotor tip speed. A report out of the Netherlands by (van den Berg et al., 2008) reports a vast amount of noise data related to wind turbines. The tables in Appendices B and C from the report clearly show these trends. Some of the data are reproduced here. Only measurements that were made by third parties (not specified by the wind turbine company) are reproduced here.

Table AD.3:

Sound power level in dB(A) from various wind turbines. (van den Berg et al., 2008).

Manufacturer **Make and model**	**Power** **kW**	**Hub Height** **m**	**Diameter** **m**	**rpm**	**4 m/s**	**5m/s**	**7m/s**	**8m/s**	**10m/s**
Enron TW1.5s	1500	80	70	11	100	100	100	100	
Enron TW1.5s	1500	81	70	22		102	102	103	104
NegMicon NM52	900	70	52	15	93	93			
NegMicon NM52	900	70	52	22		98	100	101	103
NegMicon NM54	950	46	54	15		95.6			
NegMicon NM54	950	46	54	22		101.6			
Vesta V66	1650	70	66	15	97	97	98	98	
Vesta V66	1650	70	66	19		101	101	102	102

It must be noted here that what has been reported are the sound power levels, which represents the total sound energy that propagates away from the wind turbine (i.e., the sound energy at the center of the blades, which propagates outward at the height of the hub). The sound level measured at a single position at the base of the turbine can easily be 50 dB lower (Lawrence rep.).

AD.7 Definition of Infrasound

Discussion of the aerodynamic source of sound known as thickness noise or self-noise requires one to define low frequency sound and infrasound. By definition, infrasound is a pressure wave that is not audible. Nominally this means waves with frequency less than 20 Hz. It is noted though that waves with high enough amplitude below 20 Hz may still be audible. Low frequency sound is characterized as having a frequency between 20 and 200 Hz. As mentioned earlier, some mechanical noise sources contribute to the low frequency range, and clearly some of the aerodynamic sources of broadband sound will contribute to noise in the low frequency range. Thickness noise, if present, would have an associated frequency equal to the blade passing frequency. Hence, a turbine with 3-bladed rotor turning at 20 rpm might generate thickness noise at a frequency of 1 Hz, which is clearly in the infrasonic range. Downwind rotors produce slightly stronger infrasound at the blade passing frequency because the blades interact directly with the wake behind the tower. The levels of the thickness noise generated by modern upwind turbines are not perceptible by the human auditory system. Any impulsive noise that is audible, which seems to have a frequency equivalent to the blade passing frequency, is actually the broadband noise generated by the other mechanisms being modified by differences in the flow that occur on a once-per-rev basis as discussed above. The frequencies of this pulsating sound are all in the audible range, and thus this sound is not infrasound.

Appendix E

Wind Turbine – Sound Power Level Estimates and Noise Propagation

AE.1 Approximate Wind Turbine Sound Power Level Prediction Models

The following are some approximate equations that are sometimes used to estimate the A-weighted sound power level, L_{WA}, from a typical wind turbine. The first equation gives the estimate in terms of the rated power of the turbine, P_{WT} (W). The second gives the estimate in terms of the diameter, D (m). The third gives it in terms of both the tip speed, V_{Tip} (m/s), and diameter. These equations should only be used when test data is not available.

$$L_{WA} = 10(\log_{10} P_{WT}) + 50 \tag{38}$$

$$L_{WA} = 22(\log_{10} D) + 72 \tag{39}$$

$$L_{WA} = 50(\log_{10} V_{Tip}) + 10(\log_{10} D) - 4 \tag{40}$$

AE.2 Sound Power Levels due to Multiple Wind Turbines

When multiple wind turbines are located close to each other, the total sound power can be estimated by applying logarithmic relations. For example, for two turbines with sound power levels L_{W1} and L_{W2}, the total sound power is:

$$L_{total} = 10 \log_{10} (10^{L_1/10} + 10^{L_2/10}) \tag{41}$$

For N turbines, the corresponding relation is:

$$L_{total} = 10 \log_{10} \sum_{i=1}^{N} 10^{L_i/10} \tag{42}$$

where L_{wi} is the sound power level of the i^{th} turbine. For turbines that are some distance away from each other the mathematics is more complicated, and the relations of interest (actually the sound pressure level) take into account the relative position of the turbines and the location of the observer as described below.

AE.3 Noise Propagation from Wind Turbines

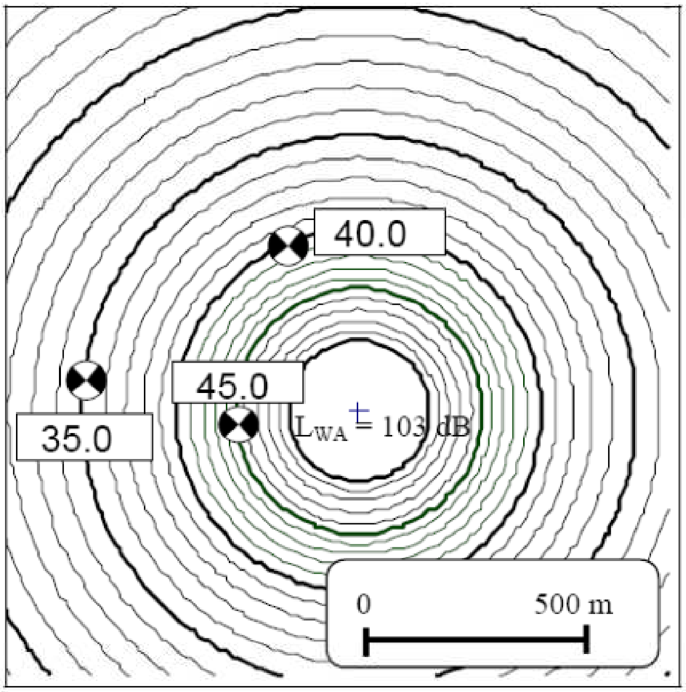
The sound pressure level will decrease with distance from a turbine. For estimation purposes, a simple model based on hemispherical noise propagation over a reflective surface, including air absorption, is given as:

$$L_p = L_W - 10\log_{10}(2\pi R^2) - \alpha R \quad (43)$$

where L_p is the sound pressure level (dB) a distance R from a noise source radiating at a power level L_W (dB) and α is the frequency-dependent sound absorption coefficient. For broadband estimates the absorption coefficient is often approximated by a constant value of 0.005 dB(A)/m.

Figure AE.1 (from Materialien 63) indicates the sound pressure level as a function of distance from a single wind turbine with a sound power level of 103 dB(A).

Figure AE.1: Typical sound pressure level vs. distance from a single wind turbine (From Materialien 63)



The results are summarized in Table AE-1.

Table AE-1

Sound pressure level vs. distance

Sound Pressure, dB(A)	Distance, m
45	280
40	410
35	620

It may be seen that Equation 43, using the broadband absorption coefficient, predicts results close to those in the table (270 m, 435 m, and 675 m respectively).

AE.4 Noise Propagation from Multiple Wind Turbines

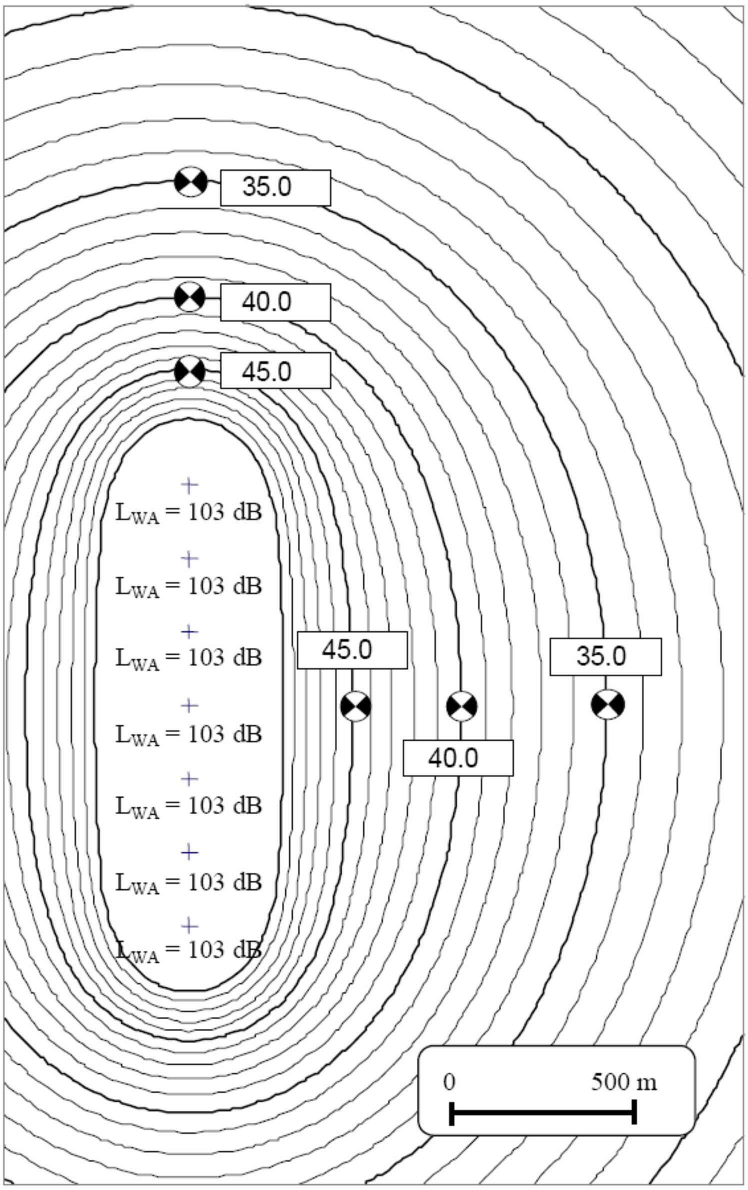
The sound perceived at a distance from multiple wind turbines is a function of the sound power level from each wind turbine and the distance to that turbine. The perceived value can be approximated by the following equation:

$$L_p = 10\log_{10}\left[\sum_{i=1}^{N} \frac{10^{\left(L_{W,i}/10 - \alpha R_i/10\right)}}{2\pi R_i^2}\right] \qquad (44)$$

Where R_i is the distance to the ith turbine.

Figure AE-2 illustrates the sound pressure level at various distances and directions from a line of seven wind turbines, each of which is operating at a sound power level of 103 dB(A).

Figure AE.2: Sound pressure level due to a line of seven wind turbines, each operating at a sound power level of 103 dB(A) (from Materialien 63



The results are summarized in the Table AE-2.

Table AE 2:

The distances shown are in the direction perpendicular to the line of the turbines

Sound Pressure, dB(A)	Distance
45	440
40	740
35	1100

.

Appendix F

Wind Turbine – Stall vs. Pitch Control Noise Issues

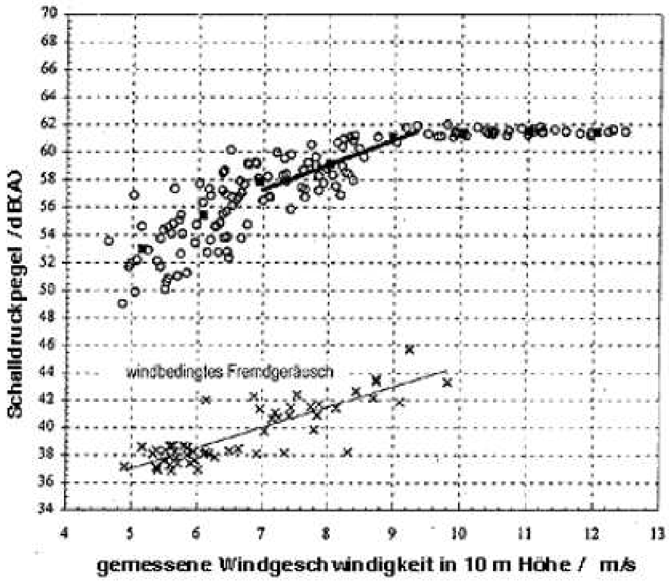
As noted in Appendix A, pitch regulated turbines are quieter than those with stall control. This is particularly the case at higher wind speeds. This appendix illustrates the difference, based on one source.

AF.1 Typical Noise from Pitch Regulated Wind Turbine

The figure below illustrates sound pressure level as a function of wind speed from a pitch regulated wind turbine (The data was taken at an unspecified distance from the turbine).

As can be seen, the noise level increases with wind speed up to a certain wind speed, here 9 m/s. After that wind speed is reached the blade pitch regulates the power and the noise level remains constant.

Figure AF.1: Sound pressure vs. wind speed from a pitch regulated wind turbine (from Materialien 63)



y-axis: sound pressure level, dB(A)

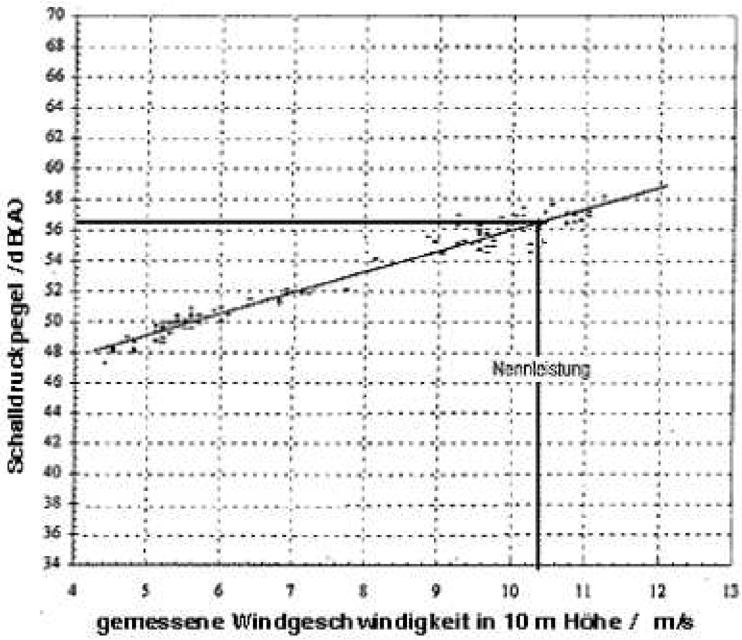
x- axis measured wind speed at 10 m height, m/s

lower line: wind-induced background noise

AF.2 Noise from a Stall Regulated Wind Turbine

The figure below illustrates sound pressure level as a function of wind speed from a stall controlled wind turbine (The data was taken at an unspecified distance from the turbine).

Figure AF.2: from Materialien 63



y-axis: sound pressure level, dB(A)

x- axis measured wind speed at 10 m height, m/s

The rated wind speed of this turbine is 10.4 m/s

As can be seen, the noise level increases approximately linearly with wind speed and does not level off.

Appendix G

Summary of Lab Animal Infrasound and Low Frequency Noise (IFLN) Studies

Table AG.1

Summary of Lab Animal Infrasound and Low Frequency Noise (IFLN) Studies

Study #	Animal Model	Endpoint	"Dose"	Timing	Measured Effects	Notes	Citation
1	Male Sprague-Dawley rats; 32 rat, 10 wks	Cardiac: ultrastructure observations, Ca2+, SERCA2 expression	5 Hz at 130 dB	2 hrs - 1 day	inc in [Ca2+]*l*; sig inc. SERCA2	No noted observation of frank toxicity. Responses increased across groups; heart rates increased in 1 day group, not in others; left ventricular pressures increased with dose chamber; Animal dose is at or slightly below 5 Hz/130 dB; Pentobarb anesthesia	Pei et al., 2007
			5 Hz at 130 dB	2 hrs - 7 days	inc in [Ca2+]*l*; Sig decr. In SERCA2 compared with control & 1 day		
			5 Hz at 130 dB	2 hrs - 14 days	inc in [Ca2+]*l*; Sig decin SERCA2 compared with control and 7 day group		
2	Male Adult Sprague-Dawley rats	Cardiac: whole-cell L-type Ca2+ currents (WLCC) in rat ventricular myocytes	5 Hz at 130 dB	2 hrs - 1 day; examined 1, 7 or 14 days post-exposure	Inc in [Ca2+](I) levels, LCC & SERCA2	No noted observation of frank toxicity. [Ca2+](I) levels as well as expression of LCC and SERCA2 may contribute to the infrasound exposure-elicited cardiac response; cannot concur with micrograph data	Pei et al., 2009
3	Male Sprague-Dawley rats	Neuronal release of stress-induced hormones	16 Hz at 130 dB	2 hrs - single exposure	activation of microglial cells and upregulation of Corticotrophin releasing hormone receptor (CRH R1); also upregulation expression is blocked by antalarmin	No noted observation of frank toxicity. .Measured in the hypothalamic paraventricular neurons. Antalarmin is a non-peptide drug that blocks the CRF-1 receptor, and, as a consequence, reduces the release of ACTH in response to chronic stress	Du et al., 2010
4	Male Sprague-Dawley rats	Neurogenesis	16 Hz at 130 dB	2 hrs/day - 7 days (sacrificed at 3, 6, 10, 14 & 18 days post-exposure)	Measured early migration and differentiation in newly generated progenitor cells by examining BUdR uptake in cells in the hippocampus (dentate gyrus)	No noted observation of frank toxicity. Authors conclude infrasound inhibits cell proliferation and that effects on proliferation appear to be reversible in the 18 days post exposure groupbackground - 40 dB; authors report reversibility, but the data don't support this - also, comparisons are with the "normal" group (in chamber, but no infrasound) but no comparison with control.	Liu et al., 2010
5	Male Albino Wistar Rats	Neural: Behavioral Performance - vestibular function	16 Hz at 72-105 dB		Rota-rod Treadmill evaluation	No noted observation of frank toxicity. Rats selected for superior performance were unaffected, but inferior rats were less able to perform for as long at same exposures.	Yamamura & Kishi, 1980
6	Male Wistar rats	Neurological - biochemical	2 Hz at 105 dB	1 hr & then sac'd	Measured brain neurepinephrine levels	No noted observation of frank toxicity. No control to determine whether Norepi levels were due to experimental design - not well controlled.	Spyraki et al., 1978
			7 Hz at 122 dB	1 hr & then sac'd	Measured brain neurepinephrine levels		
			26 Hz at 124 dB	1 hr & then sac'd	Measured brain neurepinephrine levels		
7	Female rats - no strain given	Neural	2 Hz at 105 dB 7 Hz at 122 dB 16 Hz at 124 dB		Observations made about rats' activity	Decreased time to sleep and decreased activity. Chamber and set-up is somewhat archaic and confirmatory measures are not made.	Spyraki et al., 1978
8	adult male Sprague-Dawley rats	Neural: hippocampus - dependent spatial learning and memory	16 Hz at 130 dB	14 days	Observations made using Morris water maze, measured expression and protein levels of brain-derived neurotrophic factor-tyrosine kinase receptor B.	No noted observation of frank toxicity. Calibration of sound chamber not discussed.	Yuan et al., 2009

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Assessing Sound Emissions from Proposed Wind Farms & Measuring the Performance of Completed Projects

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The National Association of Regulatory Utility Commissioners

A report for the Minnesota PUC
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BEST PRACTICES GUIDELINES FOR

ASSESSING SOUND EMISSIONS FROM PROPOSED WIND FARMS
and
MEASURING THE PERFORMANCE OF COMPLETED PROJECTS

October 13, 2011

Prepared for:

The Minnesota Public Utilities Commission

Under the auspices of the National Association of Regulatory Utility Commissioners (NARUC), Washington, DC.

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1.0 Introduction

The noise produced by wind turbines differs fundamentally from the noise emitted by other power generation facilities in terms of how it is created, how it propagates, how it is perceived by neighbors and how it needs to be measured. Essentially everything about it is unique and specialized techniques need to be employed in order to rationally assess potential impacts from proposed projects and to accurately measure the sound emissions from newly operational projects.

Existing ISO[1,2], and ANSI[3,4] standards that are perfectly appropriate for evaluating and measuring noise from conventional power generation and industrial facilities were not written with wind turbines in mind and contain certain provisions that make them unsuitable for application to wind turbines. For example, most test standards, quite sensibly, allow valid measurements only under low wind or calm conditions in order to preclude, or at least minimize, wind-induced directional effects, among other things. At a conventional power plant, which may operate around the clock, this requirement simply implies a wait for appropriate weather conditions. At a wind turbine project, however, there is nothing to measure during calm wind conditions, since the project is normally idle. Significant noise generation largely occurs during wind conditions that are generally above the permissible limit. At the present time, a lone standard, IEC 61400-11[5] exists for evaluating wind turbine sound levels, but only for the specific purpose of measuring the sound power level of a single unit. Sound power level is an arcane, intangible, derived quantity that is used as an input to analytical noise models and has little relevance to the sound level a wind farm is producing at someone's home. Consequently, this highly specialized test cannot be used or even adapted to serve as a way of determining whether a new multi-unit project is in compliance with a noise ordinance, for instance.

What all this suggests is that the standards and methodologies that exist for assessing and measuring noise from conventional industrial noise sources cannot be applied wholesale to wind turbine noise and completely different assessment and field measurement methodologies are required that are tailored to, and take into account, the unique circumstances and technical challenges surrounding their noise emissions. These guidelines seek to address this situation by describing suggested assessment and measurement techniques that have been developed over the past decade through field experience on roughly 70 wind projects, primarily in the Midwest and Eastern United States, nearly all of which were located in rural, yet moderately populated areas. Without question many mistakes were made in the early going into this uncharted field of study and many naïve assumptions about wind turbine noise were found to be incorrect. It is hoped that what was learned from this experience and what is summarized in these guidelines can help others circumvent this learning curve.

After a brief discussion on the nature of wind turbine noise, the following principal topics are discussed:

- Suggested design goals for new projects
- Evaluating potential noise impacts from proposed projects through noise modeling and field surveys of existing conditions
- Measuring the noise emissions from operational projects to determine compliance with design goals or regulatory limits

1.1 Executive Summary

Wind turbine noise differs fundamentally from the noise produced by other power generation and industrial sources in how it is produced, how it propagates and how it is perceived by neighbors. Because existing sound measurement standards were never written with wind turbines in mind they are largely unsuitable for use in wind turbine analyses, if only because measurements both prior to and after construction essentially must be performed in the windy conditions necessary for the project to operate – conditions that are prohibited by virtually all current test standards. Consequently, new and unique evaluation and measurement techniques must be used that are adapted to the special circumstances germane to wind turbines. These guidelines are intended to help remedy this situation by suggesting design goals for proposed project, outlining a methodology for evaluating potential impacts from new projects and describing how to accurately measure the noise emissions from operating projects.

Studies and field surveys of the reaction to operating wind projects both in Europe and the United States generally suggest that the threshold between what it is normally regarded as acceptable noise from a project and what is unacceptable to some is a project sound level that falls in a gray area ranging from about 35 to 45 dBA. Below that range the project is so quiet in absolute terms that almost no adverse reaction is usually observed and when the mean project sound level exceeds 45 dBA a certain number of complaints are almost inevitable. In view of this, it would be easy to avoid any negative impact by simply limiting the sound level from a proposed wind project to 35 dBA at all residences, but the reality is that such a stringent noise limit cannot normally be met even in sparsely populated areas and it would have the effect of preventing noise impacts by making it virtually impossible to permit and build most projects. In fairness then, any noise limit on a new project must try to strike a balance that reasonably protects the public from exposure to a legitimate noise nuisance while not completely standing in the way of economic development and project viability. It is important to realize that regulatory limits for other power generation and industrial facilities never seek or demand inaudibility but rather they endeavor to limit noise from the source to a reasonably acceptable level in terms of either an absolute limit or an allowable increase relative to the background level.

Based on the observed reaction to typical projects in United States, it would be advisable for any new project to attempt to maintain a mean sound level of 40 dBA or less outside all residences as an ideal design goal. Where this is not possible, and even that level is frequently difficult to achieve even in sparsely populated areas, a mean sound level of up to 45 dBA might be considered acceptable as long as the number of homes within the 40 to 45 dBA range is relatively small. Under no circumstances, however, should turbines be located in places where mean levels higher than 45 dBA are predicted by pre-construction modeling at residences. It is important to note that a project sound level of 40 dBA does not mean that the project would be inaudible or completely insignificant, only that its noise would generally be low enough that it would probably not be considered objectionable by the vast majority of neighbors.

Noise impact assessments for proposed projects can be absolute or relative in nature. In an absolute analysis the sound level contours from the project are plotted over a map of the turbine layout and the surrounding potentially sensitive receptors, normally permanent residences, and the sound levels are evaluated relative to the 40 and 45 dBA criteria discussed above. A relative assessment involves, as a first step, a field survey of the existing soundscape at the site followed by a noise modeling analysis. The potential impact of the project is evaluated in terms of the differential between the existing background sound level and the calculated project-only sound level, importantly, under identical wind conditions. As a general rule of thumb, an increase of up to 5 dBA above the pre-existing L_{A90} sound level is usually found to be acceptable whereas greater increases should be avoided. This design approach only holds for background levels of about 35 dBA or above. When lower background sound levels are found a design goal of 40 dBA or less at all residences should be sought.

Commercially available software packages based on ISO 9613-2 are suggested for noise modeling analyses. Recommended modeling procedures would consist of the following steps.

- Begin with a base map showing the turbine locations and all potentially sensitive receptors in and around the project area (residences, schools, churches, etc.)
- Build up the topography of the site in the noise model if the terrain features consist of hills and valleys with a total elevation difference of more than about 100 ft. – otherwise flat terrain can be assumed
- Locate point sources at the hub height of each turbine (typically 80 m)
- Use the maximum octave band sound power level spectrum, measured per IEC 61400-11, for the planned turbine model or the loudest model of those being considered
- Assume a ground absorption coefficient (A_g from ISO 9613-2) appropriate to the site area (a moderate value of 0.5 generally works well as an annual average for rural farmland)
- Assume ISO “standard day” temperature and relative humidity values of 10 deg. C/70% RH unless the prevailing conditions at the site are substantially and consistently different than that
- Plot the sound contours from the project assuming an omni-directional wind out to a level of 35 dBA
- Evaluate the potential impact of the project at residences relative to the suggested 40 and 45 dBA thresholds

A relative impact analysis is recommended whenever unusually high or low background levels are suspected at a site, the project is large or controversial, or when there is simply a desire to carry out a thorough analysis. The baseline field survey of existing environmental sound levels should:

- Use 6 to 14 measurement positions depending on the complexity of the site
- Select positions at residences (to the extent possible) that are representative of all the distinct settings that may be present within the site area, such as sheltered valleys, exposed hilltops, wooded areas, near major roadways, remote and secluded, etc.
- Monitor in continuous 10 minute intervals for a period of at least 14 days to capture a wide variety of wind and weather conditions
- Record a number of statistical parameters, giving precedence to the relatively conservative L_{A90} measure
- Use Type 1 or 2 integrating sound level meters fitted with oversize (7" diameter, or greater) windscreens
- Mount the microphones approximately 1 m above ground level, where feasible, to minimize self-induced wind noise
- Use one or more temporary weather stations at the most open and exposed measurement positions to record wind speed at microphone height and other parameters, such as rainfall.
- Apply a correction, if necessary, to the A-weighted sound levels for wind-induced, self-noise based on the microphone height anemometer readings
- Evaluate the L_{A90} results for consistency over the various measurement positions, segregating the results for different settings if there are clear and consistent differences
- Normalize the wind speed measured by the highest anemometers on all on-site met towers to a standard height of 10 m per Eqn. (7) of IEC 61400-11
- Correlate the design site-wide or individual setting background levels to the normalized wind speed to determine the mean value as a function of wind velocity
- Use the 6 m/s result as the critical design wind speed or determine the site-specific critical wind speed from a comparison between the turbine sound power and background levels
- Use the mean L_{A90} background level at the critical wind speed as a baseline for evaluating the modeled sound emissions of the project under those same conditions

The accurate measurement of noise from an operational project requires a determination of the concurrent background sound level present at the time each sample of operational noise is measured so that the wind and atmospheric conditions are consistent. Background levels measured at a different time and under inevitably different conditions are not suitable for use in correcting operational sound measurements.

The objective of an operational survey is to quantify the project-only sound level exclusive of background noise, which can easily be comparable to the project level at typical set back distances. Ignoring this background component will normally result in an overestimate of the project's actual sound levels.

A methodology is outlined in these guidelines for estimating the simultaneous background sound level by monitoring at a number of positions outside of the site area in locations and settings that are similar in nature to the on-site positions but remote from all turbine noise. In general, an operational survey to determine the sound emissions exclusively due to the project should:

- Use 6 to 10 on-site measurement positions depending on the complexity of the site and focused on the residences with maximum exposure to turbine noise (irrespective of their participation in the project)
- Set up 3 to 4 off-site background measurement positions at positions at least 1.5 miles from the project perimeter in diametrically opposed directions. These positions should be similar in setting and character to the on-site positions but removed from any exposure to project noise
- Monitor in continuous 10 minute intervals for a period of at least 14 days to capture a wide variety of wind and weather conditions
- Record a number of statistical parameters, giving precedence to the L_{A90} measure
- Use Type 1 or 2 integrating sound level meters fitted with oversize (7" diameter, or greater) windscreens
- Mount the microphones approximately 1 m above ground level, where feasible, to minimize self-induced wind noise
- Use one or more temporary weather stations at the most open and exposed measurement positions to record wind speed at microphone height and other parameters, such as rainfall.
- Apply a correction, if necessary, to the A-weighted sound levels for wind-induced, self-noise based on the microphone height anemometer readings
- Evaluate the off-site L_{A90} results for consistency over the various measurement positions, segregating the results for different settings if there are clear and consistent differences. Develop one or more design background levels to be used to correct the on-site levels.
- Subtract the appropriate design background level from the total measured level at each on-site receptor to derive the project-only sound level at each receptor position
- Normalize the wind speed measured by the highest anemometers on all on-site met towers to a standard height of 10 m per Eqn. (7) of IEC 61400-11
- Plot the derived project-only sound levels as a function of time or wind speed.
- Exclude all data points measured during calm conditions when the project was not operating
- Exclude all data points that appear to be associated with local contaminating noises; i.e. noise spikes, usually occurring at only one position, that are not accompanied by a simultaneous spike in wind speed
- Evaluate the final results with respect to the applicable design goal or ordinance limit. If the measured levels are lower than the design target at least 95% of the time the project can be considered in compliance.

2.0 Characteristics of Wind Turbine Noise

The magnitude and nature of wind turbine noise is entirely dependent on time-varying wind and atmospheric conditions, whereas a conventional fossil-fueled power station operates, often continuously and steadily, in a manner that is completely independent of the local environment. Consequently, a combustion turbine plant, for example, is most apt to be perceptible and a potential noise problem during calm and still weather conditions while a wind turbine project would, under most normal circumstances, not make any noise at all under those same conditions. During moderately windy conditions increased background noise would tend to diminish the perceptibility of the fossil fueled plant while the wind project would generally be at its loudest relative to the background level. At very high wind speeds background noise often becomes dominant to the extent it can obscure both sources.

In addition to simply being dependent on prevailing wind and atmospheric conditions, wind turbine noise usually has a distinctive, identifiable character to it that makes it more readily perceptible than other industrial sources of comparable magnitude[6,7,8]. The fundamental noise generation mechanism, the turbulent interaction of airflow over the moving blades, is dependent on the characteristics of the air mass flowing into the rotor plane. For example, when the airflow is fairly constant and steady in velocity over the swept area noise is generally at a minimum. While such ideal, laminar flow conditions may exist much of the time, particularly during the day, they do not occur all of the time, and the reality is that the wind often blows in the form of intermittent gusts separated by short periods of relative calm rather than as a smooth continuous stream of constant velocity. In addition, the flow may contain turbulent eddies, may be unstable in direction and the mean velocity may vary considerably over the vertical diameter of the rotor, which is typically in the 77 to 112 m (250 to 370 ft.) range on the utility scale turbines now in common use. These uneven and unstable airflow conditions generally cause more noise to be generated - and it is generated sporadically as each gust sweeps past and as the wind varies amorphously in speed or direction over the rotor plane. Such unstable conditions can lead to sound levels that change very noticeably in the short-term not only in general volume but also in character.

Qualitatively, under average circumstances rotor noise, as perceived at a common set back distance of around 400 m (1200 ft.), might be described as a churning, mildly periodic sound due to blade swish, particularly when there are several units at comparable distances from the point of observation. The normally non-synchronized and incoherent sounds from multiple units tend to blur the sound and minimize the perception of swish, although it is most commonly weak during “normal” circumstances even if only one unit is present. Another common description is that the noise is reminiscent of a plane flying over at fairly high altitude. This apt comparison is probably partly due to the basic similarity in frequency content of the two sounds but also to the phenomenon where the sound can fade in and out randomly. In the case of an actual plane it is the intervening non-homogeneous atmosphere that alternately enhances or hinders sound propagation from the distant source producing this effect while, in the case of the wind turbine, it is more likely to be short-term variations in noise generation at the source itself, or a combination of both source and path effects.

A pure path effect that occasionally occurs is the enhanced propagation of turbine noise due to thermal layering, known as a stable atmosphere, where the air is warmer above the surface than at the surface causing sound rays to diffract downward and making a distant sound louder than it would otherwise be. At night, this phenomenon, most likely in combination with the wind speed gradient, is most likely to lead to an increase in periodic noise (generally referred to as amplitude modulation, or AM)[9,10]. The exact mechanism behind this noise, particularly when it becomes unusually pronounced, is not entirely understood, but, in simple terms, it is thought to be caused when the wind speed at the top of the rotor is significantly higher than the wind speed at the bottom; i.e. when the vertical wind speed gradient is more slanted and less vertical, as is usually the case at night. Having said that, however, this phenomenon is not always present or particularly pronounced at all sites, but *when of sufficient magnitude*, the fairly pronounced swishing or thumping sound that can result on certain evenings can and does give rise to quite legitimate complaints. In fact, this is probably the primary cause of serious complaints about wind project noise. In general, the occurrence of this phenomenon in its pronounced or enhanced form is rather rare making detailed measurements difficult[11] but a major effort[(ibid)] is currently underway in the United Kingdom seeking to quantify and further understand this noise.

2.1 Low Frequency Noise and C-weighted Sound Levels

When the swishing, thumping or beating noise alluded to above does occurs it is usually at a rate of about once per second, or 1 Hz, which is the blade passing frequency of a typical three-bladed rotor turning at 20 rpm. Although the "frequency" of its occurrence at 1 Hz obviously falls at the very low end of the frequency spectrum, this noise is not "low frequency" or infrasonic noise, per se. It is simply a periodic noise where the actual frequency spectrum may contain some slightly elevated levels in the lower frequencies but where the most prominent noise is roughly centered around 500 Hz near the middle of the audible frequency spectrum. In general, the widespread belief that wind turbines produce elevated or even harmful levels of low frequency and infrasonic sound is utterly untrue as proven repeatedly and independently by numerous investigators[12,13,14,15,16] and probably arose from a confusion between this periodic amplitude modulation noise and actual low frequency noise. Problematic levels of low frequency noise (i.e. those resulting in perceptible vibrations and complaints) are most commonly associated with simple cycle gas turbines, which produce tremendous energy in the 20 to 50 Hz region of the spectrum – vastly more than could ever be produced by a wind turbine.

The mistaken belief that wind turbines produce high levels of low frequency noise can also be attributed, perhaps even more definitively, to wind-induced microphone error where wind blowing through virtually any windscreen will cause the low end, and only the low end, of the frequency spectrum to substantially increase due to self-generated distortion. The magnitude and frequency response of this error has been theoretically/mathematically quantified by van den Berg[10] and empirically by Hessler[17] by subjecting a variety of commonly used windscreens to known air speeds in a massively silenced wind tunnel – thereby directly measuring the frequency response to air flow alone (the specific results of this study and its applications are discussed further in Section 5.1). The results of this wind tunnel experiment were used to evaluate measurements of actual wind turbine noise at a site in Southern Minnesota by Hessler in 2008[18]. Figure 2.1.1 below shows, as an example, the frequency spectra measured under fairly windy conditions in a rural soybean field 1000 ft. from an isolated unit and, at the same time, in an identical soybean field 3 miles away from any turbines.

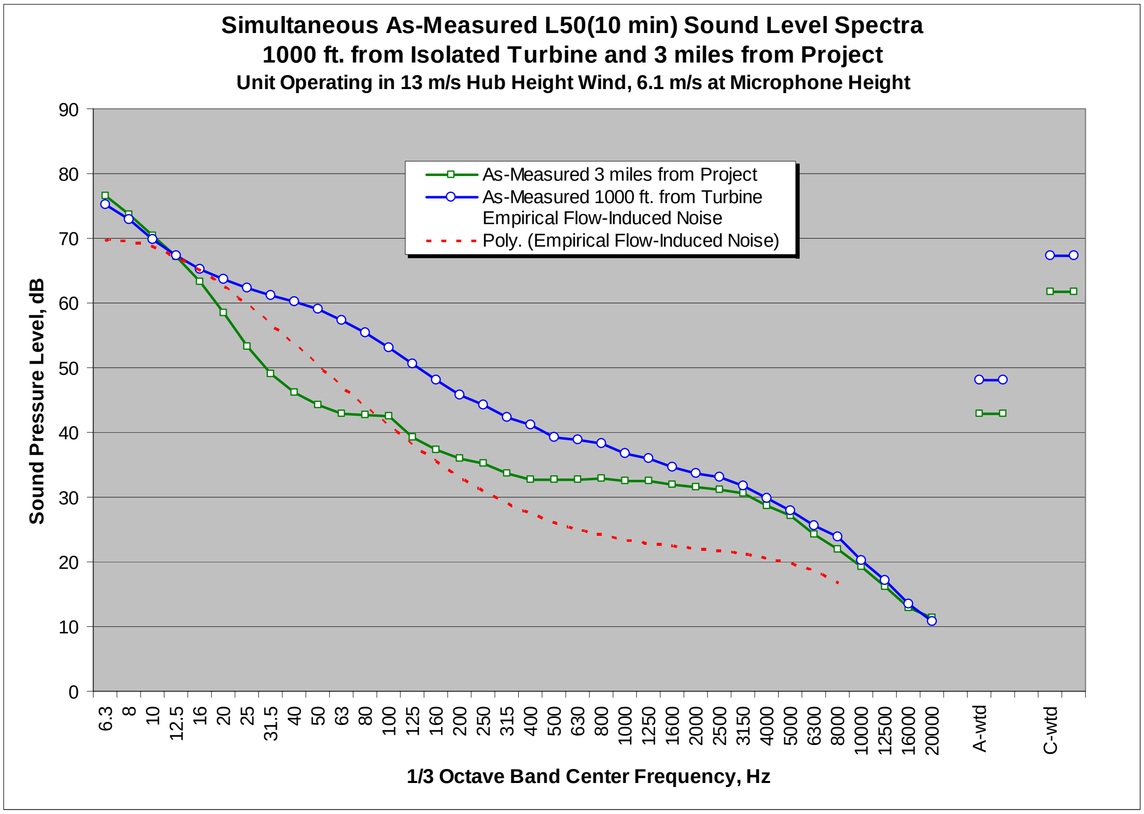

Figure 2.1.1

The two measurements show the same values in the lowest frequency bands. Since there is clearly no source of low frequency noise present in the background measurement, the low frequency levels - in both measurements – simply represent self-generated distortion and are not the actual sound emissions of anything. This can be confirmed from the wind tunnel study where the measured frequency spectrum for this particular windscreen (7" diameter) subjected to a 6.1 m/s wind is also plotted in Figure 2.1.1[a].

What all this shows is that virtually any measurement taken under moderately windy conditions will be severely affected by false-signal noise in the lower frequencies, even

[a] It should be noted that the wind tunnel results quantify the minimum amount of false-signal noise measured under more or less laminar flow conditions in the absence of possible further distortion from turbulence and atmospheric conditions.

when a large windscreen is used as in the example above. The measurement will appear to show high levels of low frequency noise - whether a wind turbine is present or not.

Figure 2.1.1 also illustrates another important point concerning C-weighted sound levels; namely, that the C-weighted levels at 1000 ft. and 3 miles are somewhat similar at 67 and 62 dBC, respectively. The significance of this is that C-weighted sound levels, as opposed to the much more common A-weighted metric, are normally used for the specific purpose of quantifying, investigating or placing a limit on noise sources that are rich in low frequency noise. The reason for this is that C-weighting does not mathematically suppress the low frequencies the way A-weighting does making it highly sensitive to and usually dominated by the low frequency content of a sound. Figure 2.1.2 shows this graphically for the example measurement at 1000 ft. from a wind turbine.

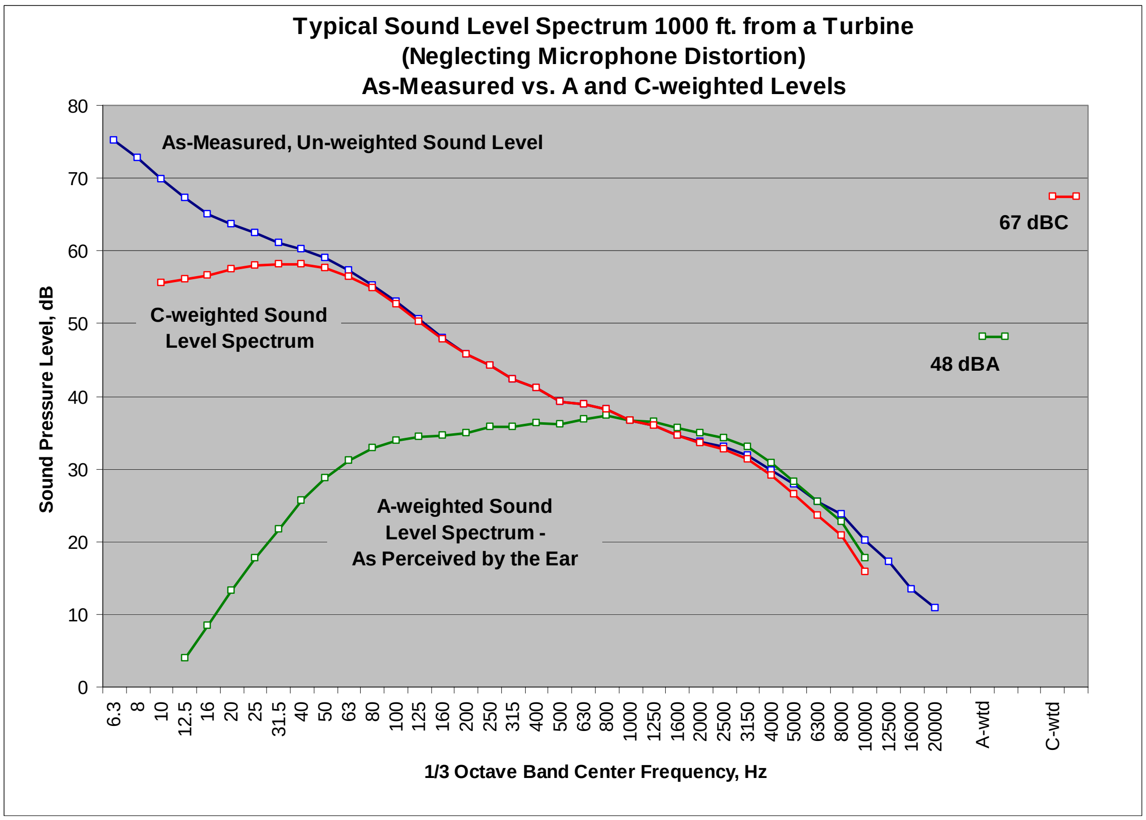

Figure 2.1.2

The as-measured sound level, warts and all, without any weighting applied is the blue trace. C-weighting reduces the low end of the frequency spectrum by a moderate amount whereas A-weighting reduces it substantially. There is no tangible or physiological rationale behind C-weighting but A-weighting serves the very useful purpose of adjusting the frequency spectrum of the sound so that it matches the way it is subjectively perceived by the human ear, which is relatively insensitive to low frequency sounds. Figure 2.1.2 shows that what is actually heard at 1000 ft. from this turbine is mid-frequency sound from roughly 100 to 2500 Hz – and even if the artificially elevated low frequency levels were actually attributable to the turbine nothing would still be audible in the low frequencies (recall that this measurement is unadjusted for low frequency false-signal noise).

The ultimate point of this discussion is that C-weighted sound levels cannot be measured in any kind of meaningful way in the windy conditions associated with turbine operation, since they essentially quantify the level of low frequency microphone distortion rather than any actual noise.

As another example, the plot below shows the C-weighted sound levels measured over a two week period at a residence surrounded by several wind turbines and simultaneously by a monitor located miles away from the project area in a similar setting (rural Midwestern farm country).

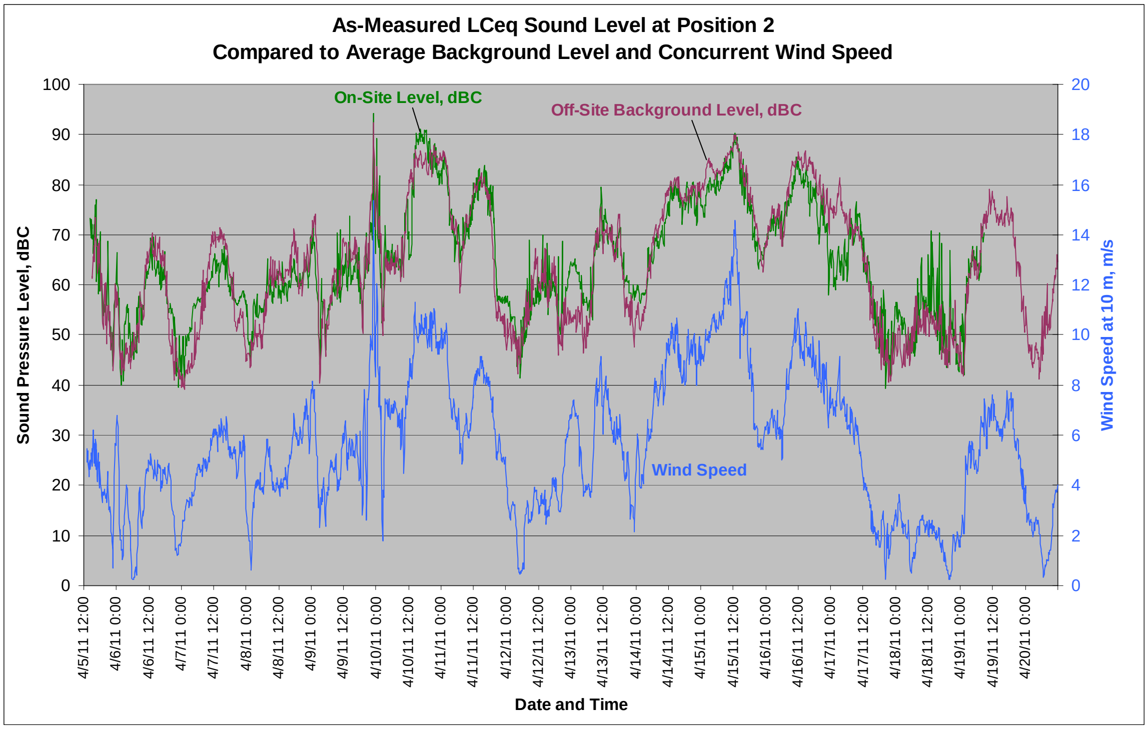

Figure 2.1.3

In essence, the levels are largely the same at both places and are more a measurement of the prevailing wind speed and its effect on the microphone rather than any real source of low frequency noise.

Consequently, despite their occasional appearance in local ordinances as an intended way of limiting the low frequency noise emissions from wind projects, by either an absolute limit or a dBA-dBC differential, C-weighted sound levels have no practical place in the measurement of wind turbine sound.

3.0 Recommended Design Goals

It would be a trivial solution to set an extremely low sound level of, say, 30 dBA as a permissible sound level for a new wind project at potentially sensitive receptors or to impose massive set back distances to any residences. While such restrictions would probably ensure that there was no adverse impact whatsoever from the project, the effective inaudibility of project noise would be due more to the fact it was never built than to its low sound emissions. Realizing virtual inaudibility or maintaining set backs of several thousand feet from all residences is generally an impracticality at all but the most remote sites. In fairness then, any noise limit on a new project must try to strike a balance that reasonably protects the public from exposure to a legitimate noise nuisance while not completely standing in the way of economic development and project viability. It is important to realize that regulatory limits for other power generation and industrial facilities never seek or demand inaudibility but rather they endeavor to limit noise from the source to a reasonably acceptable level either in terms of an absolute limit (commonly 45 dBA at night) or a relative increase over the pre-existing environmental sound level (typically 5 dBA[19]).

Research, principally by Pedersen[20,21] and Persson-Waye[22], on what the reaction is to wind turbine sound levels and what levels might be considered acceptable has been on-going for some time now in Europe. These studies analyze the responses to blind questionnaires distributed to residents living near wind farms in Sweden and The Netherlands in an effort to correlate the level of annoyance with noise and other factors with the calculated project sound level at each residence. In general, the results suggest among many other important findings that a project sound level in the 40 to 45 dBA range can lead to relatively high annoyance rates of around 20 to 25%[(ibid)]; however, it important to understand that these numbers refer to the percentage of those with exposure to such sound levels and not the entire population in the vicinity of the projects. Viewed within the context of the total survey population the rate of adverse reaction comes down to a handful of individuals or very roughly about 4 to 6% when residences are exposed to project sound levels in the 40 to 45 dBA range.

A somewhat similar rate of complaints/annoyance expressed as a percentage of the total population living within 2000 ft. of a turbine was found by Hessler[23] during compliance sound testing at a number of typical, newly operational wind projects in the United States. In each survey the total number of residents where complaints or even mild concerns about noise had been called in was obtained from project operations and the actual sound levels at all of these locations were measured over 2 to 3 week periods. The fundamental results are summarized in the following table.

Table 3.0.1 *Number of Observed Complaints Relative to the Total Number of Households in Close Proximity to Turbines [Hessler, 23]*

Project	Total Households in the Site Area (Approx.)	Number of Complaints as a Function of Project Sound Level (dBA) (a)			Total Number of Complaints	Percentage Relative to Total Households
		< 40	40 - 44	45 or Higher		
Site A	107	0	2	1	3	3%
Site B	147	0	3	3	6	4%
Site C	151	0	3	0	3	2%
Site D	268	0	2	4	6	2%
Site E	91	1	1	4	6	7%
					Overall Average:	4%
(a) Sound levels expressed as long-term, mean values						

Although the purpose of these surveys was to confirm compliance with regulatory noise and not specifically to evaluate community reaction, the findings, taken together with the European research mentioned above, suggest that the vast majority of residents living within or close to a wind farm have no substantial objections to project noise, particularly if the mean sound level is below 40 dBA. It is important to add that all of the sites investigated in these studies were just as prone as any other site to all the adverse character issues mentioned above, such as amplitude modulation, stable atmospheric conditions, highly variable sound levels and higher nighttime noise levels. While the possibility of annoyance, if not serious disturbance, can almost never be completely ruled out, it appears that the total number of complaints would be fairly small as long as the mean project level does not exceed 40 dBA. Above that point, specifically in the 40 to 45 dBA range, complaints can be expected with some certainty but, as indicated in Table 3.0.1, still at a fairly low rate of about 2% relative to the total population in close proximity to the project.

Consequently, it would be advisable for any new project to attempt to maintain a mean sound level of 40 dBA or less outside all residences as an ideal design goal. Where this is not possible, and it frequently is difficult to achieve even in sparsely populated areas, sound levels of up to 45 dBA might be considered acceptable as long as the number of homes within the 40 to 45 dBA range is relatively small. Under no circumstances, however, should turbines be located in places where mean levels higher than 45 dBA are predicted by pre-construction modeling at residences. A project sound level of 40 dBA does not mean that the project would be inaudible or completely insignificant, only that its noise would generally be low enough that it would probably not be considered objectionable by the vast majority of neighbors based on the actual reaction to other projects.

It is important to note that the sound levels in Table 3.0.1 and the suggested sound level targets discussed above are mean, long-term values and not instantaneous maxima. Wind turbine sound levels naturally vary above and below their mean or average value due to wind and atmospheric conditions and can significantly exceed the mean value at times. Extensive field experience measuring operational projects indicates that sound levels commonly fluctuate by roughly +/- 5 dBA about the mean trend line and that short-lived (10 to 20 minute) spikes on the order of 15 to 20 dBA above the mean are occasionally observed when atmospheric conditions strongly favor the generation and propagation of noise. Because no project can be designed so that all such spikes would remain below the 40 or 45 dBA targets at all times, these values are expressed as long-term mean levels, or the central trend through data collected over a period of several weeks.

4.0 Noise Impact Assessments

4.1 Noise Modeling

The principal mechanism for evaluating the potential impact of a proposed wind project is to analytically model its noise emissions. A sound level contour map showing the expected sound emissions from the project relative to all the residences in the area is essentially a graphic illustration of the potential impact. It follows from the preceding discussion of ideal design goals that predicted levels below 40 dBA at residences can be associated with a relatively low adverse impact, while higher levels, particularly those higher then 45 dBA, suggest a relatively high probability of serious complaints.

Because there are few options to reduce noise from a project once it becomes operational, any necessary noise abatement must essentially be designed into the project while it is still in the planning stage. Computer modeling allows the potential noise impact to be visualized but, importantly, also allows mitigation options to be explored, since the effects of relocating or removing individual turbines or using alternate turbine models can be easily evaluated. Such optimization studies are best performed early in the development process while there is still some flexibility to move things around. This process can be repeated iteratively as the design develops and lease and easement agreements evolve to help keep community noise levels as low as possible within the context, of course, of many other constraints.

4.1.1 *Acceptable Sound Propagation Standards*

Wind turbine noise is actually rather simple to model because the project consists of more or less ideal point sources located high in the air. Consequently, the dominant sound propagation factor is simply spherical wave spreading with distance, which is an axiomatic law of physics that is built into every modeling software package. All other effects, such as ground or air absorption, are minor subtleties by comparison so great sophistication in modeling software is not required. In fact, all that is really necessary is to calculate sound propagation from the project using ISO 9613-2 *Acoustics – Attenuation of sound during propagation outdoors. Part 2: General method of calculation* (1996)[24], which is, by far, the prevailing and most widely accepted worldwide standard for such calculations and the basis for essentially every commercial noise modeling program.

Like the other test standards alluded to in the introduction, ISO 9613-2 was not written with wind turbines in mind and its applicability to elevated sources (usually 80 m) and long propagation distances is occasionally questioned. Table 5 in the standard gives the estimated accuracy of the method for noise sources up to 30 m high and for propagation distances up to 1000 m. This 30 m height figure is sometimes interpreted to mean that the standard cannot be used for 80 m high sources, but it is just that no specific accuracy estimate is given for such cases, not that the standard is inappropriate. As mentioned earlier, the principal sound propagation loss in wind turbine modeling is simple geometric spreading of the sound wave, which is a phenomenon that has no dependence on the specific point of origin or its height above ground level.

Source height is a factor, however, in the relatively minor ground absorption loss (i.e. the tendency of the ground surface to variously absorb or reflect sound waves) but measurements of actual wind turbine sound levels vs. predictions show reasonably good agreement indicating that the calculation of the ground absorption loss and, indeed, the entire methodology, is perfectly valid for wind turbines.

Having said that, it should be noted that ISO 9613-2 does not consider atmospheric conditions, such as the wind and temperature gradients, stability, turbulence, etc., and was always intended to portray very long-term or average propagation conditions under slightly conservative downwind conditions. Consequently, the model results using this standard need to be interpreted as the expected sound level under “average” conditions, meaning that the actual sound level will be close to the prediction much of the time but higher *and* lower levels will occur with about equal regularity due to fluctuating atmospheric conditions, which affect both the generation and propagation of wind turbine noise. The plot below shows a typical comparison between the measured project-only sound levels over a two week period compared to predictions at various wind speeds. The model predictions tend to agree with the central trend line. The scatter evident in this chart is normal and inevitable and reflects the natural variability of wind turbine sound levels as observed at a distant point.

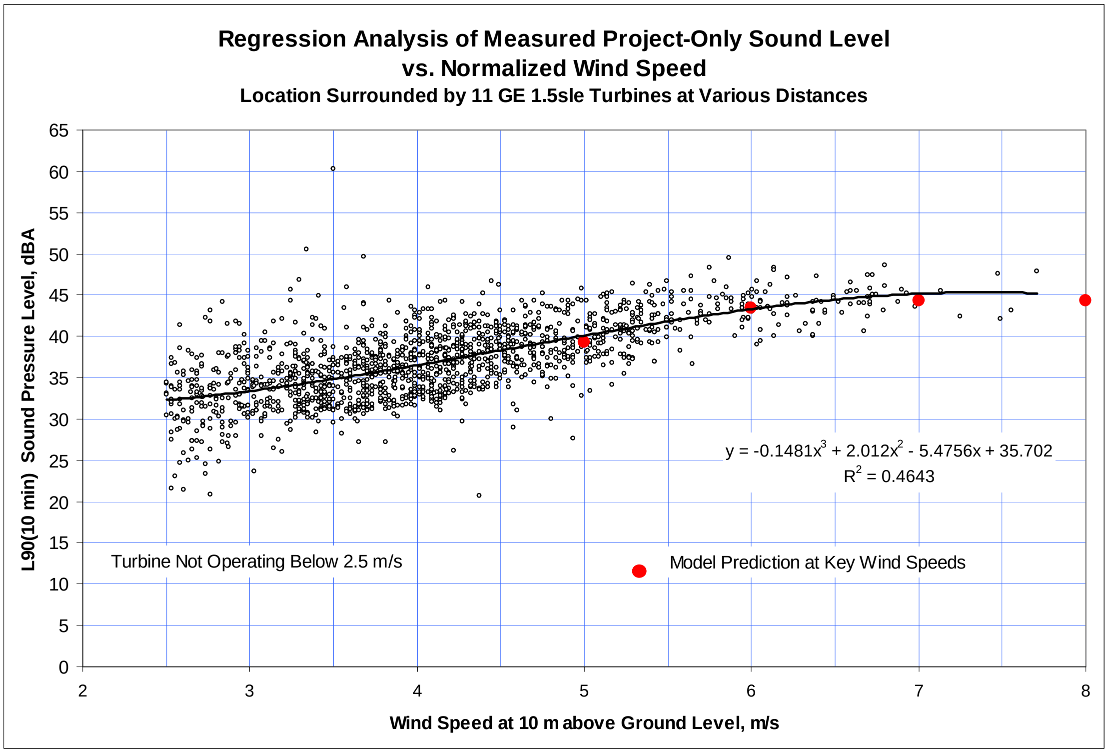

Figure 4.0.1

It should be pointed out that there is an alternative prediction methodology to ISO 9613-2 that takes atmospheric conditions into account: NORD2000[25], which is a proprietary software package that has been in development in Denmark for quite some time. However, it is rather complicated and is not in wide use partially because it has not been integrated or fully integrated into the most commonly used modeling programs. This sound emissions model is based on the fundamental mathematics of wave propagation rather than the empirical studies that form the basis for most of the propagation losses in ISO 9613-2, but despite its sophistication it does not seem to yield substantially better results than ISO 9613-2[26]. As exemplified by Figure 4.0.1, there is no reason why the more common and simpler ISO 9613-2 methodology should not be used.

4.1.2 *Modeling Software*

In theory, then, any program based on ISO 9613-2 can ostensibly be used to model wind turbines but there is more to it than the calculation of sound propagation losses. What emerges as the key differentiation between programs is basically how well and easily the site plan can be imported into the program and the quality and nature of the program's output.

Typical wind projects consist of dozens of units either spread out over many square miles in flat or rolling country or strung out along ridgelines. At the first type of site the turbines are frequently mixed in with potentially sensitive receptors (typically permanent residences) that can easily number into the hundreds. With ridgeline projects the nearest receptors are usually all around the base of the mountain or promontory on which the turbines are proposed and the effective project area (i.e. the region where residences exist within possible earshot of the project) can be vast. Consequently, it is best, if not essential, to use a modeling program that allows for the reasonably easy importation and scaling of a site map that shows not only the turbine locations but also all of the surrounding potentially sensitive receptors. Such a map is normally in shapefile (.shp) format with a layer for the turbines, a layer for structures (unfortunately not often differentiated into houses, barns, garages, commercial buildings, etc.) and layers for other features such as roads or topography. While nominally possible, it is not normally desirable to use only numerical tables of turbine coordinates to create the model for the principal reasons that a separate base map needs to be found and imported and different coordinate systems can become confused. In addition, publically available maps (used as a base map for the model) almost never show, or at least accurately show, all the residences in the vicinity of the project.

In addition to the turbines and houses the topography of the site often needs to be considered in the model – not only because of the line sight between the turbines and houses may be partially blocked or obstructed, but more generally because the source-receptor distance at sites with fairly dramatic terrain is affected and usually lengthened when modeled in three-dimensions. Consequently, a program that has the ability to import terrain contours and then mathematically consider their effect on sound propagation is essential for any project in a hilly or mountainous setting. This factor can only be safely ignored for sites with fairly flat or gently rolling topography.

In terms of output the most important element is the ability of the program to map sound contours in high resolution over the input base map. The potential impact from any wind project is normally graphically evaluated from contour plots. It is the number of houses within a certain threshold or sound level that usually determines whether the project is likely to result in complaints or not or whether it will comply with regulatory noise limits.

In terms of specific programs, Cadna/A® developed by Datakustik GmbH (Munich, Germany), appears to be used most often by engineers and consultants and is fully capable of importing shapefiles, modeling complex terrain and producing detailed contour maps.

The second most common noise prediction program is the sound emissions component of the WindPRO® software package (EMD International A/S, Denmark), which is a generalized siting tool for wind farms. The noise prediction module is only one aspect of the much larger program.

SoundPLAN® (Braustein & Berndt GmbH, Backnang, Germany), is evidently similar in capability to Cadna/A® but, for reasons that are unclear, is not often used for wind turbine analyses despite its apparent capability to integrate the NORD2000 algorithm as an optional calculation methodology.

One other program, WindFarm® (ReSoft Ltd, U.K.), is another general project design package of which the noise component is only a small part.

Any one of these programs would be generally acceptable for modeling the noise from a new project.

4.1.3 *Model Inputs*

In contrast to models of acoustically complex fossil fueled power plants that consist of dozens of major sources, the sound levels of which often need to be estimated, the input to a wind turbine project model is a single sound power level spectrum that is known with considerable accuracy. Turbine sound power levels are tested in accordance with IEC 61400-11[5], in which highly specialized and meticulous techniques are used to derive the sound power level of a wind turbine over a range of wind speeds from 6 to 10 m/s (as measured at 10 m above ground)[b]. The best input to use for any model is the maximum octave band sound power level frequency spectrum taken directly from a field test report.

Although such reports are sometimes made available by manufacturers, it is more common for the acoustical performance to be reported second-hand (based on either an IEC 61400-11 test or analytical calculations) in a technical specification document published by the manufacturer. The reported sound levels may or may not contain an explicit design margin and/or may be stated as warranted sound levels. While input sound levels that have been artificially inflated would tend to needlessly overstate the potential impact of a project, there often isn't any alternative to using whatever performance the manufacturer decides to publish. Whatever the source of the data is, it should be clearly stated in the impact assessment report.

4.1.4 *Modeling Methodology*

Recommended procedures for modeling wind turbine project noise are as follows:

- Begin with a base map showing the turbine locations and all potentially sensitive receptors in and around the project area (residences, schools, churches, etc.)
- Build up the topography of the site in the noise model if the terrain features consist of hills and valleys with a total elevation difference of more than about 100 ft. – otherwise flat terrain can be assumed
- Locate point sources at the hub height of each turbine (typically 80 m)
- Use the maximum octave band sound power level spectrum for the planned turbine model or the loudest model of those being considered
- Assume a ground absorption coefficient (A_g from ISO 9613-2) appropriate to the site area (a moderate value of 0.5 generally works well as an annual average for rural farmland, although higher values specifically for farm fields during summer conditions may be appropriate. A value of 0 (100% reflective ground) is likely to produce highly conservative results)

[b] In its current edition (2.1). A revision to this standard has been in development for some time that would expand this wind speed range and add a number of other refinements (and complexities) to the test procedure. It is unclear whether this new edition will ever actually be adopted.

- Assume ISO "standard day" temperature and relative humidity values of 10 deg. C/70% RH unless the prevailing conditions at the site are substantially and consistently different than that
- Plot the sound contours from the project assuming an omni-directional wind out to a level of 35 dBA (shading the area between each 5 dBA gradation with a different color often greatly improves legibility)

The assumption of an omni-directional wind means that the sound power level of the turbine, which is measured in the IEC 61400-11 procedure downwind of the unit, is modeled as radiating with equal strength in all directions; i.e. the sound level in every direction is the downwind sound level. Although this may seem be depict an unrealistic situation and over-predict upwind sound levels, the fact of the matter is that this approach generally results in predictions that are consistent with measurements irrespective of the where the receptor point is located. Although somewhat counterintuitive, the reason for this is that wind turbine noise under most normal circumstances is not particularly directional and generally radiates uniformly in all directions. As an example, the plot below shows the sound levels measured in three directions 1000 ft. from a typical unit in a rural project in Southern Minnesota. Although there are periods when the levels differ, implying some directionality, the majority of the time all three sound levels are generally about same irrespective of the wind direction. Moreover, the sound level at the downwind position is almost never elevated relative to other directions as one might expect.

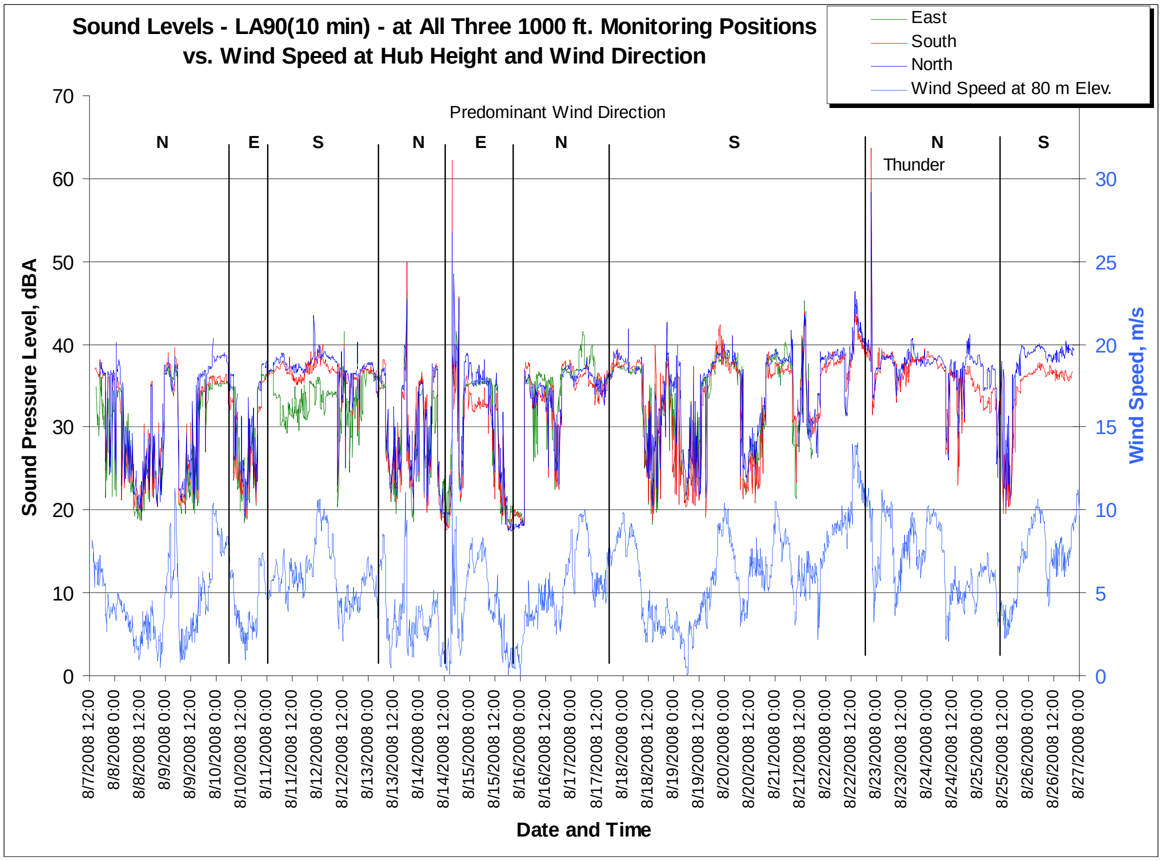

Figure 4.1.4.1 *Sound levels at 1000 ft. from a Typical Unit in Three Directions*

4.1.5 *Interpretation of Model Results*

An example plot for a hypothetical project, prepared using Cadna/A® and the procedures outlined in Section 4.1.4, is shown in Figure 4.1.5.1. In this instance, the units are located on a fairly prominent ridgeline and the topography has been recreated in the model.

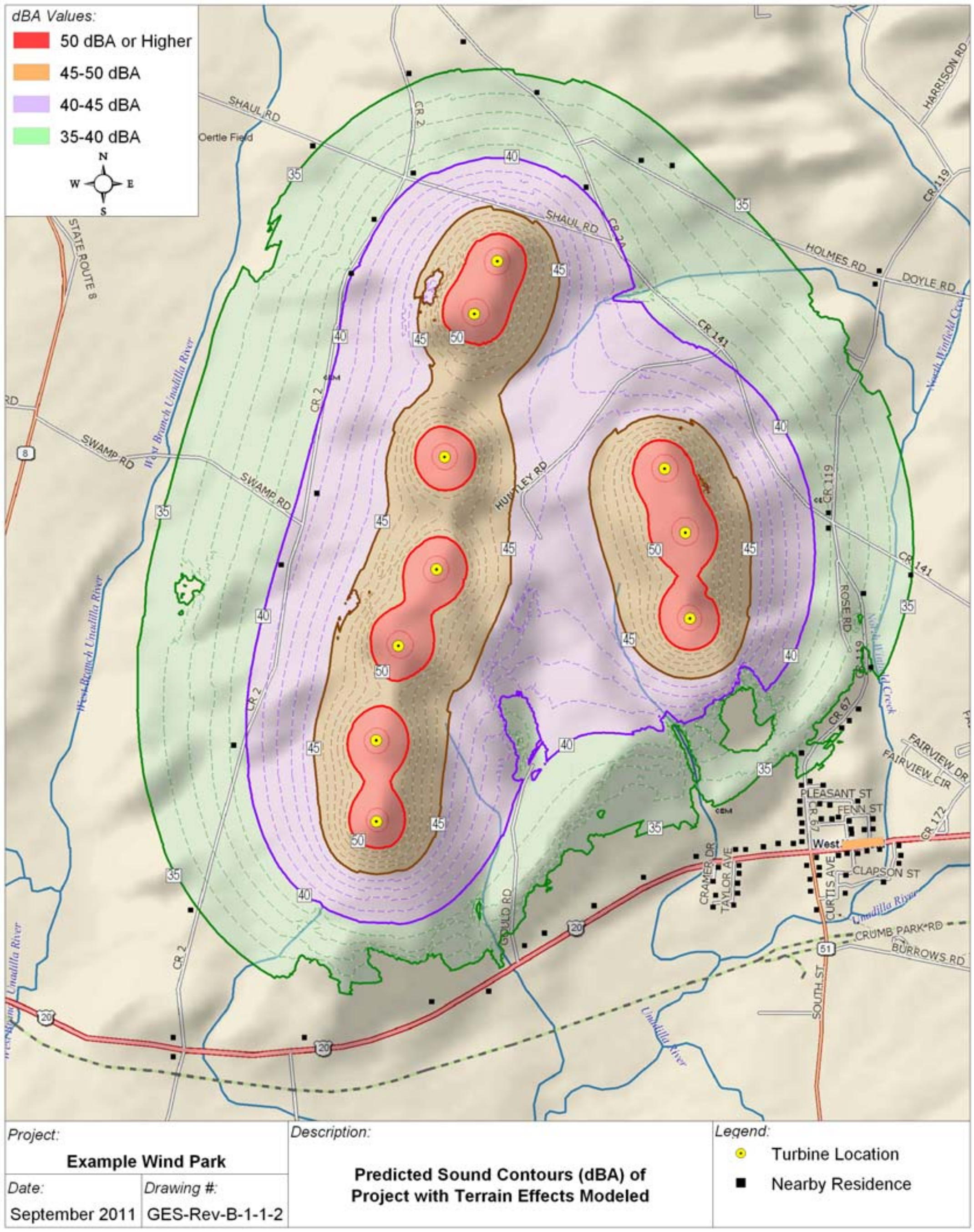

Figure 4.1.5.1 *Noise Model Plot – Example A*

Based on the plot, the potential noise impact from this project can be characterized as being fairly mild in the sense that nearly all of the residences in the vicinity of the project are expected to see a mean sound level of 40 dBA or, in most cases, less. The few houses that are nominally above 40 dBA are only marginally above that threshold and none are close to the 45 dBA absolute upper limit. The green region between 40 and 35 dBA generally represents the area where in all likelihood project noise would still be readily audible some of the time, if not much of the time, but at a fairly low magnitude. The audibility of and reaction to sound levels in this range would be somewhat dependent on the level of natural background sound in the area, since environmental sound levels in rural areas are commonly in the mid to high 30's dBA during the moderate wind conditions necessary for the project to operate – or, in other words, the background sound level could be roughly equivalent to the project sound level limiting its perceptibility. Below 35 dBA project noise generally becomes so low that it is only rarely considered objectionable even in extremely low noise environments. Complete inaudibility does not occur for quite some distance from most projects in quiet areas because of the distinctive, periodic nature of wind turbine noise. The actual distance to the point of inaudibility varies amorphously with atmospheric conditions and is generally much further at night than during the day. Consequently, the exact reaction to any project can never be predicted with certainty because project noise is often audible to some extent, at least intermittently, far from the project. However, the studies of response to wind turbine noise discussed in Section 3.0 suggest that the threshold between a mild or acceptable impact and a fairly significant adverse reaction is a gray area centered at 40 dBA.

An additional sound contour plot is shown in Figure 4.1.5.2 representing another hypothetical but typical project, this time in essentially flat Midwestern farm country.

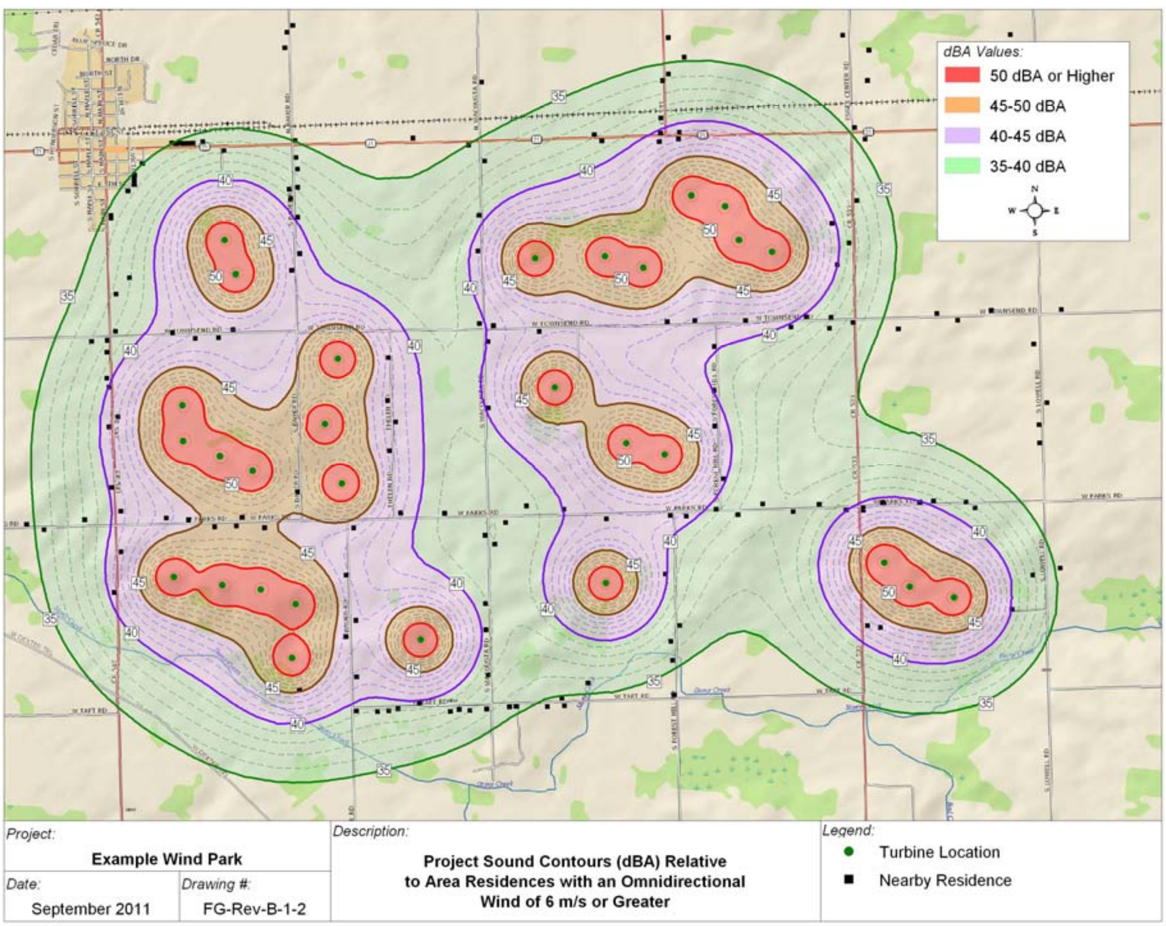

Figure 4.1.5.2 *Noise Model Plot – Example B*

In contrast to Example A, there are many homes inside of the 40 dBA sound contour in this scenario and even a few above 45 dBA, which is a common occurrence. One would have to conclude that at least a few complaints about noise would arise from this project if it were to proceed to completion in this configuration. The population density is such at this site that an optimization study should be undertaken to evaluate the feasibility of removing and relocating turbines outside of the present site area so that sound levels are substantially reduced at the homes with predicted levels of above 45 dBA and so that the number of residences above 40 dBA is dramatically diminished.

4.2 Pre-Construction Background Sound Surveys

Noise impacts can be evaluated in both absolute and relative terms. In the discussion immediately above the reaction to the example projects was estimated directly from the predicted project sound levels, neglecting background noise or essentially assuming a rural setting with generally quiet background sound levels. However, not all sites are the same and it is often prudent to perform a survey of existing conditions to establish just what the baseline sound levels are at residences in the proposed project area. In general, the audibility of, and potential impact from, any project is a function of how much, if at all, its noise exceeds the prevailing background level. A comparison between the predicted/modeled sound level from a proposed project and the actual background sound level measured in the project area under comparable wind and weather conditions gives a site-specific indication of the potential relative impact from the project.

Such a survey is not essential in all cases but is recommended when:

- Unusually high background levels are suspected (e.g. due to the proximity of a major highway, urban areas or existing industrial facilities)
- Unusually low background levels are suspected
- The project is unusually large or controversial
- There is simply a desire to carry out a complete and thorough assessment

4.3 Recommended Field Survey Methodology

The objective of a pre-construction survey is to establish what levels of environmental sound are currently being experienced at typical residences within the general project area in order to form a baseline against which the predicted sound emissions from the project can be compared. There is no need, nor would it be practical, to measure at every house. The idea is to get a set of samples that can be considered representative of the overall site area. In rural areas away from significant sources of man-made noise, it is common to find that the sound levels at all positions are generally similar indicating that background sound levels are for all intents and purposes uniform throughout the site area.

Contrary to popular belief, such a survey is *not* useful for the purpose of establishing the pre-existing environmental sound level as a baseline against which to compare the measured sound emissions from the completed project. The background sound level varies dramatically with time, typically over a dynamic range of 30 dBA or more, depending not only on the wind speed but many other factors, such as the prevailing atmospheric conditions, the time of day, season of the year, etc., so the level measured one or two years earlier cannot be taken to accurately represent the background level present during an operational compliance test. In fact, the only valid background level is the background level occurring, literally, at the same time that the operational sound level is measured. A methodology for overcoming this seeming impossibility is discussed later in Section 5.1.

4.3.1 *Measurement Positions*

Specific monitoring positions should ideally be located at or near typical residences in the site area. It is the sound level where people actually are most of the time and especially at night that is of primary importance (rather than at property lines, for instance). Permission to set up equipment on private property is usually freely granted upon request.

If a site is largely flat and homogenous in nature (e.g. rural farmland away from any major highways, urban areas or industry) monitor positions should be selected at points that are more or less evenly distributed over the project area. In such simple cases, 6 to 8 monitoring positions are usually more than sufficient even if the project area is fairly large.

For more complex sites, where the topography is significant or where man-made noise sources already exist, more monitoring positions will generally be required with the objective of capturing sound levels at residences in each kind of setting. A “setting” is defined as an area where the prevailing environmental sound level is suspected of differing significantly from other parts of the project area. For example, houses in the bottom of ravines or valleys may experience different ambient sound levels than nearby houses on exposed hilltops. Monitors should be located at positions representative of both of these settings. Another type of unique setting might be at homes that are located directly on a major road or highway or in an urban area versus others in the project area that are in remote areas. In some cases, a wind farm already exists adjacent to the area where a new project is proposed. Measurements should be made at homes that have maximum exposure to the sound emissions from the operating turbines for comparison to measurements at residences that are remote from the existing project. The total number of monitoring positions is generally limited by equipment availability and logistical concerns but no more than about 12 to 14 positions are normally required, even for the most complex sites.

4.3.2 *Survey Duration and Scheduling*

Short duration spot samples are insufficient to capture environmental sound levels over the variety of wind and atmospheric conditions that are relevant to project operation. For example, a brief sample on a calm, quiet night is meaningless in the sense that it does not represent the background sound level that will exist on a continuous basis or during the moderately windy conditions necessary for the project to generate noise. In fact, background sound levels in the rural areas where wind projects are most commonly sited are remarkable for their variability and substantial dependency on wind speed. It is the background sound level that occurs when it is moderately windy that is actually of interest for comparison to project sound emissions. In the very typical example below, the background sound level measured at four positions widely distributed over a proposed wind project site in the Midwest can be seen to parallel the concurrent wind speed and, moreover, to vary dramatically from 17 dBA during calm conditions to 54 dBA during windy conditions.

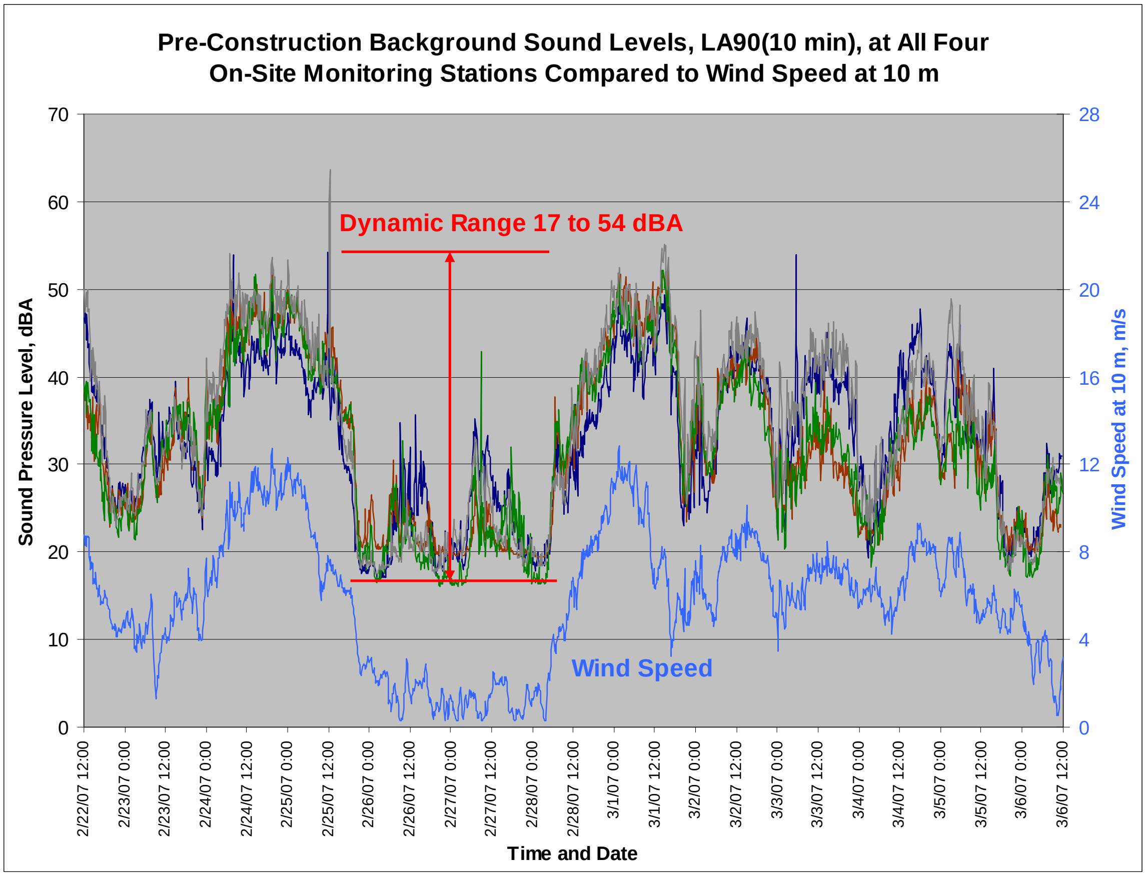

Figure 4.3.2.1

Consequently, a long-term, continuous monitoring approach is needed in which multiple instruments are set up at key locations and programmed to run day and night for a period of about two weeks or more. In essence, it is necessary to cast a wide net in order to capture sound levels during a variety of wind and atmospheric conditions and provide sufficient data so that the relationship between background noise and wind speed can be quantitatively evaluated.

Field experience suggests that an adequate range of wind speeds, from 0 to 10 m/s at 10 m above ground level, will usually be observed over any given 14 day period at most wind energy project sites, except perhaps during the low wind season at sites that might have very pronounced seasonal wind characteristics. Probably the principal reason for this observation is that this length of time is large relative to the time normally taken for weather patterns, wind directions and general atmospheric conditions to change, which essentially ensures that the data are statistically independent, as discussed in great detail in ANSI S12.9-1992/Part 2[27]. Data independence implies that the test results can be taken to represent the longer-term acoustic situation for that area, at least for the general time of year of the test. However, if a review of the weather conditions that occurred during the survey period shows that the winds were unusually calm or if an insufficient number of data points were collected at the higher wind speeds, the survey may need to be extended for another two weeks. Low wind conditions are most commonly captured and the vast majority of the measurements will be for conditions below or just above the cut-in wind speed. High winds normally occur intermittently over a few hours or a few days separated by sometimes lengthy periods of relatively calm conditions. It may sound counterintuitive, but it is not critical to capture extremely high wind conditions, say higher than about 12 m/s at 10 m, since most complaints and issues with wind turbine noise occur during moderate or even light wind conditions, while background noise tends to predominate under very windy conditions.

As a practical matter, the instruments for such a survey are set up, started and left to run unattended for the nominal two-week test period following which they can be retrieved and downloaded. Of course, one could stay on site through the test making additional intermittent manned measurements and observations but the very high cost of such an effort would be difficult to justify, particularly since it would not necessarily guarantee a better or more definitive result than could be derived from the monitor data alone.

In terms of scheduling, it is highly preferable to conduct this type of survey during cool season, or wintertime, conditions to eliminate or at least minimize possible contaminating noise from summertime insects, frogs and birds. In addition, it is best for deciduous trees to be leafless at sites where they are present in quantity to avoid elevated sound levels that might not be representative of the minimum annual level. Human activity, such as from farm machinery or lawn care, is also normally lower during the winter. While summertime surveys can be successful they should, as a general rule, be avoided wherever possible because nocturnal insect noise, for instance, can easily contaminate the data and make it impossible to quantify the relationship between sound levels and wind speed.

In addition to seasonal concerns, it is desirable, when practical, to attempt to schedule the survey set up to just precede a predicted period of moderate or high winds. This not only ensures that the survey period will capture these winds but also creates an opportunity for manned observations and measurements to be made for a day or two to augment to the longer term monitoring survey.

4.3.3 *Instrumentation and Test Set-up*

As with any field sound survey, what equipment is used and how it is deployed must adhere to certain minimum technical standards. These requirements are generally described in numerous standards, such as ANSI S12.9-1992/Part 2[27]; however, the focus of this section is not to repeat and belabor those details but rather to point up what adaptations need to be made for the specific application of performing general site-wide surveys for wind turbine projects. As mentioned earlier, no standard exists that can be directly used for this purpose, if only because they limit data collection to low wind conditions.

In terms of instrumentation, most environmental sound measurement standards recommend the use of Type 1 precision equipment per IEC 61672-1[28] or ANSI S1.43-1997[29] while also allowing for the use of Type 2 equipment. There is certainly no reason on technical grounds to oppose this recommendation but, from a practical perspective, it is often necessary to use Type 2 equipment for surveys of this type because of the large number of instruments needed. The normally negligible difference in technical performance between these two instrument classes is totally inconsequential within the inherently and unavoidably imprecise nature of this type of survey. It is much more important that the equipment is durable, reliable and specifically designed for extended use in the outdoors. Delicate and expensive Type 1 precision grade equipment can be unreliable in such applications or even unable to be programmed as a data logger.

Although high cost and extreme precision are not essential, the functional capabilities to statistically integrate sound levels over a user defined time period and automatically store the results are necessary. Because the on-site wind and weather monitoring towers, or met towers, normally integrate and store measurements in 10 minute increments it is convenient, if not necessary, to measure and store sound data in synchronization with the wind data collected by these towers for later correlation. It is evidently universal practice for met towers to store data 6 times an hour in 10 minute intervals that begin at the top of the hour; as in 9:00, 9:10, 9:20, etc. Consequently, sound data logging should be started using a trigger function to begin at the top of an hour and not randomly by the manual push of the start button. The timers on all instruments should be exactly synchronized to local time. Of course, all of the instruments must be field calibrated at the beginning of the survey and checked again for drift at the end of the survey.

Because this long-term survey approach involves unattended monitoring, the instrument and the microphone must be capable of withstanding damage, interference or outright destruction from rain and snow, which, among other things, means that the ground plate technique specified in IEC 61400-11 – where the microphone is laid flat in the center of a board on the ground and covered with one or more hemispherical windscreens – is not a viable option, despite its otherwise highly desirable advantage of minimizing wind-induced pseudo noise. Consequently, the microphone must be mounted above ground level and protected from wind-induced distortion by a spherical weather-treated windscreen, which normally entails a higher density foam that is hydrophobically treated to shed water (windscreens and wind-induced noise are discussed in detail later). As a general rule, a slightly lower than normal microphone height of about 1 m above ground level is preferred for this application on the premise that wind speed diminishes exponentially with decreasing elevation theoretically going to zero at the surface, or boundary layer. To illustrate this, the nominal wind speed profile, or shear gradient, per Eqn. (7) in IEC 61400-11 is illustrated below in Figure 4.3.3.1 for a common turbine operating condition where the wind speed is 6 m/s at the standard elevation of 10 m above ground level.

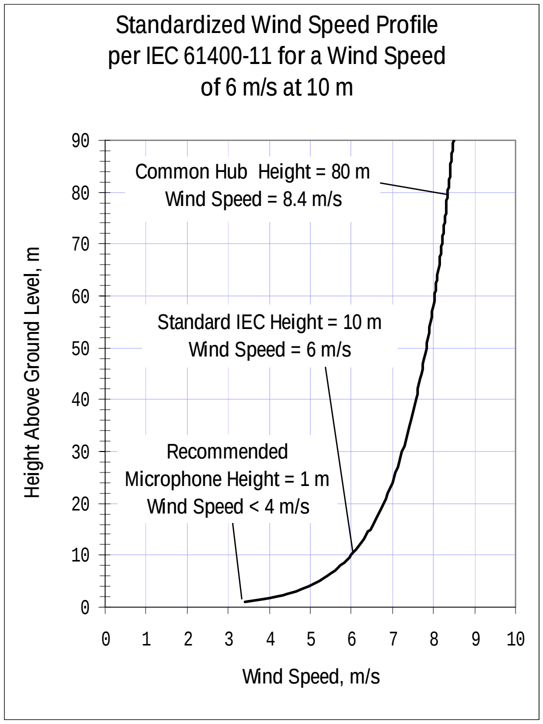

Figure 4.3.3.1

For these moderate wind conditions, the wind speed at a 1 m microphone height would be less than about 3 or 4 m/s, which as shall be seen later, means that distortion from wind blowing through the windscreen is of little or no consequence with respect to the A-weighted sound level so long as an extra large windscreen is used (typically 7" in diameter, as a minimum).

In addition to arranging for the microphone to be about 1 m off the ground so that it is not adversely affected by precipitation, it is also necessary to keep the instrument itself dry and secure in a waterproof case, which is best mounted above the ground on a fencepost, utility pole or other support.

While the microphone can be remotely connected to the instrument with a cable and independently supported, another option is to use a self-contained system where the microphone is attached to the instrument case with a rigid boom to hold the microphone away from the box and the entire assembly is mounted 1 m above ground level with a strap as shown, for example, in Figure 4.3.3.2. While there is nothing wrong with supporting the microphone separately on a tripod there is a tendency, unique to wind turbine survey work, for tripods to blow over, even after being weighted down and/or firmly staked to the ground. The use of temporary metal fence posts to support either the microphone alone or the entire system is a more reliable option and is sometimes the only option in places where there are no existing supports, such as in open fields.

Figure 4.3.3.2 *Typical Integrating Sound Monitor with 7” Weather-treated Windscreen*

In addition to sound level meters it is also advisable to set up at least one temporary weather station at the most exposed measurement position in order to measure the wind speed at microphone height and other parameters such wind direction and rainfall. All weather data should also be logged in 10 minute increments for later correlation to the sound data.

4.3.4 *Measurement Quantities*

For a background survey of this type the principal quantity of interest is the L_{A90} statistical measure, which is the A-weighted sound level exceeded 90% of the measurement interval (10 minutes in this case). What this means is that the sound level is higher than the L_{A90} value most of the time and, conversely, that the L_{A90} level represents the near-minimum sound level for each interval. It essentially captures the momentary, quiet lulls between sporadic noise events, like cars passing by, and, as such, is a conservative measure of the environmental sound level.

The average A-weighted sound level, or L_{Aeq}, which is the fundamental metric for highway noise surveys and the calculation of the Day-Night Average Level, L_{dn}, is unsuitable for wind turbine background surveys in rural areas because this level is extremely sensitive to contaminating noise events, such as from occasional traffic, planes flying over or dogs barking – things that cannot be relied on to be consistently present and available to potentially mask project noise on a permanent basis. The L_{A90} measure, on the other hand, automatically excludes these events for the most part and essentially defines the true “background” noise floor.

4.4 Analysis and Interpretation of Results

4.4.1 *Data Analysis and Wind Speed Correlation*

At the completion of the survey the L_{A90} sound levels measured at all positions should be plotted together to evaluate their consistency and to determine if the levels in different settings should be segregated. For example, if the sound levels at sheltered valley locations are consistently lower than measurements on higher ground then the data should be analyzed separately to develop typical background levels for each setting. Somewhat surprisingly, the need for this kind of separate treatment is rare and the much more common result is for the sound levels at all of the positions to be generally similar in magnitude at any given time with each generally following the same temporal trends and intertwining with each other. As a typical example, the as-measured L_{A90} levels at 7 positions spread over a fairly large site in Southern Minnesota are shown below.

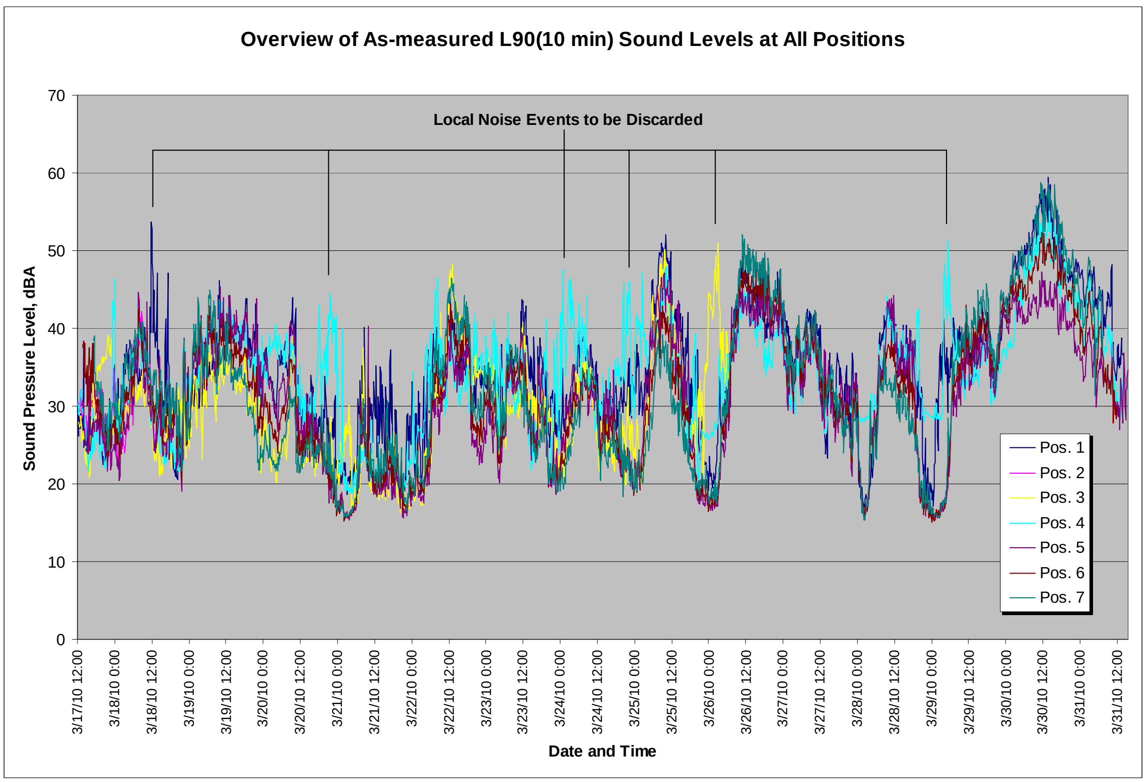

Figure 4.4.1.1

All positions follow each other and there is no one position that is consistently higher or lower than the others. Since these positions are miles apart from each other one would not expect exact agreement yet the levels are remarkably similar indicating that the environmental sound level over the entire site are is more or less uniform (sometimes termed a "macro-ambient"). If obvious contaminating events - those occurring at only one position - are discarded (as noted in the figure) the arithmetic average of the remaining data points can reasonably be considered the typical sound level over the site area. However, the question becomes: what is the sound level? The level varies substantially with time from almost complete silence (17 dBA) to nearly 60 dBA. The background level is obviously not a single number. The reason for this variation becomes clear if the average site-wide sound level is compared to the concurrent wind speed (Figure 4.4.1.2).

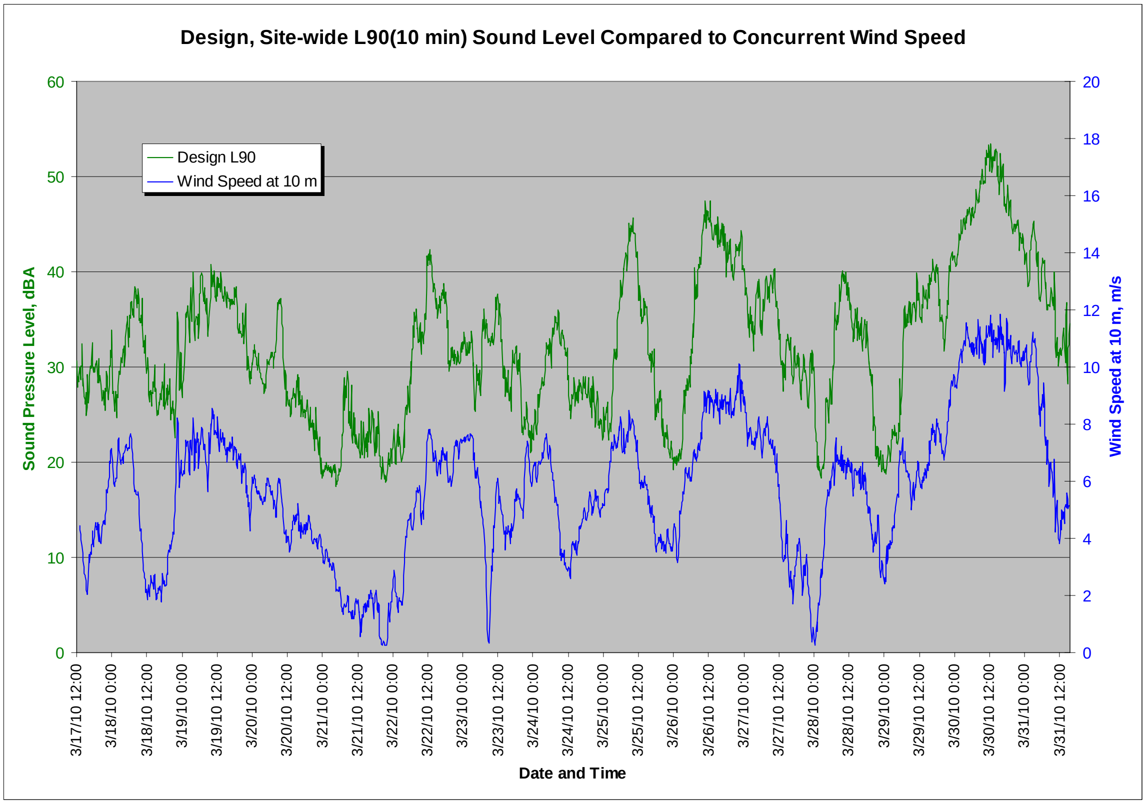

Figure 4.4.1.2

Clearly, the sound level in this area is driven by wind-induced sounds; in this case, mostly grass or crops rustling. Consequently, the sound level is almost entirely a function of the wind speed occurring at any given moment. This relationship can be quantified by re-plotting the sound levels in Figure 4.4.1.2 as a function of wind speed (normalized to a standard height of 10 m per Eqn (7) in IEC 61400-11).

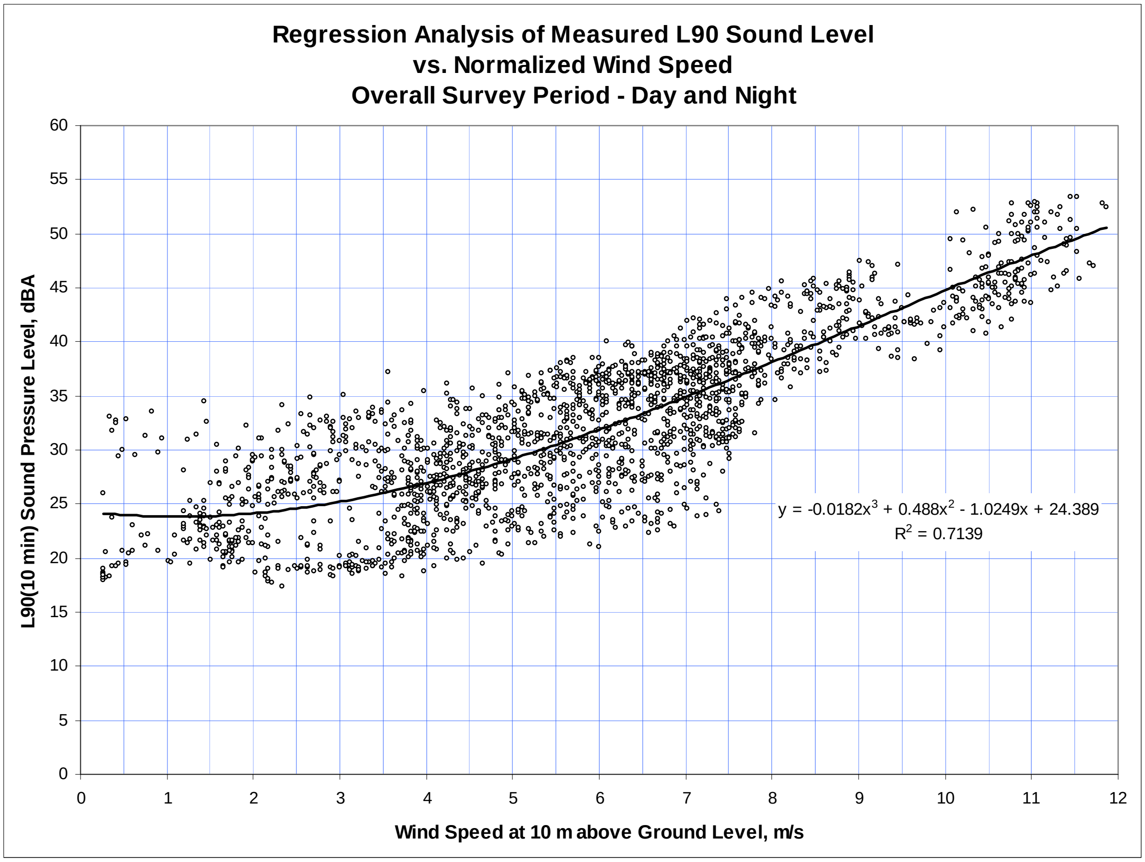

Figure 4.4.1.3

The central trendline through the data gives the mean L_{A90} sound level for any particular wind speed – at least in terms of the overall survey period.

It is important to point out in this context that, although the wind speed correlated to the sound data is the normalized value at the IEC standard elevation of 10 m, the measurement is actually taken at the top of the met tower, usually 60 m (197 ft) above ground level. Thus, the wind speed associated with turbine operation (not far below hub height) is directly correlated to the sound level measured near ground level; where the wind speed may well have been negligible. In other words, Figure 4.4.1.3 is *not* showing the relationship between the sound level and wind speed at the measurement position, as is quite often supposed.

4.4.2 *Daytime vs. Nighttime Levels*

Since nighttime conditions are of the most relevance with respect to potential disturbance from project noise, the data should be broken down into daytime (7 a.m. to 10 p.m.) and nighttime (10 p.m. to 7 a.m.) levels to see if it is significantly quieter at night - something that is not always particularly apparent in the level vs. time data (Figure 4.4.1.1). In this instance, the nighttime levels (Figure 4.4.1.4) are substantially quieter than during the day (Figure 4.4.1.5), particularly, in the vicinity of 6 m/s, which is usually the point where wind turbines first start to generate significant noise but the background level is typically still rather low thereby maximizing the potential audibility of project noise. In these examples, the mean background level for 6 m/s wind conditions during the day is 34 dBA while the nighttime level is about 28 dBA. Both of these levels are extremely quiet, but 28 dBA is so low that any potential masking from background noise can essentially be neglected as insignificant.

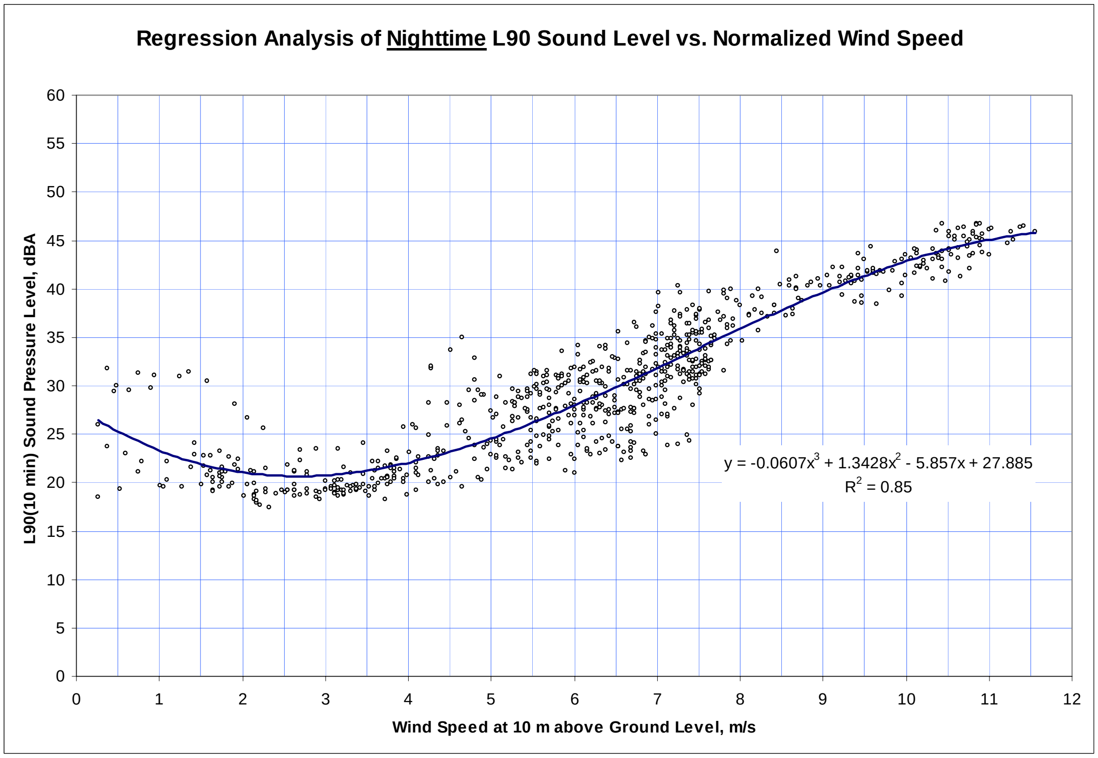

Figure 4.4.1.4

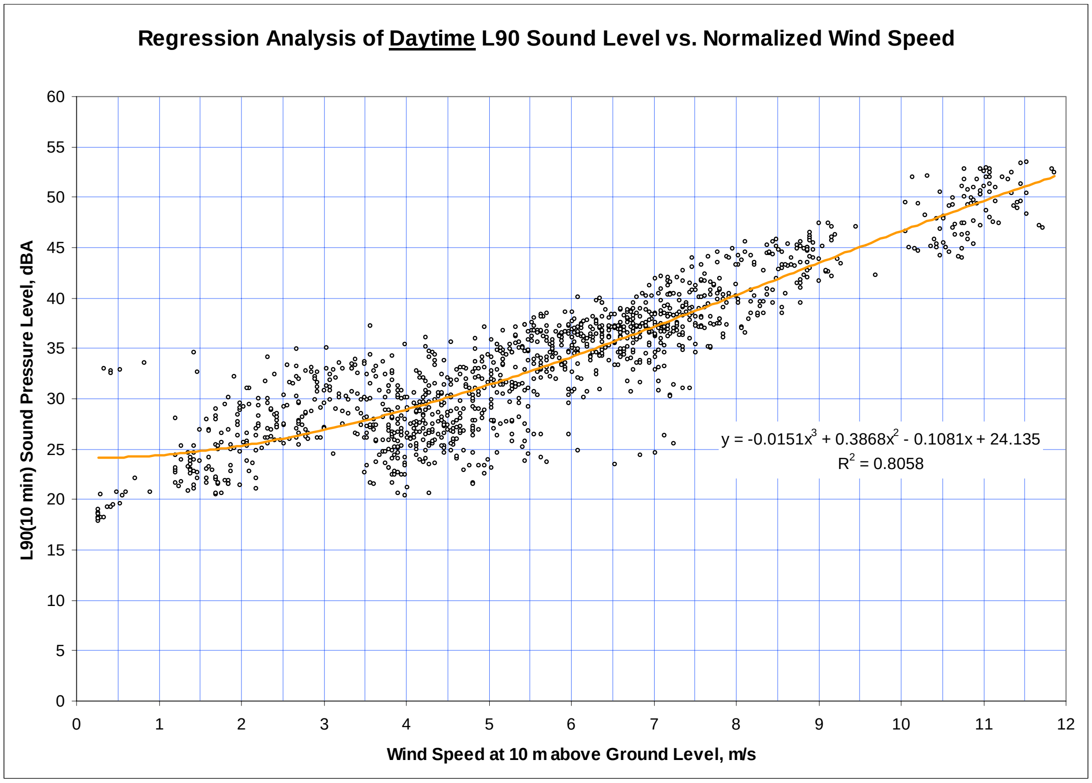

Figure 4.4.1.5

4.4.3 *Assessing the Potential Impact*

The sound levels measured in this survey, especially at night, indicate this site is an extremely quiet rural environment where any masking from wind-induced background noise can effectively be disregarded during moderate wind conditions (4 to 7 m/s). Under high wind conditions, say around 10 m/s, background noise is in the mid-40's dBA irrespective of time of day and therefore will act to partially obscure project noise, but during low wind conditions when the project is operating at low load an adverse impact can be expected unless the mean project sound level is kept to a relatively low level at residences. In this instance, it would be advisable to strictly design the project so that all residences are predicted to have average sound levels no higher than 40 dBA.

In general, background survey results may be used to establish a very rough impact threshold of 5 dBA over the ambient when the nighttime L_{A90} is about 35 dBA or more under what is usually the critical wind speed of 6 m/s. For example, if the measured level is 40 dBA then little adverse reaction might be expected from project levels up to 45 dBA (predicted with the project operating during comparable 6 m/s wind conditions). This 5 dBA increase metric does not hold for very low background levels (<35 dBA) because the background sound level and the project level both become so low as to be insignificant in absolute terms. If the background were 10 dBA, for instance, there would be no need to design a project to not exceed 15 dBA – both levels represent almost complete silence and are inconsequential. For low background situations like the example discussed above the outcome of the survey would be to set a firm upper limit of 40 dBA at residences. In terms of a potential noise impact, a low background level combined with predicted project levels of more than 40 dBA at numerous residences would be an undesirable situation likely to lead to complaints.

Although 6 m/s may be assumed in most cases to be the critical wind speed - i.e. the point where turbine noise is likely to be loudest relative to the amount of background noise available to potentially obscure it – the site-specific critical wind speed may also be calculated by comparing the sound power levels of the particular turbine model planned for the project with the L_{A90} background levels actually measured at the site. The critical condition corresponds to the point where the simple differential between these two values is maximum, as illustrated in the following example.

Table 4.4.3.1 *Comparison of Turbine Sound Power Levels to Measured Background Levels to Determine Critical Wind Speed*

Wind Speed at 10 m, m/s	Measured Overall L_{90}, dBA	Turbine Sound Power Level, dBA re 1 pW[c]	Differential
4	27	95	68
5	29	99	69
6	**32**	**102**	**70**
7	35	104	69
8	38	104	66
9	41	104	63
10	45	104	59
11	48	104	56

In this case (based arbitrarily on the data in Figure 4.4.1.3) the maximum differential of 70 occurs at 6 m/s – meaning that the sound emissions from the turbine are the highest at this particular point relative to the background level indicating that project noise would theoretically be most audible under these conditions. Ironically, the maximum audibility point does not usually correspond to the wind speed when the turbine first reaches its maximum noise emission point (in this example 7 m/s and a sound power level of 104 dBA re 1 pW).

As a side note, this analysis illustrates one of the reasons why it is beneficial to normalize the met tower wind speed data to 10 m; namely, because wind turbine sound power levels are expressed as a function of wind speed at 10 m above grade (and not at hub height). Consequently, the background sound levels and the turbine sound levels are all compared on an equal footing.

[c] The fundamental unit of sound power is Watts and sound power levels are expressed with reference to 1 picoWatt, or 10^{-12} W. By convention this reference is explicitly stated to help distinguish power levels from pressure levels, which are measured in terms of Pascals.

5.0 Measuring Wind Turbine Sound Emissions

5.1 Project-wide Compliance Testing

5.1.1 *Historical Approaches*

In general, it has been difficult, historically, to devise or settle on a completely satisfactory methodology for testing newly completed wind projects for the purpose of determining whether or not they are in compliance with permit or regulatory conditions. One of the principal stumbling blocks has generally been accounting in some meaningful way for background noise, since the total measured sound level at the typically substantial distances to residences and, therefore, the point of measurement, commonly contains a very prominent background component that cannot be disregarded without causing the result to be erroneously high. It is, of course, the project-only sound level and not the total sound level that is limited by regulations. Consequently, it is the project-only sound level that is sought in such surveys.

Existing guidelines and standards that mention the topic of compliance testing at all do not lay out or detail test procedures that are entirely satisfactory in this and other respects. For example, the often beleaguered[30] ETSU-R-97 report *The Assessment and Rating of Noise from Wind Farms*[31] published by the Department of Trade and Industry in the U.K. addresses the issue of background noise in one sentence, quoted below, by suggesting simply that one might want to measure operational turbine noise at night.

> To minimize the effects of extraneous noise sources it may be necessary to perform these measurements during night-time periods when other human and animal activity noise sources are likely to be at a minimum.

This approach, which involves measuring only for a relatively short period of time (20 to 30 $L_{A90,\ 10\ min}$ samples), is connected with the idea of taking measurements only at, or close to, a specific critical wind speed identified from "monitoring", carried out in an unspecified manner, and correlated to logged observations by complainants as to when the "noise is most intrusive" (ibid). In short, the idea is for the test engineer to be physically at the location and ready to take measurements when the wind conditions that result in maximum noise are occurring - so long as those conditions are happening at night on a night when the background sound level is negligible (i.e. roughly 10 dBA or more lower in magnitude than the turbine sound level). As might be imagined, the unfortunate reality is that the probability of all these things coming together at the same time is miniscule. In particular, it is typically difficult, for a number of reasons, for a test engineer to schedule a site visit to coincide with a particular wind speed or direction.

In general, the notion of being on hand to observe and measure wind turbine noise when it is at its loudest may sound reasonable on paper but it is seldom practical to actually do it.

Another approach to the issue of background noise that has been used, for example in the New Zealand Standard NZS 6808:1998 *Acoustics – The assessment and measurement of* *sound from wind turbine generators*[32], is to measure the background level at one time, say, prior to construction or start-up, and the operational noise from the project at another time - and then subtract the two to derive the project-only sound level. While this is often thought of or suggested as a reasonable approach, the problem is that both the background and wind turbine sound levels are extremely dependent on circumstances that vary significantly with time in both the short and long-term. The two sounds are highly specific not only to the prevailing wind speed at a particular time but also to factors such as the stability of the wind (whether it's gusty or constant in nature, for instance), wind direction, shear gradient, thermal gradient, time of day and time of year. Moreover, the background level is also exclusively influenced by foliage (bare trees vs. leafed out trees, for example), insects, frogs, distant or nearby traffic, farm equipment and a myriad of other human activities that occur sporadically and unpredictably. Consequently, a background sound level measured days, months or years before can't be used with a tremendous amount of confidence to correct a later measurement of operational noise, even if both have been normalized to similar wind speed conditions, because so many other unquantifiable factors may have had a hand in shaping the final results. What is needed, of course, is the background sound level that would have existed at that particular time and at that place if the project had not been operating.

This latter objective can sometimes be essentially realized by using the technique of temporarily shutting down, or parking, the nearest turbines to a measurement position, if not the entire project. While this technique has its applications, which will be discussed later, it is not usually a practical method that can be used for a general site-wide compliance test. Widespread or complete shutdowns would be required repeatedly over a variety of wind speed conditions and times of day to get even a minimally complete set of usable background levels.

Thus, there are certain impracticalities associated with the few existing guidelines, standards or common practices that deal with the testing of operational noise from wind turbine projects.

5.1.2 *Test Methodology*

The suggested methodology outlined below, which has been developed over time through field experience on a variety of wind projects, does not purport to completely solve the problems of background noise and capturing the periods of maximum noise, among other things, but it has been found to work very well in numerous field applications.

5.1.3 *Survey Duration and Scheduling*

In order to overcome the problem of being on hand to take short-duration measurements when conditions might favor noise generation at the source and/or sound propagation from the turbines to typical receptor points, a long-term, continuous monitoring approach is needed in which multiple instruments are set up at key locations and programmed to run day and night for a period of about two weeks or more. In essence, it is necessary to capture sound levels during a variety of wind and atmospheric conditions; something that is extremely difficult to achieve by taking intermittent manned samples, which amount to static snapshots of a dynamic situation.

Field experience suggests that an adequate range of wind speeds, from 0 to 10 m/s at 10 m above ground level, will usually be observed over any given 14 day period at most wind energy project sites, except perhaps during the low wind season at sites that might have very pronounced seasonal wind characteristics.

As a practical matter, the instruments for such a survey are set up, started and left to run unattended for the nominal two-week test period following which they can be retrieved and downloaded.

In terms of scheduling, it is highly preferable to conduct this type of survey during cool season, or wintertime, conditions to eliminate or at least minimize possible contaminating noise from summertime insects, frogs and birds. In addition, it is best for deciduous trees to be leafless at sites where they are present in quantity to decrease this source of wind-driven background noise and maximize the signal to noise ratio. Human activity, such as from farm machinery or lawn care, is also normally lower during the winter. While summertime surveys have been successful they should, as a general rule, be avoided wherever possible because nocturnal insect noise, for instance, can easily render the project sound level indeterminate at some or all of the measurement positions. If measurements are required during the summer, and they often are for reasons of project scheduling, high frequency contamination can be analytically factored out by taking the measurements in octave or 1/3 octave bands and correcting the spectra, as will be discussed later in greater detail.

In addition to seasonal concerns, it is desirable; when practical, to attempt to schedule the survey set up to just precede a predicted period of moderate or high winds. This not only ensures that the survey period will capture these winds but also creates an opportunity for manned observations and measurements to be made for a day or two to augment to the longer term monitoring survey. There is generally nothing to observe or measure at a wind turbine site when the winds are calm, so if one can be on site with the proper equipment just before a windy period useful short-term measurements can probably be made that can later be viewed within the context of the long-term monitor results for that time period.

As an alternative or supplemental approach, another opportunity for these supplemental manned observations can sometimes be arranged by coordinating the instrument retrieval visit with a predicted windy period. The specific end date for the survey is usually flexible, although instrument battery life is normally the limiting factor. The principal danger in carrying out manned measurements just before the end of a survey, however, is that all of the long-term monitors may not still be recording due to power supply issues or any number of other lamentable and sometimes comical things, such as tampering, weather damage or the removal of the windscreen by livestock.

5.1.4 *Test Positions*

The test positions should be selected to capture data at a number of potentially sensitive receptors (usually non-participating and participating residences within or near the site area) or other relevant points of interest, where maximum project sound levels might be expected either from modeling or a simple inspection of the site plan. In just about every case, it is not practical or even possible to establish a monitoring station at every house in the vicinity of a project so it is necessary to carefully select a limited but adequate number of sites that are representative of the worst-case exposures at potentially sensitive receptors in all relevant settings. Examples of specific settings would be: homes in sheltered valleys below ridge top turbines; homes on high, open ground with exposure to the wind and nearby project turbines; homes in generally flat open country with turbines in multiple directions; homes in wooded area; homes on the outer edge of a project area, etc. Because every site is unique the number of monitoring stations required to adequately evaluate project noise will vary but the general concepts are to reasonably account for different settings, to cover a number of points were maximum project sound levels are likely to occur at residences and to cover the entire project area with a generally even but somewhat random distribution. Adding one or two deliberately random positions can help increase the statistical independence of the data and avoid inadvertent bias. For sparsely populated sites in open and uniform farm country only about 4 or 5 on-site monitors might be needed while at more densely populated sites with more complex topography the number of monitoring stations would only be limited by the quantity of equipment reasonably available to the test engineer either from in-house stock or outside rental. Realistically, it is seldom possible to gather enough equipment for more than about 10 to 14 on-site monitoring points, but that is normally enough. A typical survey at a fairly large project site with numerous residences intermixed with the turbines might call for about 10 positions at receptors within the project area.

As mentioned above, the general objective is to capture sound levels throughout the site area at key receptors in all distinct settings within the project area. In addition, it is commonly necessary and desirable to establish a measurement position at all homes where complaints or concerns about noise have been expressed to the operations staff. In these instances, it is sometimes possible to enlist the help of residents by having them try to keep a date and time log of when the noise becomes particularly noticeable or unusually loud or when other non-project sounds are present; for example, from lawn moving, farm activity, etc. When this is actually done the comments can provide some valuable insights that help explain and identify peaks in the recorded sound levels.

It is often assumed that project noise is of no concern to project participants who were, and presumably still are, favorably disposed to the project and are receiving lease royalties for units on their land; however, experience at a number of sites suggests that this is not always the case largely due to the confluence of two factors: (1) these residences are typically the closest ones to turbines (sometimes only a few hundred feet away) and (2) the actual sound levels from these nearby units can turn out to be substantially louder than they expected them to be or they were led to believe. Consequently, monitoring at the homes of project participants in response to complaints is fairly common – even though participants are often, but not always, technically exempt from ordinance or permit noise limits.

It is usually best to start the site selection process a week or two in advance of the actual survey by circling proposed measurement areas on a site map or sound contour plot and submitting this to operations personnel at the site for their input on who, within or near each designated area, might be willing to host a sound monitor at their house and where else, outside of these proposed areas, it might be also be desirable to measure (at complaint locations, for instance). The objective of this preparatory review is to obtain approval and permission from homeowners to set up equipment on their property prior to arrival. Although it is desirable to inspect the proposed locations and make a judgment as to their suitability in person, attempts to arrange for permission on the day of the survey are often unsuccessful due to the simple fact that people are not at home and cannot be reached. Calling ahead usually settles the issue before the equipment is shipped to the site. Setting up the equipment in the rear yard of a house where permission has been obtained generally ensures that the equipment will still be there upon returning at the end of the survey, that the equipment won't be interfered with and that it can be minimally attended to, if necessary (replacing the windscreen after the family dog has run off with it, for example). Positions that are not at anyone's house, such as on utility poles along the public right-of-way, are sometimes necessary to collect data at strategic locations without a suitable host, but they do not have any of these advantages and, in fact, the risk of theft or tampering is uncomfortably high.

In terms of the specific placement of the monitor at each position, it should be located in an area representative of but away from the house, or any other building with large reflective surfaces, and that is not prone to frequent activity or contaminating local noises, such as from air conditioning units, milking machines at dairy farms or flowing streams or rivers.

As a final note on placement, it is best to avoid using fences or posts to mount the monitor or microphone in areas where livestock or other domestic animals may be able to get at the equipment during the survey. Microphone windscreens are evidently of keen interest to cows, horses and dogs, among others.

5.1.5 *Background Noise*

On the important issue of background noise, an approach that has worked well in a number of field applications is to set up a number of monitoring stations outside of the project area in settings similar to those at the on-site monitor positions. Of course, considerable judgment is involved in selecting these positions but in an ideal situation of, say, an isolated project in open farm country that is largely uniform in character both within and beyond the project area one would want monitors at least 1.5 to 2 miles from the perimeter of the project (nearest turbines) in the four cardinal directions. The locations should be far enough away that project noise is negligible and yet close enough that they are reasonably representative of the site area. At the end of the survey the off-site positions can then be evaluated for consistency. If the levels are generally similar, and, somewhat surprisingly, this is usually the result, the average can be taken as a time history record of the background sound level that probably would have existed within the site area and then used to correct the on-site measurements taken, importantly, at the same time under identical environmental conditions.

Figure 5.1.5.1 below is an example from a site in the Eastern United States where the landscape is rural and generally homogenous in nature within the project area and for some distance beyond it in terms of topography (rolling hills), vegetation (a mix of farm fields and wooded areas) and population density (farms and residences scattered more or less uniformly over the site area). The 80 or so 1.5 MW turbines are spread throughout a roughly 20 sq. mi. project area on numerous parcels of private land and thoroughly intermixed with the residences in the area. Proxy background measurement positions were set up about 1.5 miles beyond the perimeter of the turbine array to the northwest, east and south of the project (a neighboring wind project to the west prevented measurements in that direction) at locations that were similar in character to the various settings near on-site residences: one was on an open and exposed hilltop, another was at the edge of a field with nearby trees and a third was essentially in a forested area. The expectation was that there might be a consistent difference between these different positions – with the sheltered forest location being quieter than the windy hilltop, for instance – in which case background corrections for a particular setting would be applied to on-site measurements at positions with comparable settings. However, as can be seen from the figure, the levels at all three locations, each many miles from the others, were largely the same at any given time and, perhaps more significantly, no one position is consistently higher or lower than the others. Consequently, the arithmetic average of all three, with the site area physically lying between them, can be taken as a reasonably reliable estimate of the on-site background level at any particular time that accounts for the specific wind speed, direction, time of day and atmospheric conditions prevailing during that 10 minute period.

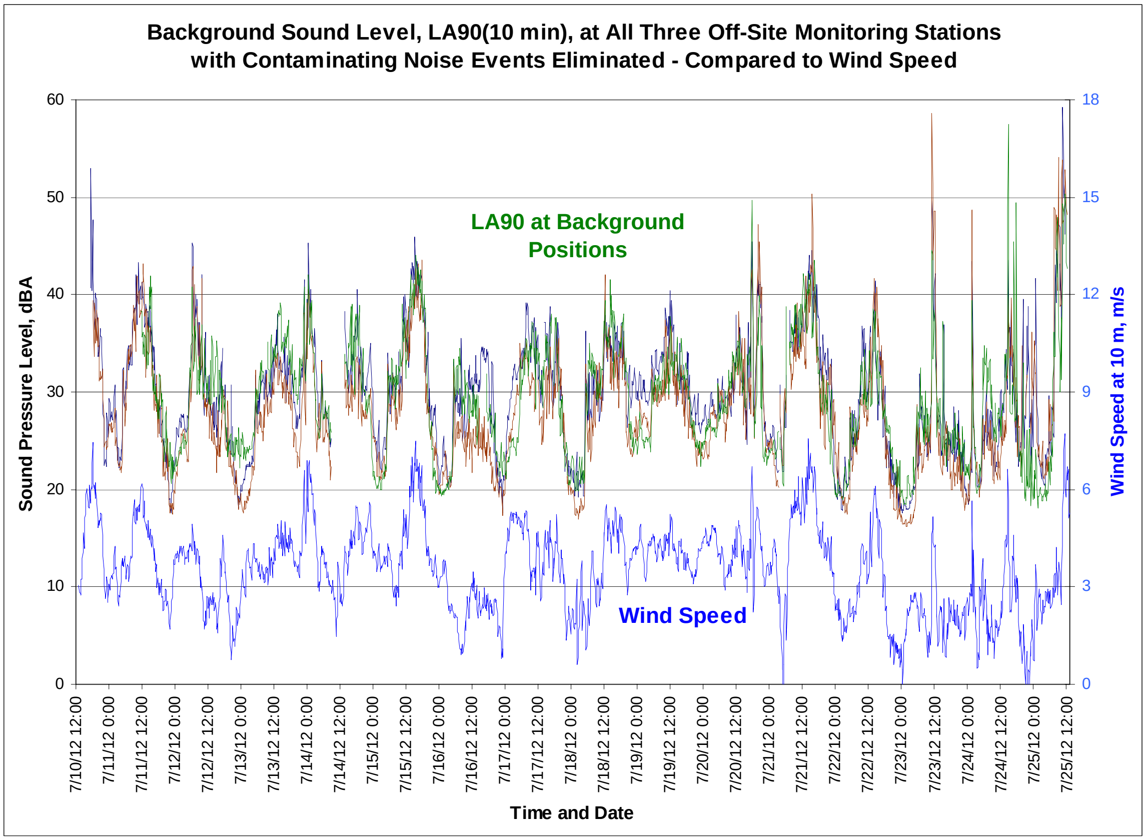

Figure 5.1.5.1 *Measured Background Sound Levels at Three Off-Site Proxy Positions*

The data in Figure 5.1.5.1 have been edited to remove noise spikes that were observed only at one position and not at any others, indicating a contaminating local noise event that is not representative of the area as a whole. Spikes were also deleted (from both the on-site and background data) if there were no concurrent spike in wind speed, even if they may have occurred at multiple locations, on the premise that the noise was not associated with the turbines and may have been due to thunder, rain, a helicopter flyover or some other area-wide noise event.

The results shown in the example above are not unique to that site and a similar consistency between the off-site proxy location sound levels has been observed at a number of other projects in rural areas even though the background monitors are deliberately set up in diverse settings. Fortunately, for the purpose of estimating simultaneous background sound levels, most wind projects are located in rural areas but, of course, not all of them are and other situations exist. In urban settings or near major highways the background sound is no less important, in fact more so, but its dependence on wind and atmospheric conditions is greatly diminished, if not relegated into complete insignificance. In such cases, the proxy background technique is still theoretically viable although the selection of background positions that are representative of receptors potentially affected by project noise becomes highly specific to the circumstances at each receptor. In the case of a highway, for instance, one might try to find a background position that is the same distance from the roadway as the actual point of interest and similar in all other ways but far enough from any turbines that they are undetectable. In this kind of a complicated situation where the background level is more dependent on man made noise than natural, wind-induced sounds it may be necessary to perform a pre-construction survey at the key receptors near turbines and at a number of candidate background positions to evaluate the validity of the proxy locations before the project turbines become operational.

5.1.6 *Sound Test Equipment and Set up*

As with any field sound survey, what equipment is used and how it is deployed must adhere to certain minimum technical standards. Most environmental sound measurement standards recommend the use of Type 1 precision equipment per IEC 61672-1[28] or ANSI S1.43-1997[29] while also allowing for the use of Type 2 equipment. There is certainly no reason on technical grounds to oppose this recommendation but, from a practical perspective, it is often necessary to use Type 2 equipment for surveys of this type because of the large number of instruments needed. The utterly intangible difference in technical performance between these two instrument classes is totally inconsequential within the inherently and unavoidably imprecise nature of this type of survey. It is much more important that the equipment is durable, reliable and specifically designed for extended use in the outdoors.

Although high cost and extreme precision are not essential, the functional capabilities to statistically integrate sound levels over a user defined time period and automatically store the results are necessary. Because the on-site wind and weather monitoring towers, or met towers, normally integrate and store measurements in 10 minute increments it is convenient, if not necessary, to measure and store sound data in synchronization with the wind data collected by these towers for later correlation. It is evidently universal practice for met towers to store data 6 times an hour in 10 minute intervals that begin at the top of the hour; as in 9:00, 9:10, 9:20, etc. Consequently, sound data logging should be started using a trigger function to begin at the top of an hour and not randomly by the manual push of the start button. The timers on all instruments should be exactly synchronized to local time or to the project's SCADA control system clock, if it is different from the actual time, which it often is.

Of course, all of the instruments must be field calibrated at the beginning of the survey and checked again for drift at the end of the survey.

Because this long-term survey approach involves unattended monitoring, the instrument and the microphone must be capable of withstanding damage, interference or outright destruction from rain and snow, which, among other things, means that the ground plate technique specified in IEC 61400-11 – where the microphone is laid flat in the center of a board on the ground and covered with one or more hemispherical windscreens – is not a viable option despite its otherwise highly desirable advantage of minimizing wind-induced pseudo noise. Consequently, the microphone must be mounted above ground level and protected from wind-induced distortion by a spherical weather-treated windscreen, which normally entails a higher density foam that is hydrophobically treated to shed water (windscreens and wind-induced noise are discussed in detail later). As a general rule, a slightly lower than normal microphone height of about 1 m above ground level is preferred for this application on the premise that wind speed diminishes exponentially with decreasing elevation theoretically going to zero at the surface, or boundary layer.

For these moderate wind conditions, which are often when turbine noise tends to be most prominent relative to the background level, the wind speed at a 1 m microphone height would be less than about 3 or 4 m/s, which as shall be seen later, means that distortion from wind blowing through the windscreen is of little or no consequence with respect to the A-weighted sound level.

In addition to arranging for the microphone to be about 1 m off the ground so that it is not adversely affected by precipitation, it is also necessary to keep the instrument itself dry and secure in a waterproof case, which is best mounted above the ground on a fencepost, utility pole or other support.

While the microphone can be remotely connected to the instrument with a cable and independently supported, another practical option is to use a self-contained system where the microphone is attached to the instrument case with a rigid boom to hold the microphone away from the box and the entire assembly is mounted 1 m above ground level with a strap. While there is nothing wrong with supporting the microphone separately on a tripod there is a tendency, unique to wind turbine survey work, for tripods to blow over, even after being weighted down and/or firmly staked to the ground. The use of temporary metal fence posts to support either the microphone alone or the entire system is a more reliable option and is sometimes the only option in places where there are no existing supports, such as in open fields.

5.1.7 *Weather Stations and Wind Speed Monitoring*

In addition to the sound monitors it is also advisable to establish at least one temporary weather station at the sound monitoring position with the most exposure to wind. The primary reason for this station is to measure the maximum wind speed at microphone height (about 1 m) for use in correcting the measured sound data for wind-induced distortion as described in a later section. Wind speed at 1 m, direction and rainfall are the primary parameters to be recorded by this station, or others set up in other settings as appropriate, such as at a sound monitoring position sheltered from the wind by the local terrain (to demonstrate, for instance, that wind-induced distortion is negligible at such locations). This data should be integrated and stored in 10 minute blocks in synchronization with the sound monitors.

This temporary anemometer at 1 m above ground is solely there to evaluate microphone wind exposure and it is the on-site met tower anemometers, usually at 50 to 80 m above ground level, that should be used to correlate the measured sound levels at ground level to the wind speed essentially experienced by the turbine rotors. Turbine nacelle anemometers scattered throughout the site may also be used to determine wind speed, but this is somewhat less desirable because a free field correction usually needs to be applied to this data to account for the energy extracted from the wind by the rotor just upstream of the wind speed sensor.

It is customary to normalize mast top or nacelle wind speeds to a standard elevation of 10 m above grade per IEC 61400-11. It is this result that is compared to the measured sound levels.

5.1.8 *Measurement Quantities and Parameters*

The objective of a compliance survey is to extract the project-only sound level from the total soundscape and compare that result to the permissible limit. As such, the principal challenge is identifying and eliminating contaminating noises that are unrelated to the project over many days and thousands of measurements. If it were practical to take a manned sample for 20 minutes, removing spurious noises by pausing the instrument or discarding contaminated subsamples, and declare the result as the performance of the project it would be a trivial matter; however, over a relatively long time period of unattended monitoring it is necessary to use the L_{A90} statistical measure to generally perform this function in an automated manner, since it captures the consistently present sound level during relatively quiet periods between common interfering and identifiable noise events like cars passing by or planes flying over. A 10 minute sampling duration has been found to work very well since it allows direct correlation with met mast wind speed data and is generally short enough that fairly rapid changes in project noise are captured.

The use of the average, or $L_{Aeq,\ 10\ min}$, sound level or a finer time resolution of, say, 1 minute come to mind as alternatives to the L_{A90}, but these approaches have their own serious drawbacks. If the L_{Aeq} is used to measure at on-site positions with the idea of better quantifying turbine sound levels, then the L_{Aeq} measured at the proxy background positions must also be used as an apples-to-apples correction factor. But the L_{Aeq} is often completely unusable for this application. As an example, multiple statistical measures were recorded at the off-site background measurement positions previously mentioned in connection with Figure 5.1.5.1, including the L_{Aeq}. Figure 5.1.8.1 below shows the average L_{A90} and L_{Aeq} levels measured at all three locations compared to wind speed.

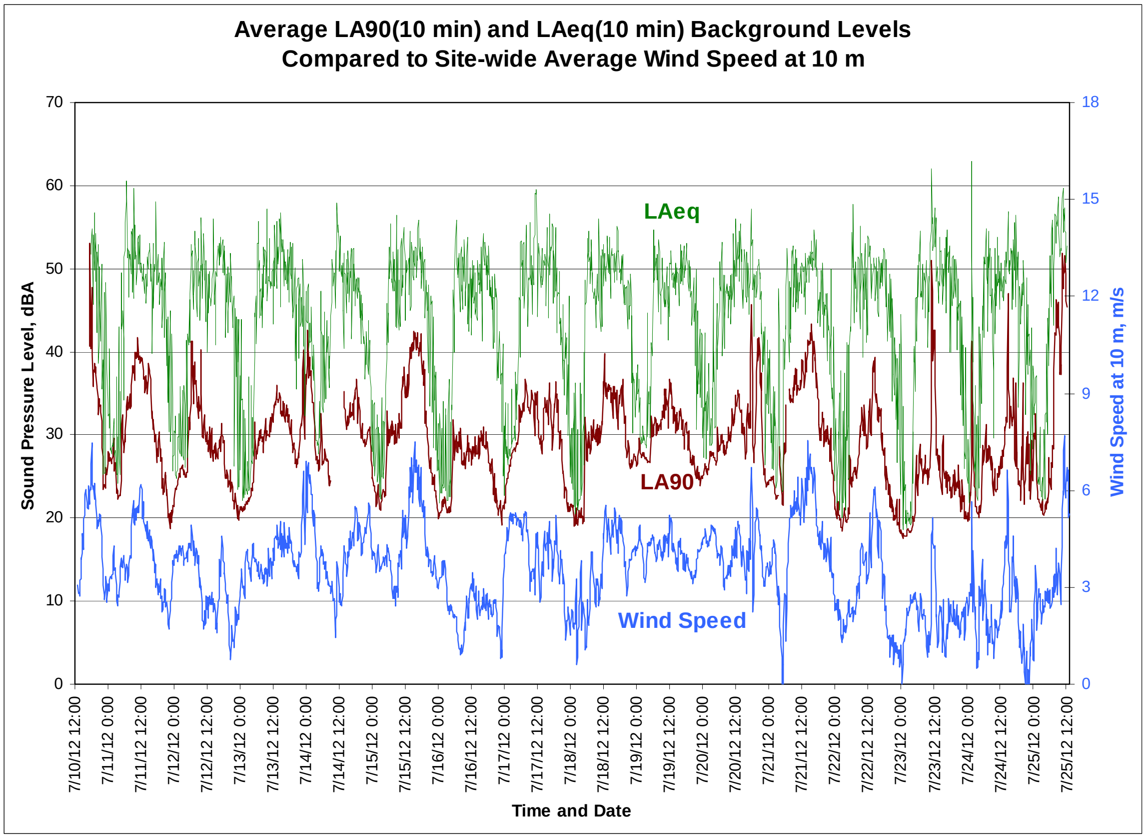

Figure 5.1.8.1

What is immediately obvious from this plot is that the $L_{Aeq,\ 10\ min}$ level is clearly driven by daily human activity; primarily intermittent vehicular noise on nearby sparsely traveled roads (noise that is filtered out by the L_{A90}). The L_{Aeq} levels rise to about 53 dBA every morning, stay there all day irrespective of the wind conditions and then gradually fall off in the evening hours bottoming out briefly somewhere around 23 dBA every night. The L_{A90} level, on the other hand, is clearly more attuned to the natural environmental sound level, which in rural areas like this one is normally a function of wind speed. The unsuitability of the $L_{Aeq,\ 10\ min}$ as a measure that might quantify project noise can be seen in Figure 5.1.8.2 where the average background L_{Aeq} level from Figure 5.1.8.1 is compared to the L_{Aeq} level measured at a typical, randomly selected on-site receptor.

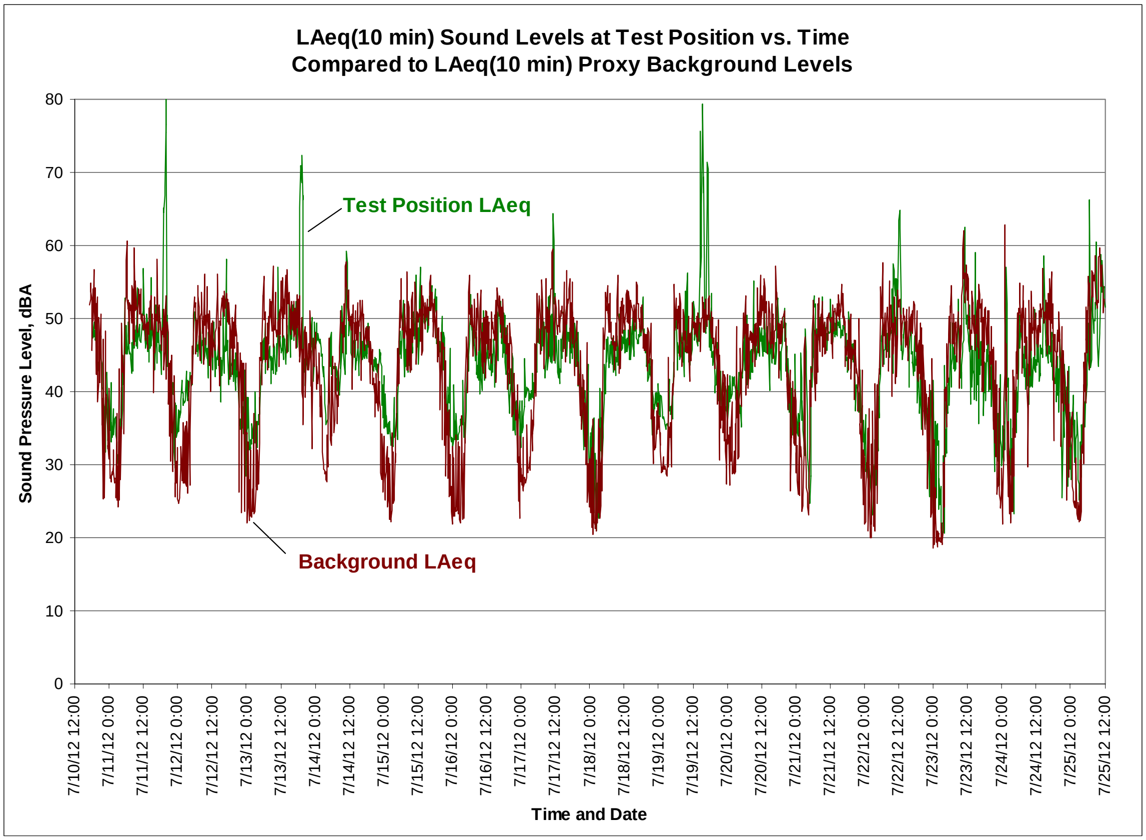

Figure 5.1.8.2

The $L_{Aeq,\ 10\ min}$ sound levels at both positions are virtually indistinguishable meaning that the project-only sound level simply cannot be deduced. Furthermore, it could even be reasoned that project noise is utterly inconsequential at this location because the on-site level is about the same or even lower than the off-site level, which is entirely free of any turbine noise, but, as we shall see later, that is not at all the case at this particular test position.

Finally, it is desirable to use instruments capable of measuring the frequency spectrum in 1/3 octave bands at one or two key locations with, usually Type 2, monitors measuring overall A-weighted levels at the majority of positions. The use of one or more frequency analyzers at key positions allows for some frequency analysis, although great caution must be exercised with the lower frequency bands, as discussed later, since wind-induced false signal noise is largely inevitable and the low frequency results cannot be taken at face value. Fortunately, this phenomenon does not significantly affect the measurement of A-weighted sound levels, however.

The use of 1/3 octave band analyzers is largely essential for surveys that, for one reason or another, must be conducted during summertime conditions when insect, frog or cicada noise is present. Measurements taken under these unfavorable conditions can be "corrected" to a certain extent by smoothing the high end of the frequency spectrum, where this kind of noise is usually obvious, and then recalculating the overall A-weighted sound level as shown in the (generic) example below.

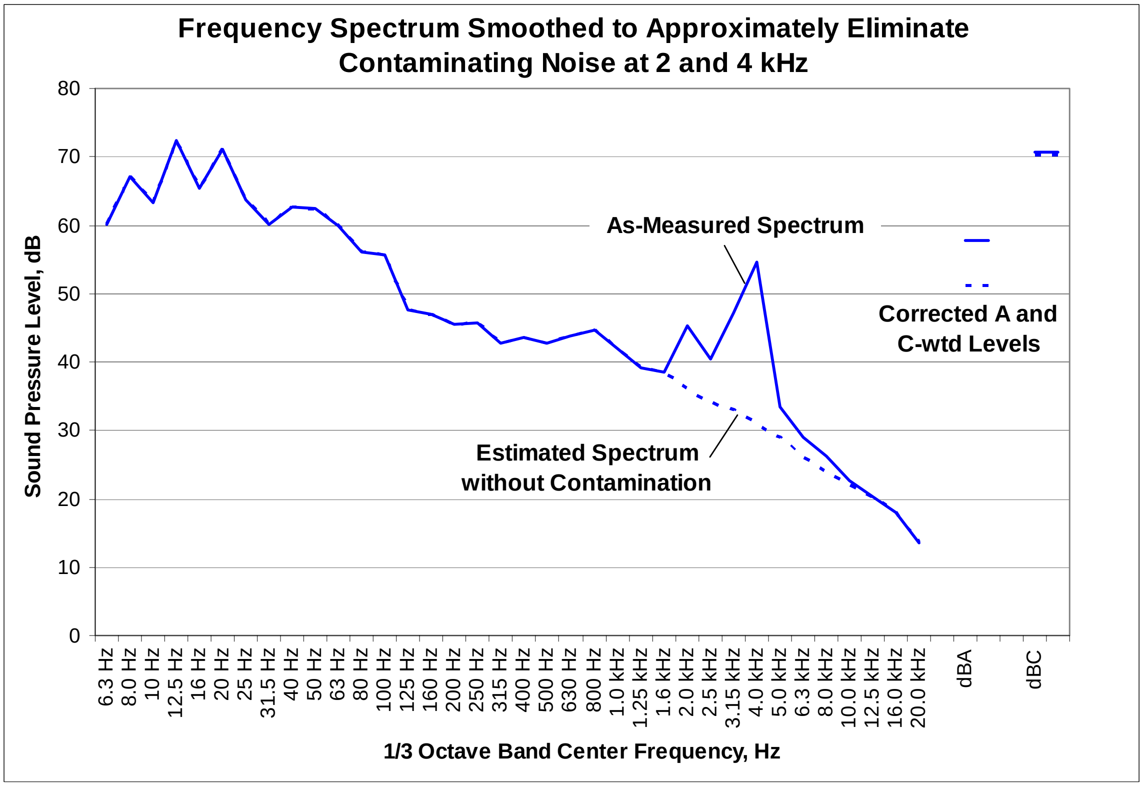

Figure 5.1.8.2

Of course, this correction would be laborious to perform for thousands or even just dozens of measurements so it is usually necessary to determine a typical correction, such as the -7 dBA adjustment that resulted in the example above, and apply that to all periods when this noise was apparently present. This is, of course, an imperfect remedy and the best policy is to avoid, if possible, measuring under these circumstances in the first place.

A solution to this common problem is currently being proposed by Hessler[33] and Schomer[34] in the form of a modified A-weighted network, termed “Ai-weighting”, where all of the measured sound above 1000 Hz, or the 1250 Hz 1/3 octave band, is disregarded in situations where insect noise is present and an adjusted A-weighted sound level is calculated from the truncated spectrum.

5.1.9 *Wind-induced Microphone Distortion*

One of the principal errors in measuring wind turbine noise is false signal noise from wind blowing through the windscreen and over the microphone tip, which is manifested in the form of artificially elevated sound levels in the lower frequency bands. Taken at face value any measurement made in moderately windy conditions will ostensibly indicate relatively high levels of low frequency noise, irrespective of whether a wind turbine is present or not. This measurement error is probably one of the principal reasons wind turbines are mistakenly believed to produce high, if not harmful, levels of low frequency and infrasonic noise.

Some degree of distortion is essentially inevitable in any measurement taken above ground level when the wind is blowing, even when using an extra-large windscreen. It is in an effort to minimize this error that the IEC 61400-11 test procedure prescribes measuring on a reflective plate at ground level, where the wind speed is theoretically, although often not actually, zero. As previously mentioned, this ground plate technique is fine for short-term, attended measurements but is impractical for long-term surveys due to the potential for rain or melted snow to damage the microphone. Consequently, for lengthy compliance and evaluation surveys it is necessary to measure above ground level using a large, weather-treated windscreen - perhaps augmented with a very large secondary windscreen, although the practicality of such devices is questionable in harsh winter conditions.

Because environmental sound measurements of most other sources apart from wind turbines are not generally conducted in windy conditions as mandated by applicable standards, the significance and even existence of this measurement error has long gone unnoticed. Although this phenomenon and its physical basis were theorized decades ago by Strasberg[35,36] it is only fairly recently that its relevance to wind turbine sound measurements has been examined in detail and quantified. In particular, the subject of wind generated self-noise was thoroughly reviewed in 2006 by van den Berg[37] where he showed that the magnitude of the distortion depends not only on the mean incident wind speed but also on the amount of atmospheric turbulence present at the microphone position (largely a function of the local surface roughness) and on atmospheric stability. Measurements taken at 1 or 2 m above a smooth surface during stable, nighttime atmospheric conditions, when the surface winds are usually light, generally contain the least amount of self-generated noise ultimately replicating the case where the principal noise generation mechanism is wake turbulence trailing off the windscreen. In other less ideal circumstances self-noise levels can be developed by estimating the local surface roughness and atmospheric turbulence factor, Ψ, from wind speed measurements at two heights and/or from observations of cloud cover, time of day, general wind conditions, or meteorological data, if available.

The minimum level of false-signal noise due to wind, excluding the effect of atmospheric turbulence, can be estimated based on an empirical wind tunnel study carried out by Hessler and Brandstätt in 2008[38] in which conventional ½” microphones fitted with an array of common windscreens and were subjected to known wind velocities in a massively silenced wind tunnel. The measured sound levels during each test were essentially a direct measure of the false-signal noise – although for more or less laminar flow conditions corresponding to an outdoor setting with a very low surface roughness in neutral atmospheric conditions. Nevertheless, for the specific windscreens examined it is possible to generally estimate both the overall A-weighted or un-weighted (dBZ) sound level of the distortion from the microphone height wind speed and then subtract it from the total measured level to *largely* reverse the error.

An example is shown in Figure 5.1.9.1 where the overall A-weighted level of self-noise is calculated as a function of wind speed and subtracted from the as-measured sound level. The plot is a three day detail of a wind turbine survey where oversized 175 mm (7") diameter treated windscreens (ACO Model WS7-80T) were used. This particular windscreen was found to be the best performer, in terms of minimizing wind-induced self-noise, in the wind tunnel study.

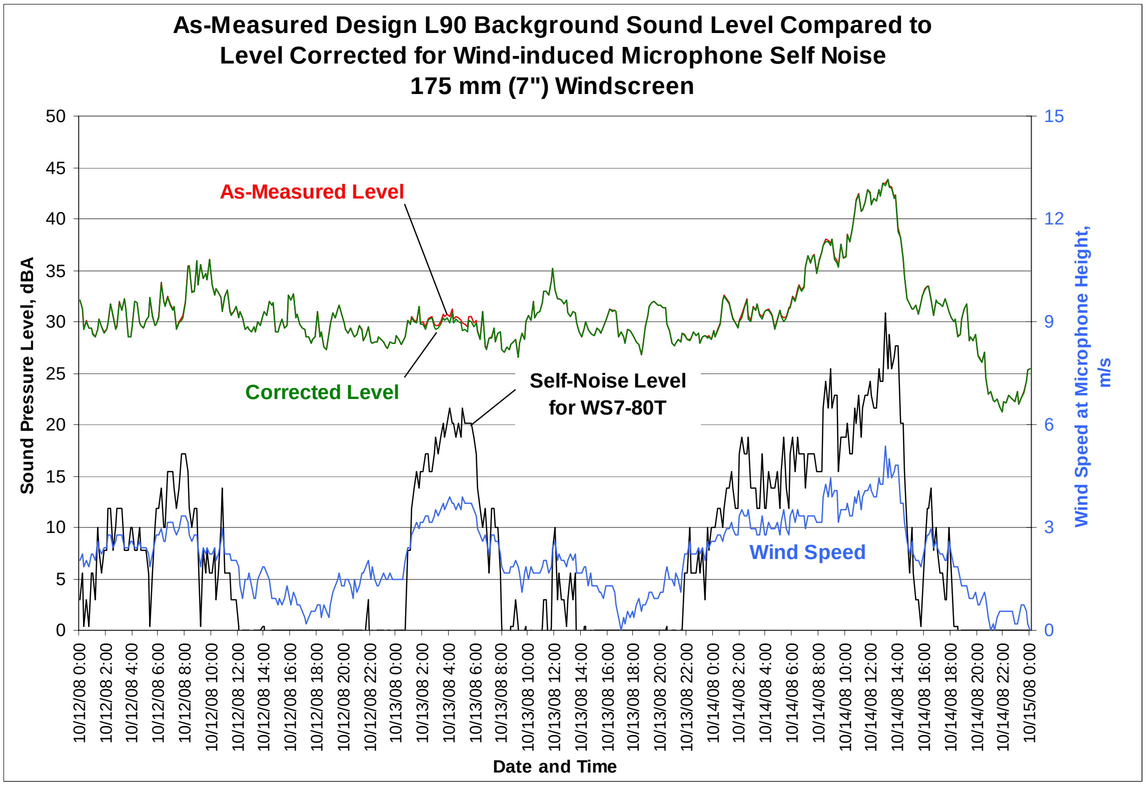

Figure 5.1.9.1

This figure shows the very typical result, at least where extra-large windscreens are used, that the correction is insignificant and can be essentially neglected when it comes to A-weighted sound levels. This is because with a large windscreen the distortion is confined to the very lowest frequencies where it has almost no impact on the A-weighted sound level. With a conventional 75 mm (3") windscreen, on the other hand, wind-induced noise begins to become significant in the mid-frequency region, between about 63 and 400 Hz, where it has much more influence on the A-weighted sound level. Consequently, standard windscreens are not recommended for this type of survey and windscreens with a minimum diameter of 7" are recommended for wind turbine field work.

The empirical wind tunnel study results for 175 and 75 mm treated windscreens are shown below.

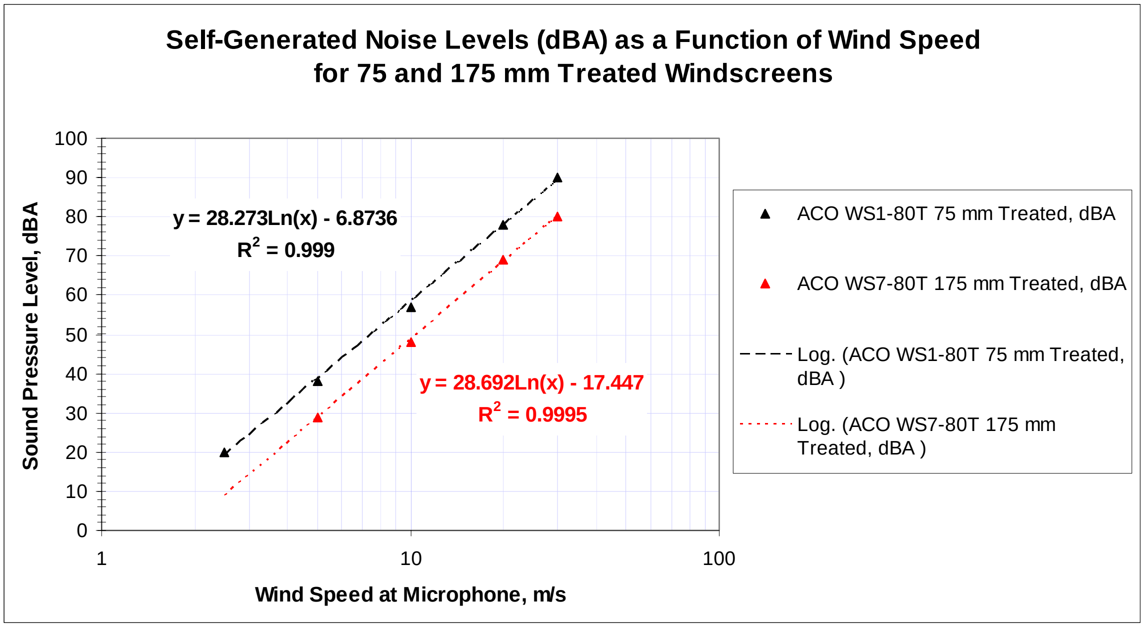

Figure 5.1.9.2

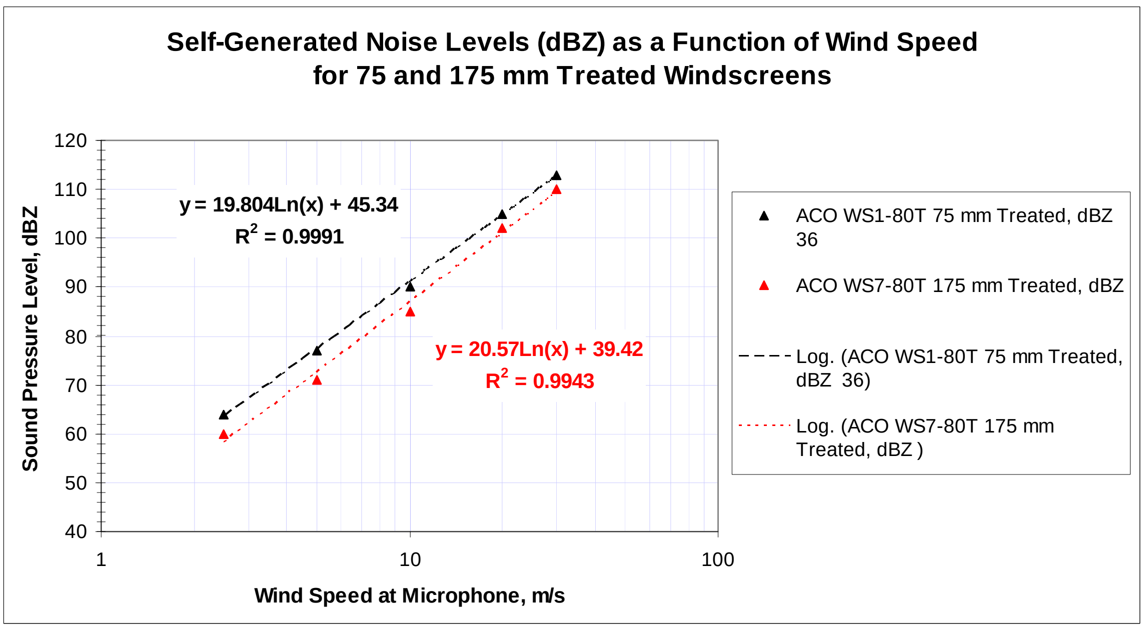

Figure 5.1.9.3

The overall level of self-generated noise for these windscreens may be estimated from the general expression below with the understanding that local atmospheric turbulence is not accounted for and a neutral atmosphere is assumed.

$$L_{p,self} = A \ln(v) + C, \text{ dB} \quad \text{for } v>1.5 \text{ m/s} \quad (1)$$

Where A and C are constants given in the table below and v is the normally incident wind speed at the microphone in m/s.

Table 1 *Constants for A and Z-wtd Self-Noise Calculation Algorithm (Neglecting Atmospheric Turbulence)*

Windscreen Type	A-weighted Sound Level, dBA		Un-weighted Sound Level, dBZ	
	A	C	A	C
75 mm (3”) Treated	28.273	-6.8736	19.804	45.34
175 mm (7”) Treated	28.692	-17.447	20.57	39.42

In a real atmosphere the sound level may be higher or lower than given in Table 1, depending on the turbulent energy present, which again depends on the stability of the atmosphere. In a neutral atmosphere, which occurs at higher wind speeds (> 6 m/s at 10 m height) or in very clouded conditions, the wind-induced level might be anywhere from 5 to 9 dB higher than the levels shown above. After sunset, when the atmosphere is more prone to be stable, the wind-induced noise levels will be more similar to the values given above.

5.1.10 *Correction for Background Noise*

Once a design L_{A90} background sound level has been developed from averaging the data collected at the off-site proxy positions it can then be subtracted in the usual logarithmic manner[d] from the levels measured at each of the on-site positions to deduce the project-only sound level. However, this correction process is only relevant to samples recorded while the turbines were actually in operation and not necessarily to all samples; consequently, the data must be sifted to ignore all periods of calm winds. This can be accomplished by dealing only with data sets collected above the effective cut-in wind speed for the turbine model in question (bearing in mind whether that wind speed is measured at 10 m or hub height) or, more preferably, by comparing the measured data to a time history of project electrical output obtained from the SCADA, or project control system. For this latter option it is best to compare the operational output of the 2 or 3 units closest to each on-site measurement position rather than the total project output because this not only accurately defines the on and off times at each monitoring station but also may reveal, the fairly common occurrence, that certain units were temporarily down for maintenance or due to some unexpected malfunction. The relevance of this, of course, is that the measurements of project noise during this period would not have captured the maximum possible sound level.

Because the proxy background level is, for practical reasons, an inexact estimation of the site-wide background level, there will usually be instances when the background level exceeds the total measured level at certain on-site positions. Under this circumstance, and when the background level is below but within 3 dB of the total level, the project-only sound level would normally be considered indeterminate. While the calculation of

[d] $Lp_{Project} = 10 \log [10^\wedge(Lp_{Total}/10) - 10^\wedge(Lp_{Background}/10)]$, dBA

the project-only sound level is mathematically possible when the background level is below but within 3 dB of the total level, doing so tends to create spurious mathematical artifacts where the project level can be estimated at unrealistically low and obviously incorrect sound levels. Since most standards, such as ISO 3746[39], essentially disallow this calculation it is best to follow that policy here as well.

5.1.11 *Typical Test Results and Comparison to Model Predictions*

Representative examples from typical test positions within two different wind projects using two different turbine models and located in two different states are discussed below as a way of illustrating the outcome of the test methodology outlined above.

Example 1

The first example is from a test position at a residence within a project in a rural area in the Eastern United States where the turbines and homes are thoroughly mixed together – a common situation in this region and the Midwest. This location is surrounded in nearly all directions by a number of turbines at various distances, the closest being about 490 m (1600 ft.) away from the home with another 10 lying within a 1500 m (4900 ft.) radius. The terrain is gently rolling hills with a mixture of open fields and wooded areas. Mild complaints about noise had been received by the project from the residents of this home, which is the primary reason it was selected as a monitoring position.

The overall test results from a two week measurement survey in terms of the total measured level at the test point, the design background level derived from proxy positions and the normalized 10 m wind speed, are shown in Figure 5.1.11.1. This is same test position that was previously discussed in conjunction with Figure 5.1.8.2 and L_{Aeq} sound levels.

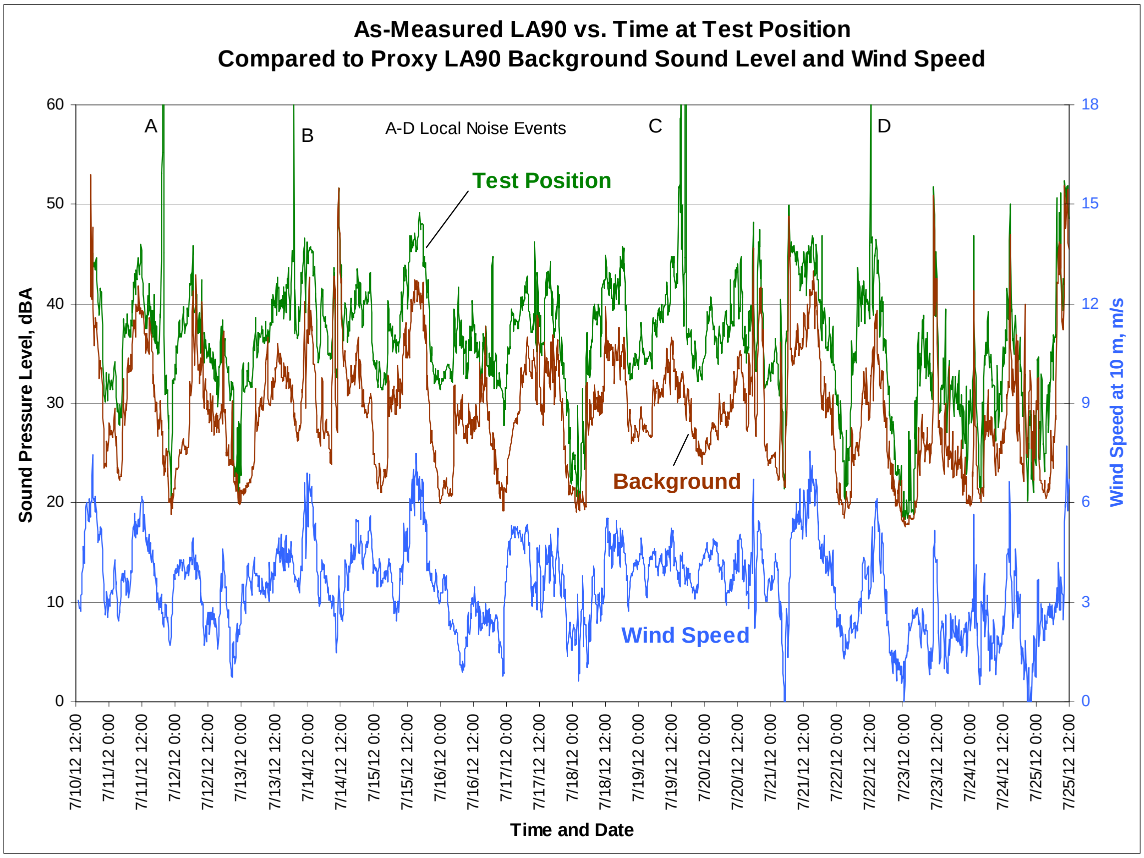

Figure 5.1.11.1

Although the raw results may appear unintelligible at first glance, a closer look reveals that the design background level (developed from an average of three off-site measurement positions) and the sound level at the test position both generally parallel the wind speed indicating that the measured levels are due to wind-induced sounds associated with the natural environment in the first case and to both natural and wind turbine sound in the second. As expected, the on-site level at the position surrounded by almost a dozen turbines is usually substantially higher than the background whenever a moderate wind is blowing and, also as expected, the on-site level is similar to the background during calm conditions when the project is not operating. It is the difference between these two levels during windy conditions that essentially constitutes and quantifies the noise impact of the project. As is evident from the plot, it is an ever-changing dynamic situation where the project sound level variously exceeds the background by anywhere from 0 to 10 dBA. This figure graphically points up the inadequacy of attempting to determine the project's noise emissions from a few short-term manned samples. The greatest differentials between the on- and off-site level tend to occur at night but it is important to note that while the project level may be quite a bit higher than the background, the sound level at the receptor point often remains very low in absolute terms with unadjusted raw levels commonly in low to mid 30's dBA.

Taking these test results through the next steps of correcting the on-site level for background noise and parsing out the low wind periods when the project was idle produces the following plot where the nominal project-only sound level is shown as a function of time over the survey period.

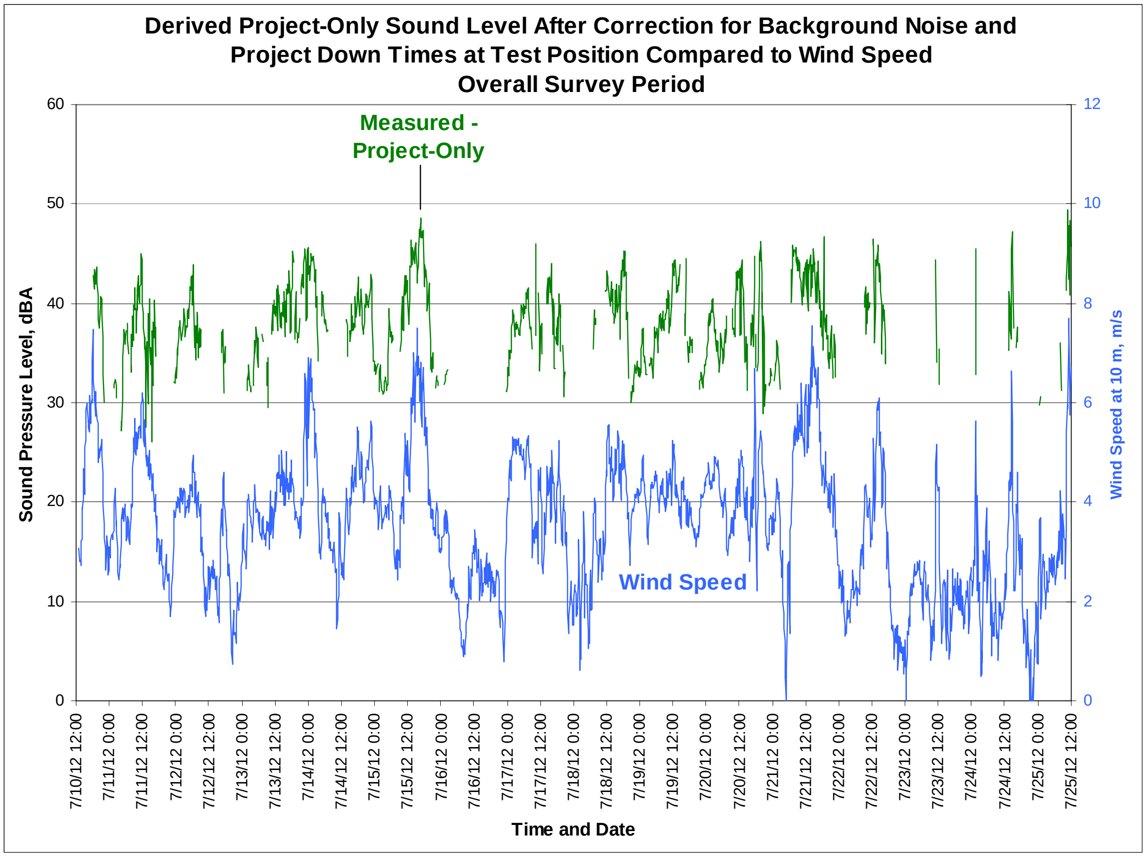

Figure 5.1.11.2

In terms of magnitude the project apparently generates sound levels ranging from 30 to 49 dBA at this location, depending largely but not only on wind speed. The fact that the project sound level does not exactly parallel the wind speed (which was derived from high elevation, rotor height anemometers) indicates that other atmospheric factors play a significant role in determining exactly how loud the project is at this location at any given moment.

What Figure 5.1.11.2 is technically showing is the baseline - L_{A90} - project sound level that is consistently present during each 10 minute measurement period. This means that somewhat higher sound level excursions lasting a few seconds to a few minutes are possible, if not probable, but it is not practical to capture the moment to moment variation over the lengthy survey period needed to adequate evaluate long-term project sound levels. However, comparing these results to model predictions based on the turbine sound power level indicates that the L_{A90} approach does not inadvertently underestimate project levels, as might be suspected. Figure 5.1.11.3 plots the modeled project sound level at this test position (using the procedures outlined in Section 4.1) against the measured project-only sound level. For clarity a detail of a representative three day period from the third to the sixth day of the survey is shown.

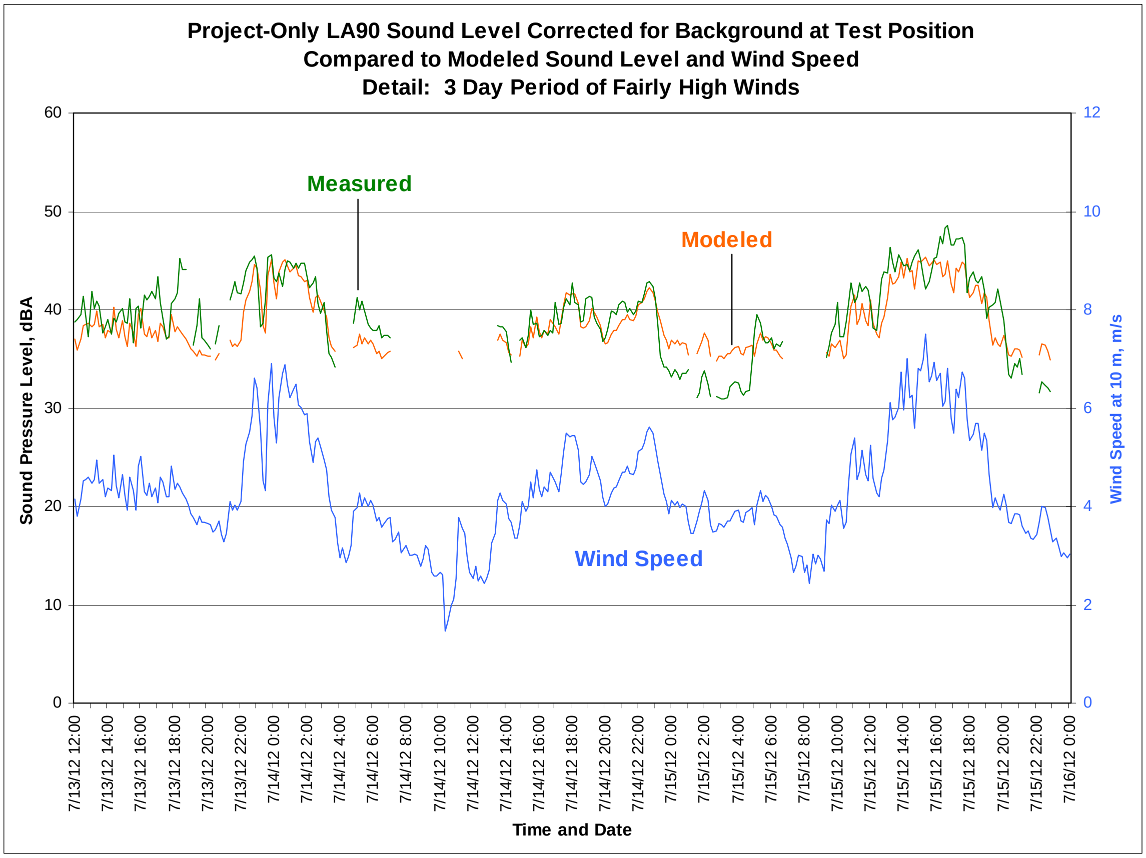

Figure 5.1.11.3

The modeled level is derived using a curve-fit polynomial function based on the predicted project sound level at integer wind speeds, which in turn is based on the turbine sound power level at those wind speeds taken directly from an IEC 61400-11 field test report. In general, the plot shows that the model prediction, based solely on the turbine's sound power level at specific wind speeds, provides a reasonably good approximation of the actual observed sound level.

Example 2

The second example is from a site in the Midwestern United States where the turbines are again intermixed with scattered homes and farms in a rural setting. This particular test location was adopted in response to, what turned out to be understandable, complaints about noise from a participant's "own" turbine that had been sited at the unfortunate distance of only 180 m (600 ft.) from the house. The raw test results are summarized in Figure 5.1.11.4.

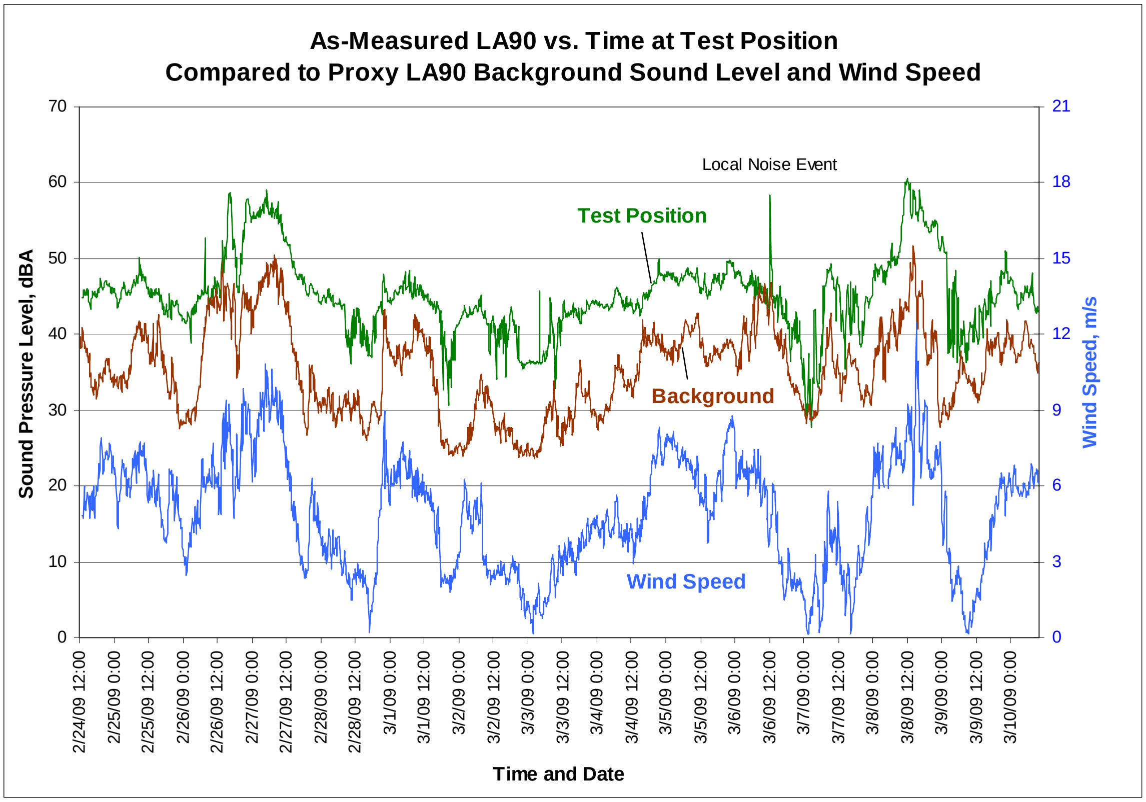

Figure 5.1.11.4

In this instance, the total sound level at the house is consistently and not surprisingly well above the background level developed from four off-site monitoring stations, meaning that much of the time background noise was largely insignificant, if not inaudible. The corrected project-only sound level for a three day windy period near the beginning of the survey is shown below compared to model predictions.

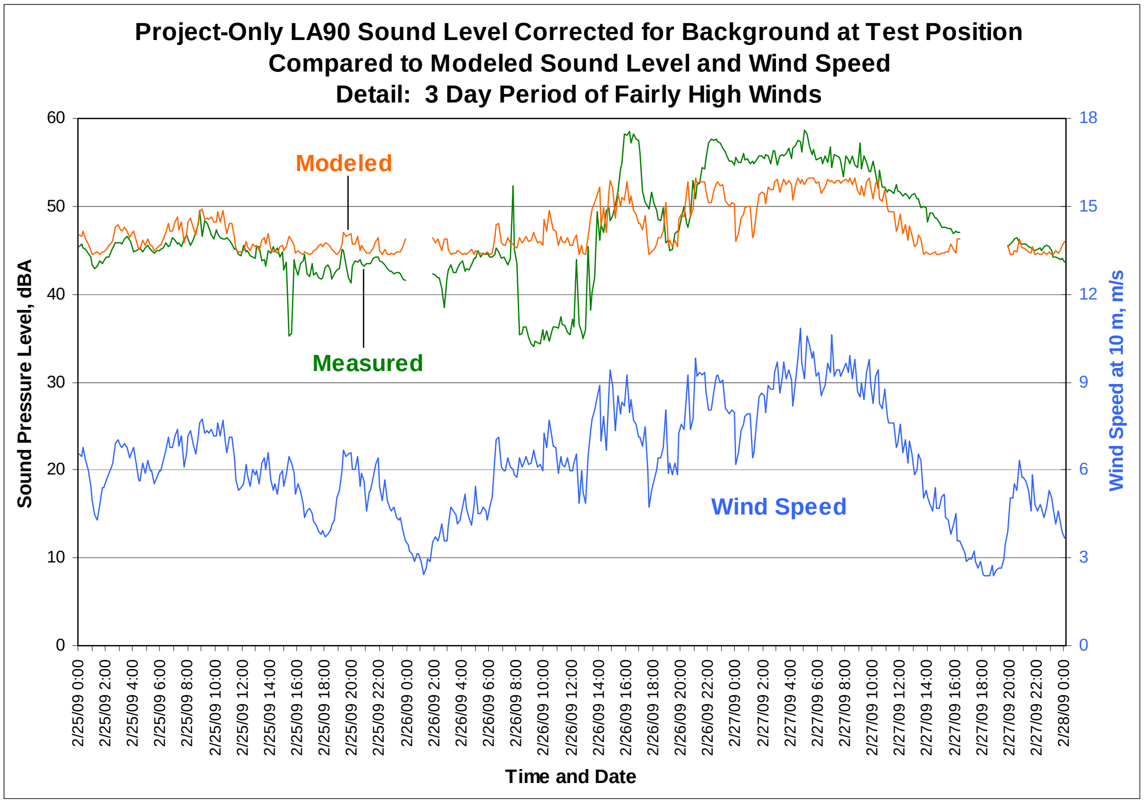

Figure 5.1.11.5

In this instance, as with Example 1, the predicted level intertwines with the measured level, sometimes over-estimating, sometimes underestimating but generally capturing the mean project sound level. The variation above and below the predicted level is largely a measurement of how all other factors beyond the simple wind speed are affecting the total sound level perceived at this location. One of these factors may be unique to the turbine model used at this site, which, based on other surveys and observations, appears to have a tendency to produce sound levels in excess of the manufacturer's stated performance in high wind conditions, which may be part of the reason the actual level significantly exceeds the expected levels in the second half of this sample period. This same departure between the predicted and measured levels also appears in the regression analysis below for the entire survey period where the project-only sound levels are plotted as a function of wind speed.

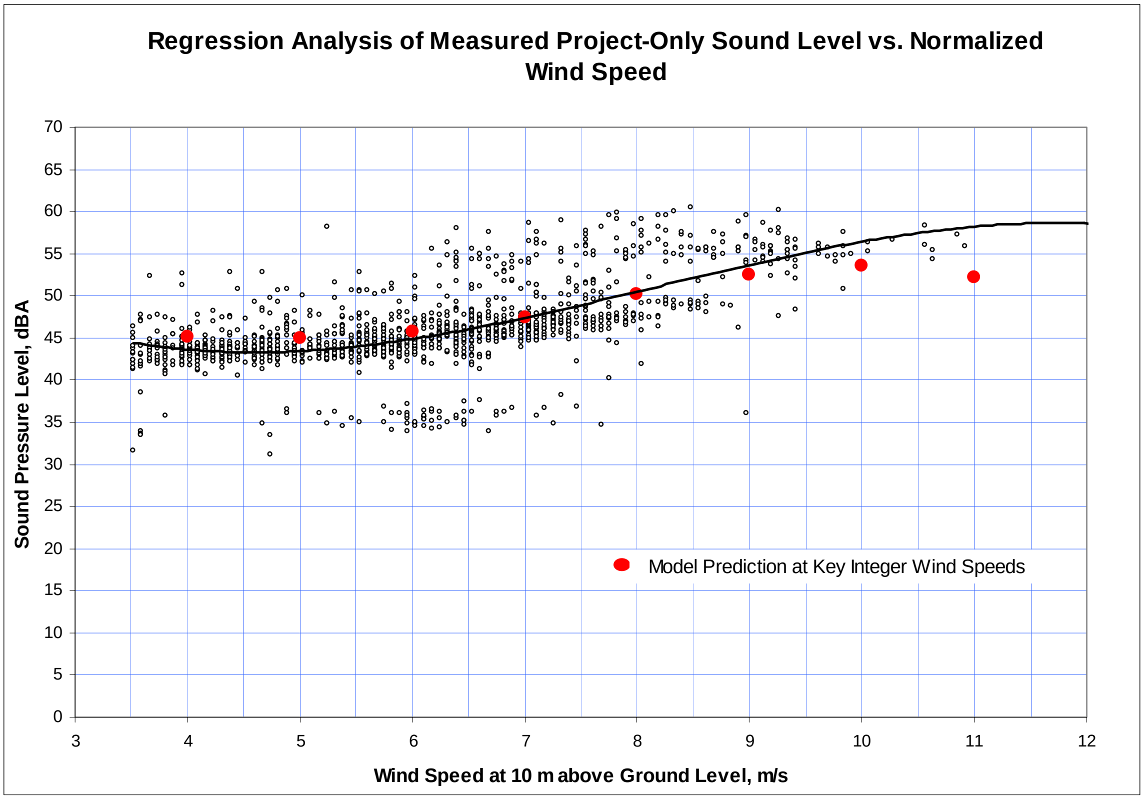

Figure 5.1.11.6

Good agreement with the mean trend is evident up to about 9 m/s but not beyond it.

These two examples are presented to illustrate the outcome of the test methodology and are generally representative of the typical results obtained at a number of test positions over a number of such surveys. That is not to say, however, that the method is infallible and that mismatches between measured and predicted levels will never be found. Testing wind turbine noise is challenging and inherently imprecise because the sound sources themselves and the propagation of sound from them to a given point of interest is dependent on the environment in general and amorphous wind and atmospheric conditions in particular.

5.1.12 *Interpretation of Test Results Relative to Permit Limits*

The regression plot above (Figure 5.1.11.6) exhibits the typical behavior where there is a scatter to the test results and the project sound level is not a perfectly fixed quantity at a given wind speed. This is an unavoidable consequence of the nebulous atmospheric conditions mentioned above. The question that this raises, however, is how to interpret the results of the survey relative to the absolute, or in some cases relative, noise limits contained in planning consent or permit conditions. Excursions, sometimes very substantial excursions, above the mean project sound level are inevitable and under all normal circumstances it would be a complete impossibility to design and lay out a project so that the sound level never exceeded a specific value at a particular point or, more realistically, at a large number of residences within the vicinity of the project. Only projects in obviously remote locations could ever be comfortably designed to such a limit. Consequently, the possibility, even likelihood, that project noise will occasionally spike for short periods should be factored in to regulatory limits. That this issue is not addressed in current laws or limits pertaining to wind turbines is simply a result of the understandable fact that few are aware that it is even an issue.

As a suggestion, it seems reasonable to conclude that a project is in compliance with an absolute regulatory limit if the measurements indicate that the project-only sound level is lower than the stated limit at least 95% of the time, taking that number from the commonly used statistical confidence interval.

5.2 Single Site Investigations

In addition to evaluating operational sound levels on a project-wide basis with regard to regulatory compliance, it is sometimes necessary to carry out dedicated field surveys, usually in response to complaints, that are focused only on a specific point. Although each of these situations is certainly unique, the general test approach outlined above can generally be applied with the exception that more resources can be brought to bear on understanding the project sound level at that particular location.

5.2.1 *General Test Design*

The general test set up for a diagnostic or investigative sound survey at a single point would follow the procedures described for a site-wide test in terms of survey length, equipment and measurement technique with the following enhancements.

The primary measurement position will be outside the residence or point of interest where it is usually prudent to use multiple instruments for redundancy and/or increased functional capability. For example, it is highly desirable to measure the overall A-weighted sound level, the frequency content in 1/3 octave bands and to store audio recordings whenever an appropriate trigger level is reached. While all three of these things can be achieved by some instruments, it would be safer to use the 1/3 octave band analyzer to store numerical data and use a second instrument to store both back-up A-weighted data and the audio files. In any case, having multiple instruments can also allow for additional time resolutions (beside the standard 10 minute periods) to be recorded at the same time; 1 minute or 1 hour data, for instance. In addition to the sound recording equipment a weather station recording wind speed at microphone height, wind direction and rainfall, among other common parameters, should be set up nearby.

The specific measurement position should be at a location with exposure to all of the nearest turbines or at a place that replicates the exposure of the residence to the project but is removed from any sources of local contaminating noise (HVAC equipment, farm machinery, human activities, etc.).

As with a more general survey, the background level is still of just as much concern so 2 to 3 proxy background measurement positions should be found in opposite directions that are remote from any turbines and, in this particular case, replicate as closely as possible the setting of the principal test location in terms of terrain, exposure to wind and exposure to other noise, such as from a road.

The principal and proxy background positions above will theoretically determine what the project sound level is at the residence but may not indicate why it is. To this end several additional monitoring stations close to the 3 or 4 nearest turbines are recommended that are ideally located in line with the principal position at the standard IEC 61400-11 test distance of the hub height plus half the rotor diameter (typically around 125 m, or 400 ft.). A hypothetical test set up involving four nearby turbines is shown in Figure 5.2.1.1.

Figure 5.2.1.1

Note that several of the intermediate positions are slightly off the direct sight line to keep them in open and reasonably accessible areas. Although this hypothetical example was conveniently conducive to this test set up, additional complications are likely to arise; in particular access to private property, which may call for some creativity in designing the test layout. Nevertheless, the idea is to gauge the individual contribution from all of the nearest units over a variety of wind directions and weather conditions to determine if the problematic noise levels are principally associated with perhaps one unit or a particular set of wind conditions. Moreover, the principal purpose for measuring the noise emissions of all the nearest units is to be able to estimate the actual sound power level of each unit and analytically calculate, by means of a simple spreadsheet model, or modeling software, the total sound level at the house for comparison to the measured level there. This approach allows the individual contribution from each unit to be quantified for different conditions and also helps confirm, in a manner independent from the proxy monitoring approach, how much of the received signal at the principal measurement location is due to the project and how much is background noise. In addition, the sound power level of each unit can be informally checked against the manufacturer's warranty value.

While the ground board technique specified in IEC 61400-11 is not practical for long-term, unattended measurements - mainly because of concern about rain - a comparable, if somewhat less rigorous, result can be obtained from measuring at 1 m above grade by placing the microphone or monitor on a tripod or temporary post at the appropriate distance. In Figure 5.2.1.2, for example, measurements were made simultaneously at 1 second resolution with a microphone on a ground plate and with two additional microphones at 1 and 2 m above it. The average and consistent differential between both above ground positions and the microphone on the reflective plate was 2.7 dB, which is close to the ideal 3 dB differential that one would expect.

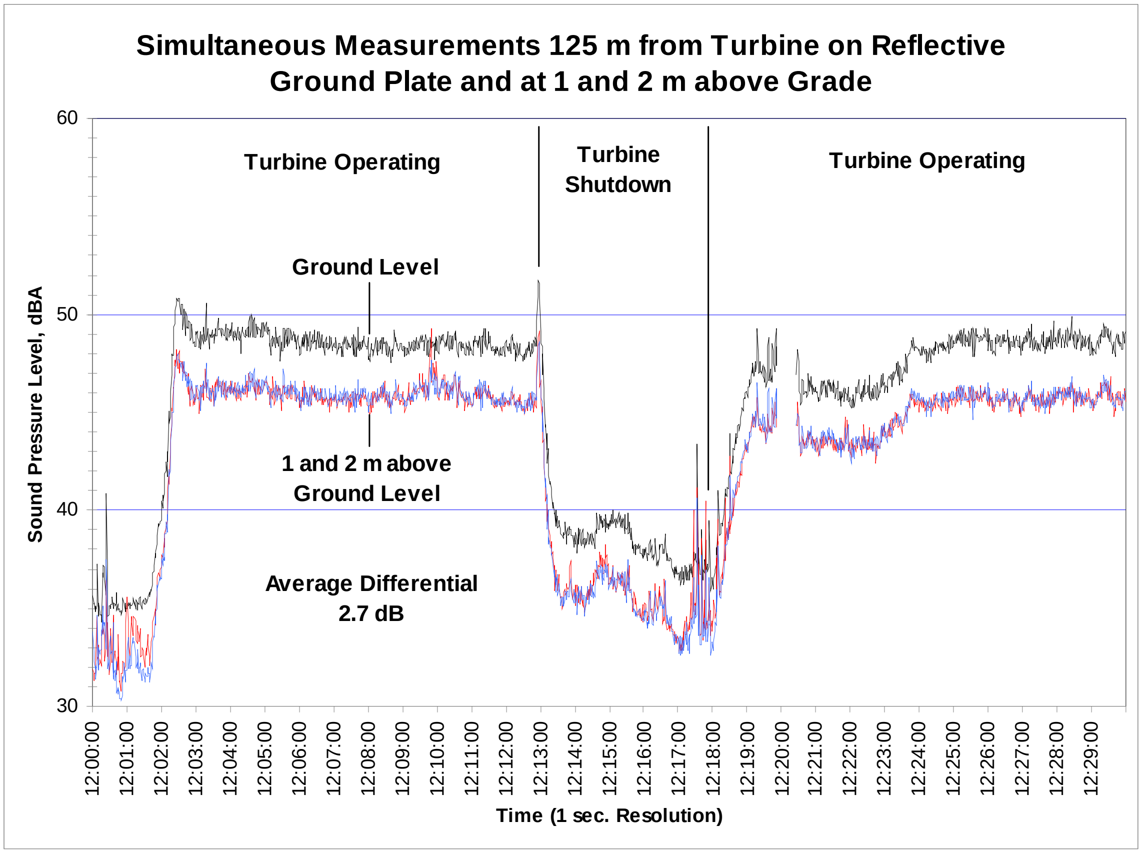

Figure 5.2.1.2

This example illustrates that it is possible under certain circumstances to reasonably measure the apparent A-weighted turbine sound power level above ground level without serious degradation due to wind distortion. Of course, this may not be true when it is particularly windy at 1 m above ground level. Another potential complication arises when multiple turbines are in unusually close proximity to each other, as they are in Figure 5.2.1.1, and background noise or cross-contamination from one unit to another must be taken into account in such cases. In general, however, the only substantive modification to the IEC 61400-11 process for calculating sound power level would be to change the constant “6” to “3” in Eqn. (9) of the standard since above ground measurements are being used.

As suggested by Figure 5.2.1.2, an additional tool that is normally useful and practical for single site investigations is to temporarily shutdown, for 10 to 20 minutes, the nearest turbines to the point of interest, if not all those that could conceivably be affecting the sound level there, in order to obtain direct measurements of the background level so the project-only level can be derived with some confidence from the operational sound levels occurring just before or after the shutdown. A short-duration shutdown helps ensure that the wind and weather conditions are essentially identical for both the on and off measurements. This technique also offers a way of verifying the validity of the levels measured at the off-site background positions. It is usually during the times of peak noise that it is most desirable to have an exact measurement of project’s sound level, since these are the noise levels that most likely engendered the complaint in the first place. Consequently, it becomes a matter of either being there when these conditions occur, which is frequently at night, to organize the shutdown - or putting control over the shutdown in the hands of the resident who can call in by pre-arrangement to the control room if and when the noise becomes objectionable in terms of its overall magnitude and/or begins to exhibit some adverse character, such as from amplitude modulation. Although this latter approach of allowing the resident identify the time of maximum noise has been used successfully to quantify the overall magnitude of project noise and its frequency content in 1/3 octave bands, one must really be on hand to manually measure amplitude modulation, since it calls for the use of an extremely fine time resolution, on the order of milliseconds, to capture the sound oscillations that normally have a period of roughly 1 second. Such manual measurements can be taken indoors, where this kind of noise is most often observed to be objectionable, as well as outdoors.

Only with attended measurements it is possible, and then only occasionally, to measure indoor sound levels in any kind of meaningful way because contaminating noises can be observed and, hopefully, factored out. Long-term monitoring is effectively limited to the outdoors for the fundamental reason that there is no way to ascertain the background sound level inside of a dwelling at a particular time with the project operating. This is because the background sound level indoors is driven by a unique set of seemingly minor but significant sound sources that cannot be replicated by a proxy measurement position. Indoor background sound levels are partially a function of the outdoor conditions, particularly when it is windy or raining, but are also driven by such things as air flow from the heating and air conditioning system, appliances, computers and, of course, human activity even when it is in a distant part of the house. These usually very minor sounds are significant because the intruding noise level from the project is often very low or extremely low in terms of the A-weighted sound level. For example, it would not be unusual for a project sound level to be in the vicinity of 30 dBA inside of the house (perhaps being in the 40 to 45 dBA range outdoors). The successful measurement of the project-only sound level would then require the indoor background level to be 20 dBA or less, which is usually not the case. Sound levels in a bedroom at night are commonly at least 30 dBA even when no wind project is present.

In any event, it is sound level outside of dwellings that is normally (but not always) restricted by regulations or permit conditions and this level can typically be measured with the long-term monitoring methodology described above.

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Exhibit A41-4

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Low frequency noise and infrasound from wind turbines

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A common issue raised with wind energy developers and operators of utility-scale wind turbines is whether the operation of their wind turbines may create unacceptable levels of low frequency noise and infrasound. In order to answer this question, one of the major wind energy developers commissioned a scientific study of their wind turbine fleet. The study consisted of three parts: 1) a world-wide literature search to determine unbiased guidelines and standards used to evaluate low frequency sound and infrasound, 2) a field study to measure wind turbine noise outside and within nearby residences, and 3) a comparison of the field results to the guidelines and standards. Wind turbines from two different manufacturers were measured at an operating wind farm under controlled conditions with the results compared to established guidelines and standards. This paper presents the results of the low frequency noise and infrasound study. Since the purpose of this paper is to report on low frequency and infrasound emissions, potential annoyance from other aspects of wind turbine operation were not considered, and must be evaluated separately.

Primary subject classification: 14.5.4; Secondary subject classification: 21.8.1

1 INTRODUCTION

Early down-wind wind turbines in the US created low frequency noise; however current up-wind wind turbines generate considerably less low frequency noise. Epsilon Associates, Inc. ("Epsilon") was retained by NextEra Energy Resources, LLC ("NextEra"), formerly FPL Energy, to investigate whether the operation of their wind turbines may create unacceptable levels of low frequency noise and infrasound. This question has often been posed to NextEra, and other wind energy developers and operators of utility-scale wind turbines. NextEra is one of the world's largest generators of wind power with approximately 7,600 net megawatts (MW) in operation as of July 2010.

The project was divided into three tasks: 1) literature search, 2) field measurement program, and 3) comparison to criteria. Epsilon conducted an extensive literature search of the technical and scientific literature on the effects of low-frequency noise and infrasound and existing criteria in order to evaluate low-frequency noise and infrasound from wind turbines. After completion of the literature search and selection of criteria, a field measurement program was developed to measure wind turbine noise to compare to the selected criteria.

The frequency range 20–20,000 Hz is commonly described as the range of "*audible*" noise. The frequency range of low frequency sound is generally from 20 Hertz (Hz) to 200 Hz, and the range below 20 Hz is often described as "*infrasound*". However, audibility extends to frequencies below 20 Hz.

Low frequency sound has several definitions. American National Standards ANSI/ASA S12.2[1] and ANSI S12.9 Part 4[2] have provisions for evaluating low frequency noise, and these special treatments apply only to sounds in the octave bands with 16, 31.5, and 63-Hz mid-band frequencies. For these reasons, in this paper on wind turbine noise, we use the term "low frequency noise" to include 12.5 Hz–200 Hz with emphasis on the 16 Hz, 31 Hz and 63 Hz octave bands with a frequency range of 11 Hz to 89 Hz.

International Electrotechnical Commission (IEC) standard 60050-801:1994[3] defines "*infrasound*" as "Acoustic oscillations whose frequency is below the low frequency limit of audible sound (about 16 Hz)." This definition is *incorrect* since sound remains audible at frequencies well below 16 Hz provided that the sound level is sufficiently high. In this paper we define infrasound to be below 20 Hz, which is the limit for the standardized threshold of hearing. Since there is no sharp

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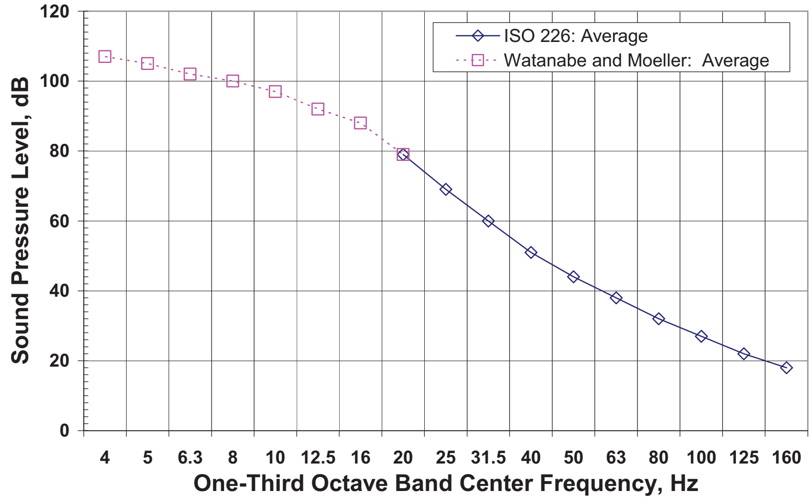

Fig. 1—Low frequency average threshold of hearing from ISO 226[6] and Watanabe and Moeller[7].

change in hearing at 20 Hz, the division into "low-frequency sound" and "infrasound" should only be considered "practical and conventional."

2 EFFECTS AND CRITERIA OF LOW FREQUENCY SOUND AND INFRASOUND

We performed an extensive world-wide literature search of over 100 scientific papers, technical reports and summary reports on low frequency sound and infrasound—hearing, effects, measurement, and criteria. Leventhall[4] presents an excellent and comprehensive study on low frequency noise from all sources and its effects. The Leventhall report also presents criteria in place at that time, which does not include some of the more recently developed ANSI/ASA standards on outdoor environmental noise and indoor sounds.

The United States government does not have specific criteria for low frequency noise. The US Environmental Protection Agency (EPA) has guidelines for the protection of public health with an adequate margin of safety in terms of annual average A-weighted day-night average sound level (L_{dn}), but there are no corrections or adjustments for low frequency noise. The US Department of Transportation (DOT) has A-weighted sound pressure level criteria for highway projects and airports, but these do not have adjustments for low frequency noise. The following sections describe the low frequency and infrasound criteria to which wind turbine sounds are compared in later sections.

2.1 Threshold of Hearing and Audibility

Moeller and Pedersen[5] present an excellent summary on human perception of sound at frequencies below 200 Hz. The ear is the primary organ for sensing infrasound. Hearing becomes gradually less sensitive for decreasing frequencies. But, humans with a normal hearing organ can perceive infrasound at least down to a few hertz if the sound level is sufficiently high.

The threshold of hearing is standardized for frequencies down to 20 Hz[6]. Based on extensive research and data, Moeller and Pedersen propose normal hearing thresholds for frequencies below 20 Hz; however, their proposed threshold is higher than that obtained by Watanabe and Moeller[7]. To be conservative, we have used the data from Watanabe and Moeller[7] for the region below 20 Hz. (See Fig. 1.) Moeller and Pedersen[5] suggest that the curve for low frequency thresholds for normal hearing is "probably correct within a few decibels, at least in most of the frequency range."

The hearing thresholds show considerable variability from individual to individual with a standard deviation among subjects of about 5 dB independent of frequency between 3 Hz and 1000 Hz with a slight increase at 20−50 Hz. This implies that the audibility threshold for 97.5% of the population is greater than the values in Fig. 1 minus 10 dB and for 84% of the population is greater than the values in Fig. 1 minus 5 dB. Moeller and Pedersen suggest that the "pure-tone threshold can with a reasonable approximation be used as a guideline for the thresholds also for [low frequency] non-sinusoidal sounds"[5]; ISO 226 has thresholds for frequencies at and above 20 Hz and approximately equates the thresholds and equal loudness contours for non-sinusoidal sounds to those in the standard for sinusoidal sounds[6].

As frequency decreases below 20 Hz, if the noise source is tonal, the tonal sensation ceases. Below 20 Hz tones are perceived as discontinuous. Below 10 Hz it is possible to perceive the single cycles of a tone, and the perception changes into a sensation of pressure at the ears.

Below 100 Hz, the dynamic range of the auditory system decreases with decreasing frequency, and the compressed dynamic range has an effect on equal loudness contours: a slight change in sound level can change the perceived loudness from barely audible to loud. This combined with the large variation in individual hearing may mean that a low frequency sound that is inaudible to some may be audible to others, and may be relatively loud to some of those for whom it is audible. Loudness for low frequency sounds grows considerably faster above threshold than for sounds at higher frequencies[5].

Non-auditory perception of low frequency and infrasound occurs only at levels above the auditory threshold. In the frequency range of 4−25 Hz and at "*levels* 20−25 dB *above [auditory] threshold it is possible to feel vibrations* in various parts of the body, e.g., the lumbar, buttock, thigh and calf regions. A feeling of pressure may occur in the upper part of the chest and the throat region" [emphasis added][5].

2.2 ANSI S12.9-Parts 4 and 5—Evaluating Outdoor Environmental Sound

American National Standard ANSI/ASA S12.9-2007/Part 5[8] has an informative annex which provides guidance for designation of land uses compatible with existing or predicted annual average adjusted day-night average outdoor sound level (DNL). Ranges of the DNL are outlined, within which a specific region of compatibility may be drawn. These ranges take into consideration the noise reduction in sound level from outside to inside buildings as commonly constructed in that locality and living habits there. There are adjustments to day-night average sound level to account for the presence of low frequency noise, and the adjustments are described in ANSI S12.9 Part 4, which use a sum of the sound pressure levels in octave bands with center frequencies of 16, 31 and 63 Hz.

ANSI S12.9/Part 4 identifies two thresholds: annoyance is minimal when the 16, 31.5 and 63 Hz octave band sound pressure levels are each less than 65 dB and there are no rapid fluctuations of the low frequency sounds. The second threshold is for increased annoyance which begins when rattles occur, which begins at L_{LF} 70−75 dB. L_{LF} is 10 times the logarithm of the ratio of time-mean square sound pressure in the 16, 31.5, and 63-Hz octave bands divided by the square of the reference sound pressure.

The adjustment procedure for low frequency noise to the average annual A-weighted sound pressure level in ANSI S12.9/Part 4 uses a different and more complicated metric and procedure (Equation D.1) than those used for evaluating low frequency noise in rooms contained in ANSI/ASA S12.2. (See Sec. 2.3). Since we are evaluating low frequency noise and not A-weighted sound levels, we do not recommend using the procedure for adjusting A-weighted levels. Instead we recommend using the following two guidelines from ANSI S12.9/Part 4: a sound pressure level of 65 dB in each of the 16-, 31.5-, and 63 Hz octave bands as an indicator of minimal annoyance, and 70−75 dB for the summation of the sound pressure levels from these three bands as an indicator of possible increased annoyance from rattles.

2.3 ANSI/ASA S12.2—Evaluating Room Noise

ANSI/ASA S12.2-2008[1] discusses criteria for evaluating room noise, and has two separate provisions for evaluating low frequency noise: (1) the potential to cause perceptible vibration and rattles, and (2) meeting low frequency portions of room criteria curves. Since the ANSI S12.2 criteria are for indoor sounds, in order to determine equivalent outdoor criteria for comparison to outdoor measurements, data from Sutherland[9] and Hubbard and Shephard[10] were used to determine typical noise reductions from outdoor to indoor with windows open. (The Appendix of this paper describes the noise reductions used to determine equivalent outdoor criteria to indoor criteria.) Table A1 presents octave band noise reductions applied in this evaluation along with the average low frequency octave band noise reductions from outdoor to indoors from Refs. 9 and 10 for open and closed windows. Table A2 presents the one-third octave band noise reductions applied in the analysis that were determined in the same manner using data from the same references.

Vibration and Rattles: Outdoor low frequency sounds of sufficient amplitude can cause building walls to vibrate and windows to rattle. Homes have low values of transmission loss at low frequencies, and low frequency noise of sufficient amplitude may be audible within homes. Window rattles are not low frequency noise, but may be caused by low frequency noise. ANSI/ASA S12.2 presents limiting levels at low frequencies for assessing (a) the probability of *clearly* perceptible acoustically induced vibration and rattles in lightweight wall and ceiling constructions, and (b) the probability of *moderately* perceptible acoustically induced vibration in similar constructions. The limiting sound pressure levels in the octave bands with center frequencies of 16, 31.5 and 63 Hz are presented in Table 1.

Applying the outdoor to indoor attenuations for wind turbine sources with windows open given in the last row of Table A1 to the ANSI/ASA S12.2 indoor sound pressure levels in Table 1 yields the equivalent

Table A1—Average low frequency octave band home noise reductions from outdoor to indoors in dB (from Ref. 9 and 10).

Noise Source	Window condition	Octave Band Center Frequency 16 Hz	31.5 Hz	63 Hz	125 Hz
Average aircraft and traffic sources	Closed windows	16	15	18	20
Average aircraft and traffic sources	Open windows	(11)*	(10)*	12	11
Average Wind Turbine	Closed windows	8	11	14	18
Average Wind Turbine	Open windows	(3)*+	(6)*+	9+	9+

* No data are available for windows open below 63 Hz octave band. The values for 16 Hz and 31 Hz were obtained by subtracting the difference between the levels for 63 Hz closed and open conditions to the 16 and 31 Hz closed values.
\+ Used in this paper to determine equivalent outdoor criteria from indoor criteria in Tables 2 and 4

outdoor sound pressure levels that are consistent with the indoor criteria and are presented in Table 2.

Room Criteria Curves: ANSI/ASA S12.2 has three primary methods for evaluating the suitability of noise within rooms: a survey method—A-weighted sound levels, an engineering method—noise criteria (NC) curves, and a method for evaluating low-frequency fluctuating noise using room noise criteria (RNC) curves. ANSI/ASA S12.2 states "The RNC method should be used to determine noise ratings when the noise from HVAC systems at low frequencies is loud and is suspected of containing sizeable *fluctuations or surging*." [emphasis added] The NC curves are appropriate to evaluate low frequency noise from wind turbines in homes since wind turbine noise does not have significant fluctuating low frequency noise sufficient to warrant using RNC curves and since A-weighted sound levels do not adequately determine

Table A2—Average low frequency one-third octave band noise reduction in dB for homes from outdoor to indoors.

Condition	One-Third Octave Band Center Frequency, Hz 10	12.5	16	20	25	31.5	40	50	63	80	100	125	160
Open Window*	2	2	3	4	4.5	5	7	8	9	9	9	9	9
Average Closed Window with wind turbines[10] **	8	7	8	8	8	11	13	14	15	12	18	18	18

* Used to determine equivalent outdoor levels as shown in Table 7.
** Used to determine equivalent outdoor levels as shown in Table 9.

Table 1—ANSI/ASA S12.2 measured interior sound pressure levels for perceptible vibration and rattle in lightweight wall and ceiling structures.[1]

Condition	Octave-band center frequency (Hz) 16	31.5	63
Clearly perceptible vibration and rattles likely	75 dB	75 dB	80 dB
Moderately perceptible vibration and rattles likely	65 dB	65 dB	70 dB

Table 2—Equivalent outdoor sound pressure levels to the ANSI/ASA S12.2 indoor sound pressure levels for perceptible vibration and rattle in lightweight wall and ceiling structures for wind turbines.

	Octave-band center frequency (Hz)		
Condition	16	31.5	63
Clearly perceptible vibration and rattles likely	78 dB	81 dB	89 dB
Moderately perceptible vibration and rattles likely	68 dB	71 dB	79 dB

if there are low frequency problems. [ANSI/ASA S12.2, Sec. 5.3 gives procedures for determining if there are large fluctuations of low frequency noise.]

Annex C.2 of ANSI/ASA S12.2 contains recommended room criteria curves for bedrooms, which are the rooms in homes with the most stringent criteria: NC and RNC criteria curve between 25 and 30. The recommended NC and RNC criteria for schools and private rooms in hospitals are the same. The values of the sound pressure levels in the 16−125 Hz octave bands for NC curves 25 and 30 are shown in Table 3. Applying the outdoor to indoor attenuations for wind turbine sources with windows open given in the last row of Table A1 to the ANSI/ASA S12.2 indoor sound pressure levels for NC-25 and NC-30 in Table 3 yields the equivalent outdoor sound pressure levels that are consistent with the indoor criteria and are presented in Table 4.

ANSI/ASA S12.2 also presents a method to determine if the levels below 500 Hz octave band are too high in relation to the levels in the mid-frequencies which could create a condition of "spectrum imbalance". The method for this evaluation is:

- Calculate the speech interference level (SIL) for the measured spectrum. [SIL is the arithmetic average of the sound pressure levels in the 500, 1000, 2000 and 4000 Hz octave bands.] Select the NC curve equal to the SIL value with a symbol NC(SIL).
- Plot the measured spectra and the NC curve equal to the SIL value on the same graph and determine the differences between the two curves in the octave bands below 500 Hz.
- Estimate the likelihood that the excess low-frequency levels will annoy occupants of the space using Table 5.

Table 3—ANSI/ASA S12.2 low frequency octave band sound pressure levels for noise criteria curves NC-25 and NC-30. [Table 1 from Ref. 1].

	Octave-band-center frequency, Hz			
NC Criteria	16	31.5	63	125
NC-25	80	65	54	44
NC-30	81	68	57	48

2.4 Other Criteria

2.4.1 World Health Organization (WHO)

No specific low frequency noise criteria are proposed by the WHO. The Guidelines for Community Noise report[11] mentions that if the difference between

Table 4—Equivalent outdoor sound pressure levels to the ANSI/ASA S12.2 low frequency octave band sound pressure levels for noise criteria curves NC-25 and NC-30. [Table 1 from Ref. 1].

	Octave-band-center frequency, Hz			
NC Criteria	16	31.5	63	125
NC-25 equivalent outdoor	83	71	63	53
NC-30 equivalent outdoor	84	74	66	57

Table 5—Measured sound pressure level deviations from an NC (SIL) curve that may lead to serious complaints[1].

Octave-band frequency, Hz=>	Measured Spectrum—NC(SIL), dB			
	31.5	63	125	250
Possible serious dissatisfaction	*	6–9	6–9	6–9
Likely serious dissatisfaction	*	>9	>9	>9

* Insufficient data available to evaluate

Table 6—DEFRA proposed criteria[13] for the assessment of low frequency noise disturbance: Indoor L_{eq} one-third sound pressure levels for non-steady and steady low frequency sounds.

	One-Third Octave Band Center Frequency, Hz												
Location	10	12.5	16	20	25	31.5	40	50	63	80	100	125	160
Non-Steady L_{eq}, dB	92	87	83	74	64	56	49	43	42	40	38	36	34
Steady L_{eq}, dB	97	92	88	79	69	61	54	48	47	45	43	41	39

the C-weighted sound level and A-weighted sound level is greater than 10 decibels, then a frequency analysis should be performed to determine if there is a low frequency issue. A document prepared for the World Health Organization states that "there is no reliable evidence that infrasounds below the hearing threshold produce physiological or psychological effects. Infrasounds slightly above detection threshold may cause perceptual effects but these are of the same character as for 'normal' sounds. Reactions caused by extremely intense levels of infrasound can resemble those of mild stress reaction and may include bizarre auditory sensations, describable as pulsation and flutter"[12].

2.4.2 The UK Department for Environment, Food, and Rural Affairs (DEFRA)

The report prepared by the University of Salford for the UK Department for Environment, Food, and Rural Affairs (DEFRA) on low frequency noise proposed one-third octave band sound pressure level L_{eq} criteria and procedures for assessing low frequency noise[13]. The guidelines are based on complaints of disturbance from low frequency sounds and are intended to be used by Environmental Health Officers.

Existing low frequency noise criteria from several countries were reviewed and experiences with low frequencies complaints were considered in developing the proposed guidelines. The criteria are "based on 5 dB below the ISO 226 average threshold of audibility for steady [low frequency] sounds." However, the DEFRA criteria are at 5 dB lower than ISO 226 only at 20−31.5 Hz; at higher frequencies the criteria are equal to the Swedish criteria which are higher levels than ISO 226 less 5 dB. For frequencies lower than 20 Hz, DEFRA uses the thresholds from Ref. 7 less 5 dB.

The DEFRA criteria are based on measurements in an unoccupied room, and it was noted by a practicing consultant that measurements should be made with windows closed[14]. However, we conservatively used windows open conditions for our assessment to determine equivalent outdoor criteria since the DEFRA measurement procedure does not explicitly state measurements are with windows closed. If the low frequency sound is "steady" then the criteria may be relaxed by 5 dB. A low frequency noise is considered steady if either $L_{10}-L_{90} < 5$ dB or the rate of change of sound pressure level (Fast time weighting) is less than 10 dB per second in the third octave band which exceeds the criteria by the greatest margin.

Applying indoor to outdoor one-third octave band transfer functions for open windows (as presented in Table A2 from analysis of data in Refs. 9 and 10) yields *equivalent* one-third octave band sound pressure level proposed DEFRA criteria for outdoor sound levels. Table 6 presents the indoor DEFRA proposed criteria for non-steady and steady low-frequency sounds. Table

Table 7—Equivalent outdoor L_{eq} one-third sound pressure levels for non-steady and steady sounds to the DEFRA indoor criteria[13] for the assessment of low frequency noise disturbance.

	One-Third Octave Band Center Frequency, Hz												
Location	10	12.5	16	20	25	31.5	40	50	63	80	100	125	160
Non-Steady Equivalent outdoor * L_{eq}, dB	94	89	86	78	68.5	61	56	51	51	49	47	45	43
Steady Equivalent Outdoor* L_{eq},	99	94	91	83	73.5	66	61	56	56	54	52	50	48

* With windows open

Table 8—Japan Ministry of Environment Guidance for evaluating complaints of low frequency noise: Reference one-third octave band sound pressure level values for complaints of rattling.

	One-Third Octave Band Center Frequency, Hz										
Location	5	6.3	8	10	12.5	16	20	25	31.5	40	50
Outdoor L_{eq}, dB	70*	71*	72*	73	75	77	80	83	87	93	99

* The reference values are several dB lower than the supporting data contained in Ref. 15. At 5 Hz, window rattles started at about 74 dB in one study and 79 dB in another; at 6.3 Hz, rattles started at 74 dB in the first study and at 78 dB in the second; and at 8 Hz, window rattle started at 74 dB in the first study and 77 dB in the second study.

7 presents the DEFRA equivalent outdoor criteria for non-steady and steady low frequency sounds.

2.4.3 Japan Ministry of Environment

The Japan Ministry of Environment has published a handbook to deal with low frequency noise problems and has established reference values for guidance in dealing with complaints of rattling windows and doors and complaints of "mental and physical discomfort"[15]. It was noted that traditional Japanese houses have relatively light-weight and sensitive windows and partitions[16].

Table 8 presents the Japanese reference outdoor one-third octave band sound pressure level values for guidance in dealing with complaints of rattling from environmental sounds from 5 Hz to 50 Hz. From 10 Hz to 50 Hz the guidance levels are equal to the observed threshold of rattles from two studies with a total of 78 samples. However, for the bands centered at 5, 6.3 and 8 Hz, the reference values are several dB lower than the supporting data contained in these two studies[15]. At 5 Hz, the lowest observed window rattle was at 74 dB in one study and 79 dB in another; at 6.3 Hz, rattles started at 74 dB in the first study and at 78 dB in the second; and at 8 Hz, window rattle started at 74 dB in the first study and 77 dB in the second study. Thus the reference values at 5, 6.3 and 8 Hz in Table 8 are conservative in comparison to the other values by 4, 3, and 2 dB respectively.

Table 9 presents the Japanese reference one-third octave band sound pressure level values for guidance in dealing with complaints of mental and physical discomfort from environmental sounds when evaluated indoors. Evaluation measurements are to be performed with windows closed to the outside. The values in Table 9 are less stringent than the DEFRA values in Table 6 for non-steady sounds but more stringent than the DEFRA values for steady sounds in some one-third octave bands. In order to obtain equivalent outdoor sound levels, the average noise reduction from wind turbine noise with windows closed from Ref. 10 was applied to the Japan reference values. Table 9 presents the Japanese indoor reference values, the noise reductions for windows closed[10] and the equivalent outdoor reference values. These equivalent outdoor values are less stringent than the equivalent outdoor DEFRA values in Table 7 for both non-steady sounds and steady sounds except for the 80 Hz band in which the Japanese level is 1 dB more stringent than the DEFRA level for steady sounds.

2.4.4 C-weighted minus A-weighted ($L_{pC}-L_{pA}$)

Leventhall[4] and others indicate that the difference in C-weighted and A-weighted sound pressure levels can be a predictor of annoyance. Leventhall states that if ($L_{pC}-L_{pA}$) is greater than 20 dB there is "a potential for a low frequency noise problem." He further states that ($L_{pC}-L_{pA}$) cannot be a predictor of annoyance but is a simple indicator that further analysis may be needed. This is due in part to the fact that the low frequency noise may be inaudible even if ($L_{pC}-L_{pA}$) is greater than 20 dB.

3 LITERATURE REVIEW

The authors performed an extensive literature search of over 100 scientific papers, technical reports and summary reports on low frequency sound and infrasound—hearing, effects, measurement, and criteria. The following paragraphs briefly summarize the findings from some of these papers and reports.

3.1 Leventhall

Leventhall[4] presents an excellent study on low frequency noise from all sources and its effects. The report presents criteria in place at that time and includes data relating cause and effects. Leventhall[17] reviewed data and allegations on alleged problems from low frequency noise and infrasound from wind turbines, and concluded the following: "It has been shown that there is insignificant infrasound from wind turbines and that there is normally little low frequency noise." "Turbulent air inflow conditions cause enhanced levels of low frequency noise, which may be disturbing, but the overriding noise from wind turbines is the fluctuating audible swish, mistakenly referred to

Table 9—Japan Ministry of Environment Guidance for evaluating complaints of low frequency noise: Reference one-third octave band sound pressure level values for complaints of mental and physical discomfort.

	One-Third Octave Band Center Frequency, Hz									
Location	10	12.5	16	20	25	31.5	40	50	63	80
Indoor L_{eq}, dB	92	88	83	76	70	64	57	52	47	41
Noise Reduction*, dB	8	7	8	8	8	11	13	14	15	12
Equivalent Outdoor L_{eq}, dB	100	95	91	84	78	75	70	66	62	53

* from Hubbard[10] windows closed condition

as "infrasound" or "low frequency noise". "Infrasound from wind turbines is below the audible threshold and of no consequence". Other studies have shown that wind turbine generated infrasound levels are below threshold of perception and threshold of feeling and body reaction.

3.2 DELTA

The Danish Energy Authority project on "low frequency noise from large wind turbines" comprises a series of investigations in the effort to give increased knowledge on low frequency noise from wind turbines[18]. One of the conclusions of the study is that wind turbines do not emit audible infrasound, with levels that are "far below the hearing threshold." Audible low frequency sound may occur both indoors and outdoors, "but the levels in general are close to the hearing and/or masking level." "In general the noise in the critical band up to 100 Hz is below both thresholds". The final report notes that for road traffic noise (in the vicinity of roads) the low frequency noise levels are higher [than wind turbine] both indoors and outdoors.

3.3 Hayes McKenzie Partnership

Hayes McKenzie Partnership Ltd performed a study for the UK Department of Trade & Industry (DTI) to investigate complaints of low frequency noise that came from three of the five farms with complaints out of 126 wind farms in the UK[14]. The study concluded that:

- Infrasound associated with modern wind turbines is not a source which will result in noise levels that are audible or which may be injurious to the health of a wind farm neighbor.
- Low frequency noise was measureable on a few occasions, but below DEFRA criteria. Wind turbine noise may result in indoor noise levels within a home that is just above the threshold of audibility; however, it was lower than that of local road traffic noise.
- The common cause of the complaints was not associated with low frequency noise but the occasional audible modulation of aerodynamic noise, especially at night.
- The UK Department of Trade and Industry, which is now the UK Department for Business Enterprise and Regulatory Reform (BERR), summarized the Hayes McKenzie report: "The report concluded that there is no evidence of health effects arising from infrasound or low frequency noise generated by wind turbines."[19].

3.4 Howe

Howe performed extensive studies on wind turbines and infrasound and concluded that infrasound was not an issue for modern wind turbine installations—"while infrasound can be generated by wind turbines, it is concluded that infrasound is not of concern to the health of residences located nearby."[20]. Since then Gastmeier and Howe[21] investigated an additional situation involving the alleged "perception of infrasound by individual." In this additional case, the measured indoor infrasound was at least 30 dB below the audibility threshold given by Ref. 7 as presented in Fig. 1.

3.5 Branco

Branco and other Portuguese researchers have studied possible physiological affects associated with high amplitude low frequency noise and have labeled these alleged effects as "Vibroacoustic Disease" (VAD)[22]. "Vibroacoustic disease (VAD) is a whole-body, systemic pathology, characterized by the abnormal proliferation of extra-cellular matrices, and caused by excessive exposure to low frequency noise."

Hayes[23,24] concluded that levels from wind farms are not likely to cause VAD after comparing noise levels from alleged VAD cases to noise levels from wind turbines in homes of complainers. Noise levels in aircraft in which VAD has been hypothesized are considerably higher than wind turbine noise levels. Hayes also concluded that it is "unlikely that symptoms will result through induced internal vibration from incident wind farm noise."[23]. Other studies have found no VAD indicators in environmental sound that have been alleged by VAD proponents[25].

3.6 French National Academy of Medicine

In 2006, the French National Academy of Medicine recommended[26] "*as a precaution* construction should be suspended for wind turbines with a capacity exceeding 2.5 MW located within 1500 m of homes." [emphasis added] However, this precaution is not because of definitive health issues but because:

- Sound levels one km from some wind turbine installations "occasionally exceed allowable limits" for France (note that the allowable limits are long term averages).
- French prediction tools for assessment did not take into account sound levels created with wind speeds greater than 5 m/s.
- Wind turbine noise has been compared to aircraft noise (even though the sound levels of wind turbine noise are significantly lower), and exposure to high level aircraft noise "involves neurobiological reactions associated with an increased frequency of hypertension and cardiovascular illness. Unfortunately, no such study has been done near wind turbines."[27].

In March 2008, the French Agency for Environmental and Occupational Health Safety (AFSSET) published a report on "the health impacts of noise generated by wind turbines", commissioned by the Ministries of Health and Environment in June 2006 following the report of the French National Academy of Medicine in March 2006[28]. The AFSSET study recommends that one does not define a fixed minimum distance between wind farms and homes, but rather to model the acoustic impact of the project on a case-by-case basis. One of the conclusions of the AFSSET report is: "The analysis of available data shows: The absence of identified direct health consequences concerning the auditory effects or specific effects usually associated with exposure to low frequencies at high level." ("L'analyse des données disponibles met en évidence: L'absence de conséquences sanitaires directes recensées en ce qui concerne les effets auditifs, ou les effets spécifiques généralement attachés à l'exposition à des basses fréquences à niveau élevé.").

4 FIELD PROGRAM

Two types of utility-scale wind turbines were studied for this field program. These two turbines are among the most commonly used in the NextEra fleet: General Electric (GE) 1.5sle (1.5 MW), and Siemens SWT-2.3-93 (2.3 MW).

Sound levels for these wind turbine generators (WTGs) vary as a function of wind speed from cut-in wind speed to maximum sound level. Cut-in wind speed for the GE 1.5sle wind turbine is 3.5 m/s while the Siemens wind turbine has a cut-in wind speed of 4 m/s. Maximum reference sound power levels for the GE 1.5sle and Siemens 2.3-93 are approximately 104 dB and 105 dB respectively as provided by the manufacturer. These sound power levels are reached at electrical output levels of approximately 924 kW and 1767 kW for the GE and Siemens units, respectively. Under higher wind speeds, the sound levels from the wind turbines do not increase although electrical power output does continue to increase up to the rated power of each wind turbine (1500 kW and 2300 kW respectively).

Each wind turbine manufacturer has an uncertainty factor "K" of 2 dB to guarantee the turbine's sound power level. (K accounts for both measurement variations and production variation[29].) The results presented later in this paper include sound power values which have added the manufacturer's K value to the reference values, that is, 2 dB above the expected reference levels for the measured wind conditions and power output.

Real-world data were collected from operating wind turbines to compare to the low frequency noise guidelines and criteria discussed previously in Sec. 2. These data sets consisted of outdoor measurements at various reference distances, and concurrent indoor/outdoor measurements at residences within the wind farm.

NextEra provided access to the Horse Hollow Wind Farm in Taylor and Nolan Counties, Texas in November 2008 to collect data on the GE 1.5sle and Siemens SWT-2.3-93 wind turbines. The portion of the wind farm used for testing is relatively flat with no significant terrain. The land around the wind turbines is rural and primarily used for agriculture and cattle grazing. The siting of the sound level measurement locations was chosen to minimize local noise sources except the wind turbines and the wind itself. Hub height for these wind turbines is 80 meters above ground level (AGL).

Two of the authors collected sound level and wind speed data over the course of one week under a variety of operational conditions. Weather conditions were dry the entire week with ground level winds ranging from calm to 12.5 m/s (28 mph) over a 1-minute average. In order to minimize confounding factors, the data collection tried to focus on periods of maximum sound levels from the wind turbines (moderate to high hub height winds) and light to moderate ground level winds.

Ground level (2 meters AGL) wind speed and direction were measured continuously at one representative location. Wind speeds near hub height were also measured continuously using the permanent meteorological towers maintained by the wind farm.

A series of simultaneous interior and exterior sound level measurements were made at four houses owned by participating landowners within the wind farm. Two sets were made of the GE WTGs, and two sets were made of the Siemens WTGs. Data were collected with both windows open and windows closed. Due to the necessity of coordinating with the homeowners in advance, and reasonable restrictions on time of day to enter their homes, the interior/exterior measurement data sets do not always represent ideal conditions. However, enough data were collected to compare to the criteria and draw conclusions on low frequency noise.

Sound level measurements were also made simultaneously at two reference distances from a string of wind turbines under a variety of wind conditions. Using the manufacturer's sound power level data, calculations of the sound pressure levels as a function of distance in flat terrain were made to aid in deciding where to collect data in the field. Based on this analysis, two distances from the nearest wind turbine were selected—305 meters (1,000 feet) and 457 meters (1,500 feet)—and were then used where possible during the field program. Distances much larger than 457 meters (1,500 feet) were not practical since an adjacent turbine string could then be closer and affect the measurements, or would put the measurements beyond the boundaries of the wind farm property owners. Brief background sound level measurements were conducted several times during the program whereby the Horse Hollow Wind Farm operators were able to shutdown the nearby WTGs for a brief (20 minutes) period. This was done in real time using cell phone communication.

All the sound level measurements described above were attended. One series of unattended overnight measurements was made at two locations for approximately 15 hours to capture a larger data set. One measurement was set up approximately 305 meters (1,000 feet) from a GE 1.5sle WTG and the other was set up approximately 305 meters (1,000 feet) from a Siemens WTG. The location was chosen based on the current wind direction forecast so that the sound level equipment would be downwind for the majority of the monitoring period. By doing this, the program was able to capture periods of strong hub-height winds and moderate to low ground-level winds.

All sound levels were measured using two Norsonic Model Nor140 precision sound analyzers, equipped with a Norsonic-1209 Type 1 Preamplifier, a Norsonic-1225 half-inch microphone and a 7-inch Aco-Pacific untreated foam windscreen Model WS7. The instrumentation meets the "Type 1—Precision" requirements set forth in American National Standards Institute (ANSI) S1.4 for acoustical measuring devices[30]. The microphone was tripod-mounted at a height of 1.5 meters (five feet) above ground. The measurements included simultaneous collection of broadband (A-weighted) and one-third-octave band data (3.15 hertz to 20,000 hertz bands). Sound level data were primarily logged in 10-minute intervals to be consistent with the wind farm's Supervisory Control And Data Acquisition (SCADA) system which provides electrical power output (kW) in 10-minute increments. A few sound level measurements were logged using 20-minute intervals for use in determining home transmission loss values. The meters were calibrated and certified as accurate to standards set by the National Institute of Standards and Technology. These calibrations were conducted by an independent laboratory within the past 12 months. Ground level wind speed and direction were measured with a HOBO H21-002 micro weather station (Onset Computer Corporation). The wind data were sampled every three seconds and logged every one minute.

5 RESULTS AND COMPARISON TO CRITERIA

Results from the field program are organized by wind turbine type. For each wind turbine type, results are presented per location type (outdoor or indoor) with respect to applicable criteria. Results are presented for 305 meters (1,000) feet from the nearest wind turbine. Data were also collected at 457 meters (1,500 feet) from the nearest wind turbine which showed lower sound levels. Therefore, wind turbines that met the criteria at 305 meters also met it at 457 meters. Data were collected under both high turbine output and moderate turbine output conditions (defined as sound power levels 2 or 3 dB less than the maximum sound power levels), and low ground-level wind speeds. The sound level data under the moderate conditions were equivalent to or lower than the high turbine output scenarios, thus confirming the conclusions from the high output cases. None of the operational sound level data were corrected for background noise. A-weighted sound power levels presented in this section (used to describe turbine operation) were estimated from the actual measured power output (kW) of the wind turbines and the sound power levels as a function of wind speed plus an uncertainty factor K of 2 dB.

Outdoor measurements are compared to criteria for audibility, for UK DEFRA disturbance using equivalent outdoor levels, for rattle and annoyance criteria as

Table 10—Summary of operational parameters—Siemens SWT-2.3-93 (Outdoor).

Parameter	Sample #34	Sample #39
Distance to nearest WTG	305 meters	305 meters
Time of day	22:00-22:10	22:50-23:00
WTG power output	1,847 kW	1,608 kW
A-weighted sound power level*	107 dB	106.8 dB
Measured wind speed @ 2 m	3.3 m/s	3.4 m/s
L_{Aeq}	49.4 dB	49.6 dB
L_{A90}	48.4 dB	48.6 dB
L_{Ceq}	63.5 dB	63.2 dB

* Includes K, uncertainty factor of 2 dB

contained in ANSI S12.9/Part 4, for evaluating complaints of rattling using Japan Ministry of Environment guidance, and for perceptible vibration using equivalent outdoor levels from ANSI/ASA S12.2. Indoor measurements are compared to criteria for audibility, for UK DEFRA disturbance, for evaluating complaints of mental and physical discomfort using Japan Ministry of Environment guidance, and for suitability of bedrooms, hospitals and schools and perceptible vibration from ANSI/ASA S12.2.

5.1 Siemens SWT-2.3-93

5.1.1 Outdoor measurements—Siemens SWT-2.3-93

Sound levels during six 10-minute periods of high wind turbine output and relatively low ground wind speed (which minimized effects of wind noise) were measured outdoors approximately 305 meters (1,000 feet) from the closest Siemens WTG. This site was actually part of a string of 15 WTGs, four of which were within 610 meters (2,000 feet) of the monitoring location. Representative sound level data from two 10-minute periods are presented herein and include contributions from all wind turbines as measured by the recording equipment. One data set is representative of time periods with low frequency sound level values near the maximum measured and the other data set is representative of the mean. The standard deviations for the low frequency one-third octave band levels for the six measurement periods were between 0.2–0.7 dB. The key operational and meteorological parameters during these two measurement periods are listed in Table 10.

Figure 2 plots the one-third octave band sound levels (L_{eq}) for both samples of high output conditions. The results show that infrasound is inaudible to even the most sensitive people 305 meters (1,000 feet) from these wind turbines (more than 20 dB below the median thresholds of hearing). Low frequency sound above 40 Hz may be audible depending on background sound levels.

Figure 3 plots the one-third octave band sound levels (L_{eq}) for both samples of high output conditions. The low frequency sound was "steady" according to DEFRA procedures, and the results show that all outdoor equivalent DEFRA disturbance criteria are met.

Figure 4 compares the one-third octave band sound levels (L_{eq}) for both samples of high output conditions to the Japan Ministry of Environment levels for evaluating complaints on rattle. The rattle criteria is met at all frequencies except at 5 Hz where the mean value is 1 dB (standard deviation of 0.4 dB) higher than the Japanese evaluation value. When one considers that the 5 Hz sound level is 3 dB lower than the observed threshold of rattle, one concludes that the Japanese criteria are met.

The measured outdoor sound levels also meet the outdoor equivalent Japan Ministry of Environment

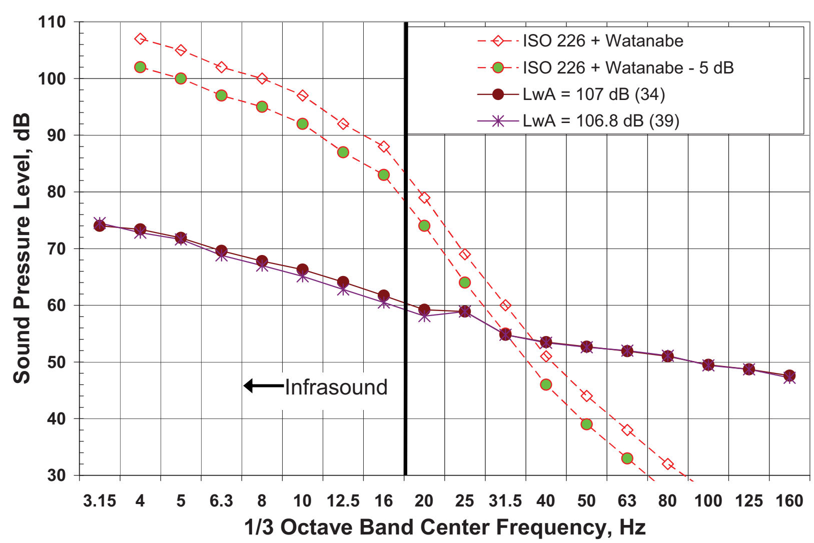

Fig. 2—Siemens SWT-2.3-93 wind turbine outdoor sound levels at 305 meters compared to audibility criteria.

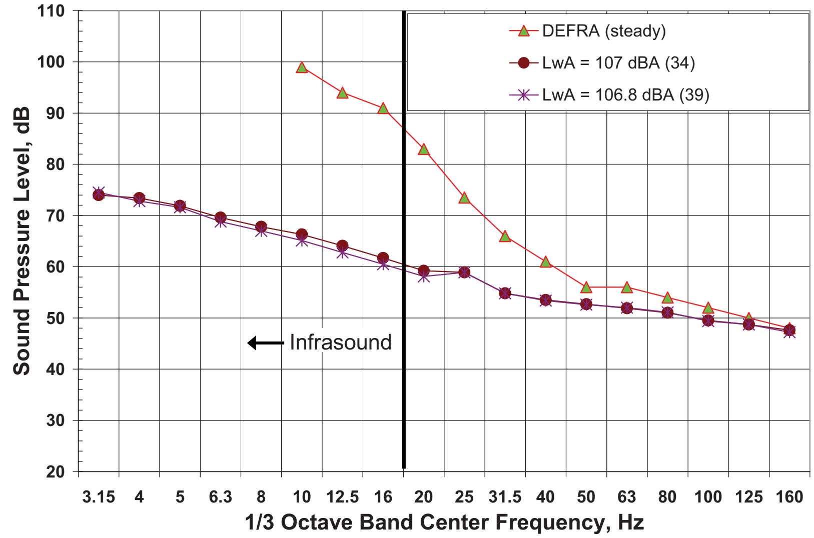

Fig. 3—Siemens SWT-2.3-93 wind turbine outdoor sound levels at 305 meters compared to outdoor equivalent DEFRA criteria.

criteria for evaluating complaints of mental and physical discomfort. This comparison is not presented in a figure since these criteria are generally less stringent than the DEFRA criteria.

Figure 5 plots the 16, 31.5, 63, and 125 Hz octave band sound levels (L_{eq}) for both samples of high output conditions. The results show that all outdoor equivalent ANSI/ASA S12.2 perceptible vibration criteria are met. In addition, the results show that all outdoor equivalent ANSI/ASA S12.2 low frequency NC-25 and NC-30 criteria for bedrooms are met. The low frequency sound levels are below the ANSI S12.9 Part 4 thresholds for the beginning of rattles (16, 31.5, 63 Hz total less than 70 dB). The 31.5 and 63 Hz sound levels are below the level of 65 dB identified for minimal annoyance in ANSI S12.9 Part 4, and the 16 Hz sound level is within 1.5 dB of this level, which is an insignificant increase since the levels were not rapidly fluctuating.

5.1.2 Indoor measurements—Siemens SWT-2.3-93

Simultaneous outdoor and indoor measurements were made at two residences at different locations within the wind farm to determine indoor audibility of low frequency noise from Siemens WTGs. In each house a 10-minute measurement was made in a room facing the wind turbines with a window both open and closed. Results from the testing at one of the homes are not presented due to the very high ground level winds

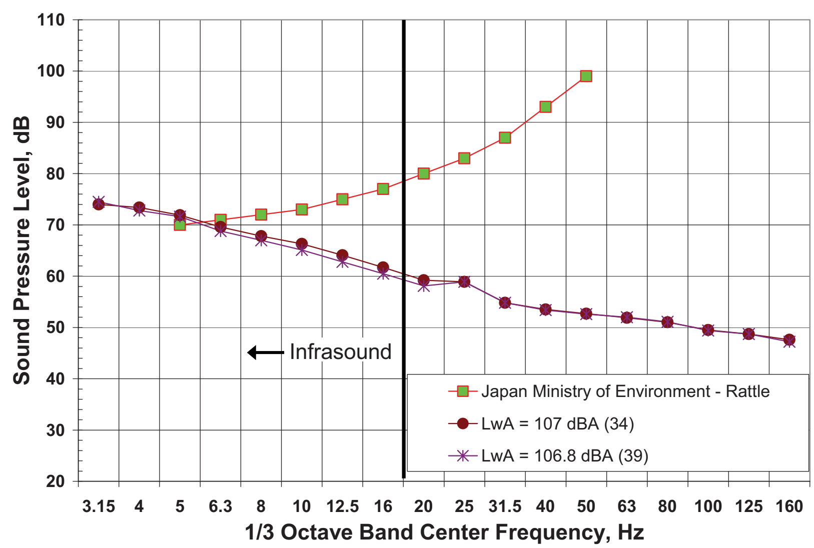

Fig. 4—Siemens SWT-2.3-93 wind turbine outdoor sound levels at 305 meters compared to Japan Ministry of Environment rattle criteria.

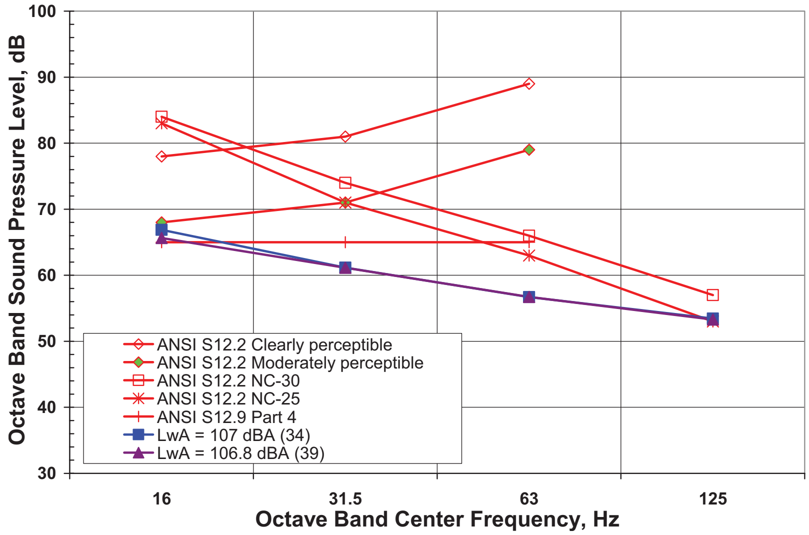

Fig. 5—Siemens SWT-2.3-93 wind turbine outdoor sound levels at 305 meters compared to ANSI criteria.

(~9 m/s) which dominated the sound environment. The remaining residence is designated Home "A" and was approximately 323 meters (1,060 feet) from the closest Siemens WTG. The home was near a string of multiple WTGs, four of which were within 610 meters (2,000 feet) of the house. The sound level data presented herein include contributions from all wind turbines as measured by the recording equipment. The key operational and meteorological parameters during these measurements are listed in Table 11.

The room in Home "A" where interior measurements were made had the following characteristics: approximately 3.6 meters wide (12 feet) by 4.9 meters long (16 feet), no furniture, carpeted flooring, two relatively new double-hung windows (no storm windows), sheetrock interior walls, and clapboard exterior walls. The sound level meter was located in the center of the room.

Figure 6 plots the indoor one-third octave band sound levels (L_{eq}) for Home "A". The results show that infrasound is inaudible to even the most sensitive people approximately 1,000 feet from these wind turbines with

Table 11—Summary of operational parameters—Siemens SWT-2.3-93 (Indoor).

Parameter	Home "A" (closed/open)
Distance to nearest WTG	323 meters
Time of day	07:39-07:49/07:51-08:01
WTG power output	1,884 kW/1564 kW
A-weighted sound power level*	107 dB/106.7 dB
Measured wind speed @ 2 m	3.2 m/s/3.7 m/s
L_{Aeq}	33.8 dB/38.1 dB
L_{A90}	28.1 dB/36.8 dB
L_{Ceq}	54.7 dB/57.1 dB

* Includes K, uncertainty factor of 2 dB

the windows open or closed (more than 20 dB below the median thresholds of hearing). Low frequency sound at or above 50 Hz may be audible depending on background sound levels.

Figure 7 plots the indoor one-third octave band sound levels (L_{eq}) for Home "A". The low frequency sound was "steady" according to DEFRA procedures under the window open condition, and the results show that all indoor DEFRA disturbance criteria are met.

Although not shown in Fig. 7, the one-third octave band levels meet the Japan Ministry of Environment criteria for evaluating complaints of mental and physical discomfort since in the frequency range of the Japan criteria both samples meet the more stringent DEFRA criteria for "non-steady" sounds, which is more stringent than the Japan criteria.

Figure 8 plots the indoor 16 Hz to 125 Hz octave band sound levels (L_{eq}) for Home "A". The results show the ANSI/ASA S12.2 low frequency criteria for perceptible vibration were easily met for both windows open and closed scenarios. The ANSI/ASA S12.2 low frequency NC-25 and NC-30 criteria for bedrooms, classrooms and hospitals were met, the spectrum was balanced, and the criteria for moderately perceptible vibrations in lightweight walls and ceilings were also met.

5.2 GE 1.5sle

5.2.1 Outdoor measurements—GE 1.5sle

Sound level data during twelve 10-minute periods of high wind turbine output and relatively low ground wind speed (which minimized effects of wind noise) were measured outdoors approximately 305 meters (1,000 feet) from the closest GE 1.5sle WTG. This site was actually part of a string of more than 30 WTGs, four of which were within 610 meters (2,000 feet) of the

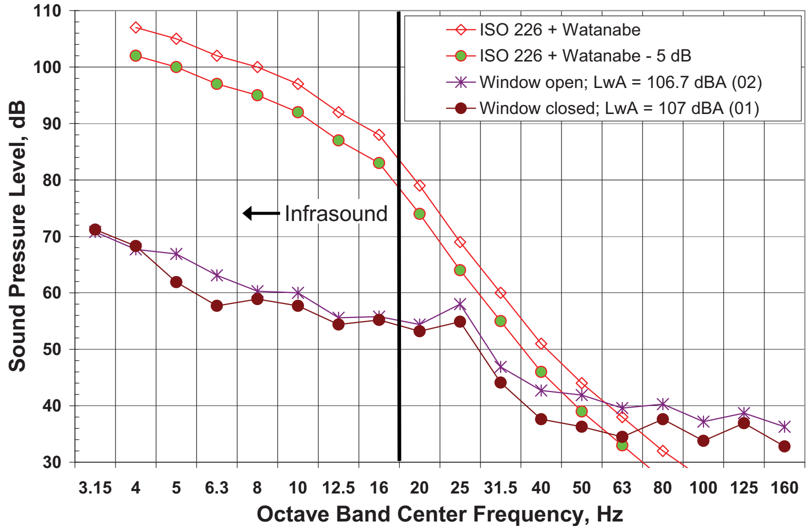

Fig. 6—Siemens SWT-2.3-93 wind turbine indoor sound levels at 323 meters compared to audibility criteria (Home "A").

monitoring location. Representative sound level data from two 10-minute periods are presented herein and include contributions from all wind turbines as measured by the recording equipment. One data set is representative of time periods with low frequency sound level values near the maximum and the other data set is representative of the mean. The standard deviations for the low frequency one-third octave band levels for the twelve measurement periods were between 0.3–1.9 dB with the largest variation in the 10–16 Hz bands and the lowest at 160 Hz. The key operational and meteorological parameters for these two measurement periods are listed in Table 12.

Figure 9 plots the one-third octave band sound levels (L_{eq}) for both samples of high output conditions. The results show that infrasound is inaudible to even the most sensitive people 305 meters (1,000 feet) from these wind turbines (more than 20 dB below the median thresholds of hearing). Low frequency sound at and above 31.5–40 Hz may be audible depending on background sound levels.

Figure 10 plots the one-third octave band sound levels (L_{eq}) for both samples of high output conditions. The low frequency sound was "steady" according to DEFRA procedures, and the results show the low frequency sound meet or are within 1 dB of outdoor equivalent DEFRA disturbance criteria.

Figure 11 compares the one-third octave band sound levels (L_{eq}) for both samples of high output conditions to the Japan Ministry of Environment levels for evaluating complaints on rattle. The rattle criteria is met at all

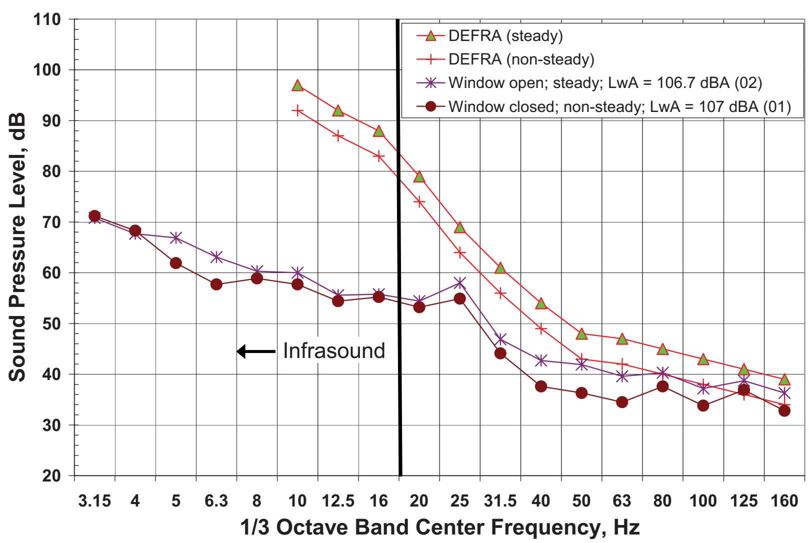

Fig. 7—Siemens SWT-2.3-93 wind turbine indoor sound levels at 323 meters compared to DEFRA criteria (Home "A").

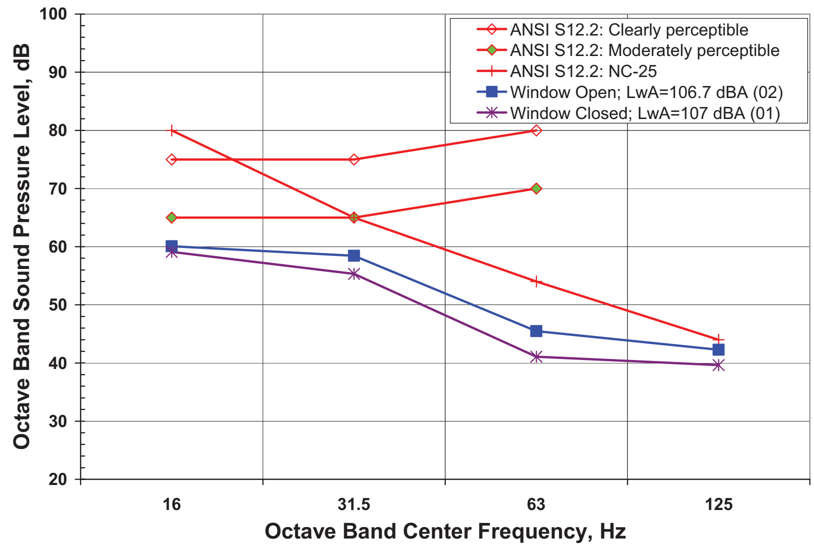

Fig. 8—Siemens SWT-2.3-93 wind turbine indoor sound levels at 323 meters compared to ANSI 12.2 criteria for perceptible vibrations and NC-25 (Home "A").

frequencies; at 5 Hz the mean value is 70 dB (standard deviation=0.9 dB), while the two presented measurements are approximately 1 dB higher, an insignificant increase. When one considers that the 5 Hz sound level is 3 dB lower than the observed threshold of rattle, one concludes that the Japanese criteria are met.

Table 12—Summary of operational parameters—GE 1.5sle (Outdoor).

Parameter	Sample #46	Sample #51
Distance to nearest WTG	305 meters	305 meters
Time of day	23:10-23:20	00:00-00:10
WTG power output	1,293 kW	1,109 kW
A-weighted sound power level*	106 dB	106 dB
Measured wind speed @ 2 m	4.1 m/s	3.3 m/s
L_{Aeq}	50.2 dB	50.7 dB
L_{A90}	49.2 dB	49.7 dB
L_{Ceq}	62.5 dB	62.8 dB

* Includes K, uncertainty factor of 2 dB

The measured outdoor sound levels also meet the outdoor equivalent Japan Ministry of Environment criteria for evaluating complaints of mental and physical discomfort. This comparison is not presented in a figure since these criteria are generally less stringent than the DEFRA criteria.

Figure 12 plots the 16, 31.5, 63 and 125 Hz octave band sound levels (L_{eq}) for both samples of high output conditions. The results show that all outdoor equivalent ANSI/ASA S12.2 perceptible vibration criteria are met. The results show that all outdoor equivalent ANSI/ASA S12.2 low frequency NC-25 and NC-30 criteria for

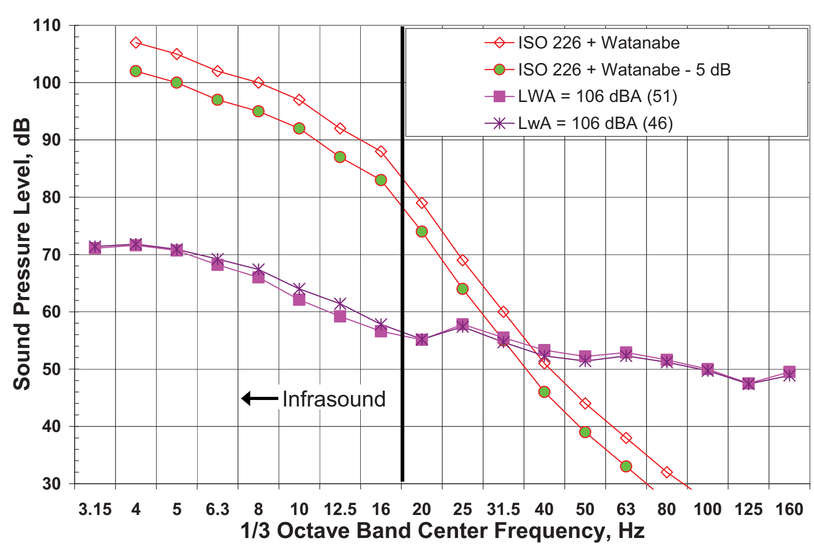

Fig. 9—GE 1.5sle wind turbine outdoor sound levels at 305 meters compared to audibility criteria.

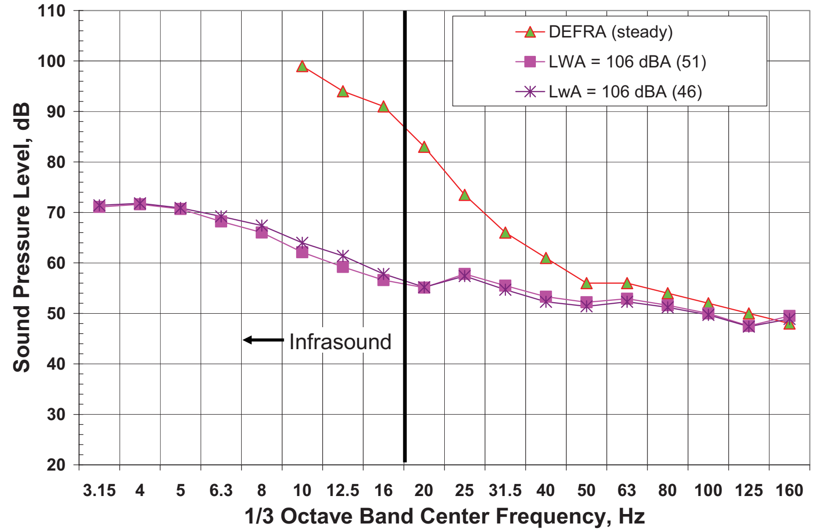

Fig. 10—GE 1.5sle wind turbine outdoor sound levels at 305 meters compared to outdoor equivalent DEFRA criteria.

bedrooms are met. The low frequency sound levels are below the ANSI S12.9 Part 4 thresholds for the beginning of rattles (16, 31.5, 63 Hz total less than 70 dB). The 16, 31.5, 63 Hz sound levels are below the level of 65 dB identified for minimal annoyance in ANSI S12.9 Part 4.

5.2.2 Indoor measurements—GE 1.5sle

Simultaneous outdoor and indoor measurements were made at two residences at different locations within the wind farm to determine indoor audibility of low frequency noise from GE 1.5sle WTGs. In each house, measurements were made in a room facing the wind turbines, and were made with a window both open and closed. These residences are designated Homes "B" and "C" and were approximately 305 meters (1,000 feet) from the closest GE WTG. Operational conditions were maximum turbine noise and high ground winds at Home "B", and within 1.5 dB of maximum turbine noise and high ground level winds at Home "C". Home "B" was near a string of multiple WTGs, four of which were within 610 meters (2,000 feet) of the house, while Home "C" was at the end of a string of WTGs, two of which were within 610 meters of the house. The sound level data presented herein include contributions from all wind turbines as measured by the recording equipment. The key operational and meteorological parameters during these measurements are listed in Table 13.

The room in Home "B" where interior measurements were made had the following characteristics:

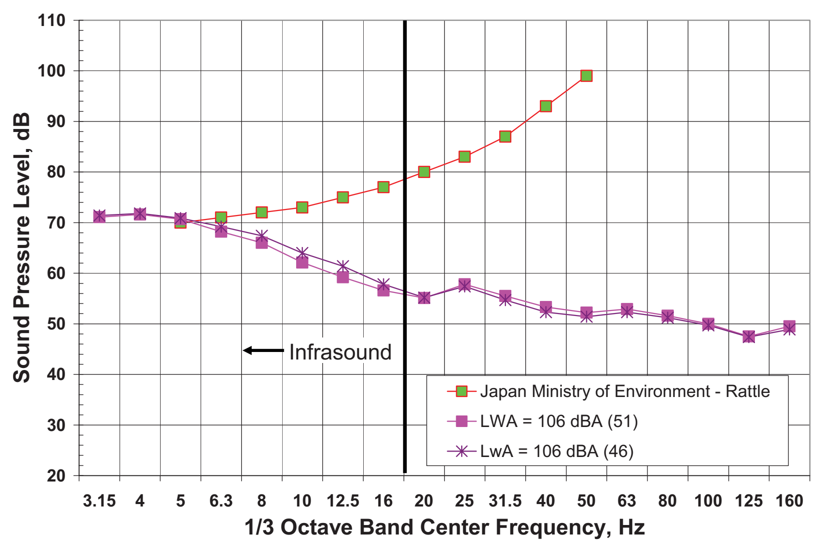

Fig. 11—GE 1.5sle wind turbine outdoor sound levels at 305 meters compared to Japan Ministry of Environment rattle criteria.

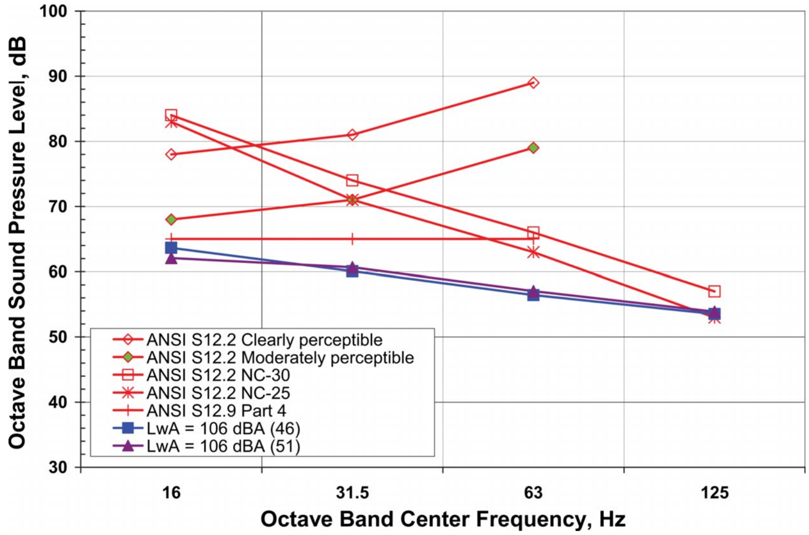

Fig. 12—GE 1.5sle wind turbine outdoor sound levels at 305 meters compared to ANSI criteria.

approximately 3.0 meters wide (10 feet) by 3.6 meters long (12 feet), bedroom furniture, carpeted flooring, two relatively new double-hung windows (no storm windows), paneling on the interior walls, and bricked exterior walls. The sound level meter was located just off-center in the room. The room in Home "C" where interior measurements were made had the following characteristics: approximately 2.4 meters wide (8 feet) by 3.6 meters long (12 feet), bathroom fixtures, linoleum flooring, one old casement window (no storm window), paneling on the interior walls, and wooden exterior walls. The sound level meter was located in the center of the room.

Figure 13 plots the indoor one-third octave band sound levels (L_{eq}) for Home "B", and Fig. 14 plots the indoor one-third octave band sound levels for Home "C". The results show that infrasound is inaudible to even the most sensitive people at around 305 meters (1,000 feet) from these wind turbines with the windows open or closed (more than 20 dB below the median thresholds of hearing). Low frequency sound at and above 63 Hz may be audible depending on background sound levels.

Figure 15 plots the indoor one-third octave band sound levels (L_{eq}) for Home "B", and Fig. 16 plots the indoor one-third octave band sound levels (L_{eq}) for Home "C". The results show the DEFRA disturbance criteria were met for steady and non-steady low frequency sounds.

Although not shown in Figs. 15 and 16, the one-third octave band levels meet the Japan Ministry of Environment criteria for evaluating complaints of mental and physical discomfort since both samples meet the more stringent DEFRA criteria for "non-steady" sounds, which is more stringent than the Japan criteria.

Figure 17 plots the indoor 16 Hz to 125 Hz octave band sound levels (L_{eq}) for Home "B", and Fig. 18 plots the indoor 16 Hz to 125 Hz octave band sound levels (L_{eq}) for Home "C". The results show the ANSI/ASA S12.2 low frequency criteria for perceptible vibration were met for both windows open and closed scenarios. The ANSI/ASA S12.2 low frequency NC-25 and NC-30 criteria for bedrooms, classrooms and hospitals were met,

Table 13—Summary of operational parameters—GE 1.5sle (Indoor).

Parameter	Home "B" (closed/open)	Home "C" (closed/open)
Distance to nearest WTG	290 meters	312 meters
Time of day	09:29-09:39/09:40-09:50	11:49-11:59/12:00-12:10
WTG power output	1,017 kW/896 kW	651 kW/632 kW
A-weighted sound power level	106 dB/105.8 dB	104.7 dB/104.6 dB
Measured wind speed @ 2 m	6.2 m/s/6.8 m/s	6.4 m/s/5.9 m/s
L_{Aeq}	27.1 dB/36.0 dB	33.6 dB/39.8 dB
L_{A90}	23.5 dB/33.7 dB	27.6 dB/34.2 dB
L_{Ceq}	47.1 dB/54.4 dB	50.6 dB/55.1 dB

* Includes K, uncertainty factor of 2 dB

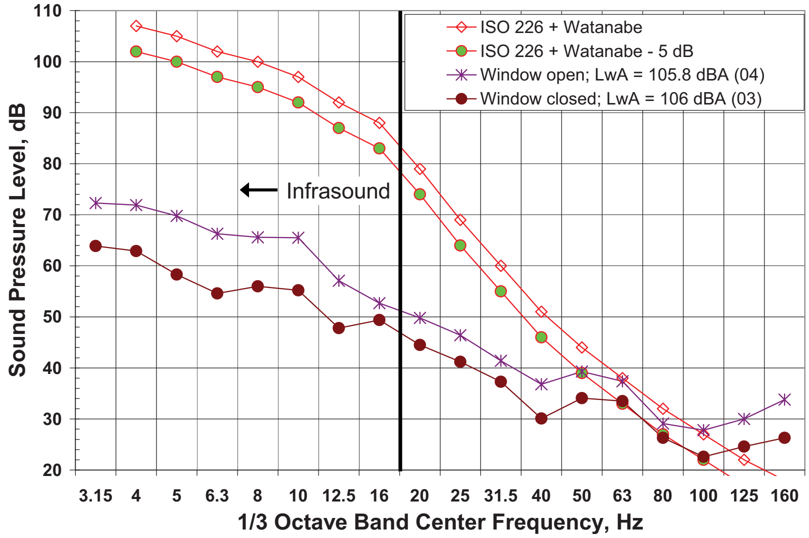

Fig. 13—GE 1.5sle wind turbine indoor sound levels at 290 meters compared to audibility criteria (Home "B").

the spectrum was balanced, and the criteria for moderately perceptible vibrations in light-weight walls and ceilings were also met.

5.3 Noise Reduction from Outdoor to Indoor

Simultaneous outdoor and indoor measurements made at the three residences within the Horse Hollow Wind Farm discussed above, were used to determine noise reductions of the homes for comparison to that used in the determination of equivalent outdoor criteria for indoor criteria, such as ANSI/ASA S12.2 and DEFRA. Indoor measurements were made with windows open and closed. Tables 11 and 13 list the conditions of measurement for these houses.

Figures 19 and 20 present the measured one-third octave band noise reduction for the three homes with windows closed and open, respectively. Also presented in these same figures are the one-third octave noise reductions discussed in the Appendix of this paper to obtain equivalent outdoor criteria for the indoor DEFRA criteria as well as the equivalent outdoor criteria for the Japanese mental and physical discomfort indoor criteria. It can be seen that for the window closed condition in Fig. 19, the measured noise reductions for all houses were greater than that used in our analysis for determining the equivalent outdoor criteria for the Japanese mental and physical discomfort indoor criteria. For the open window case in Fig. 20, which

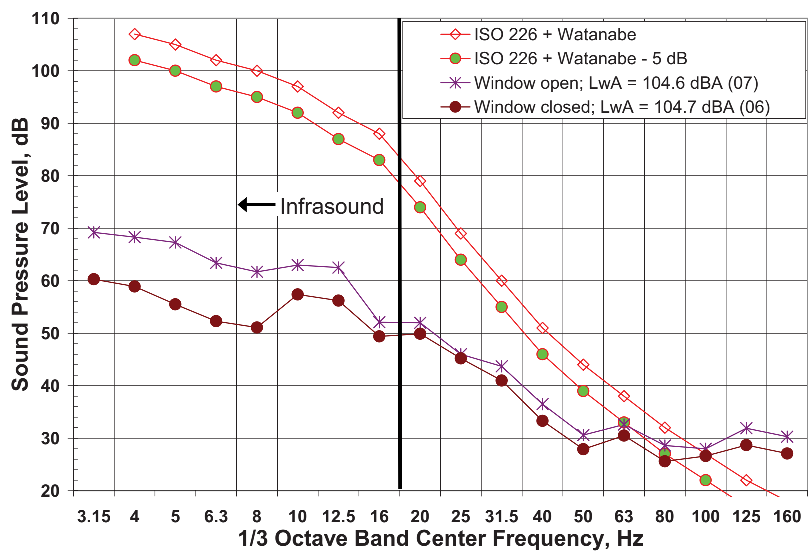

Fig. 14—GE 1.5sle wind turbine indoor sound levels at 312 meters compared to audibility criteria (Home "C").

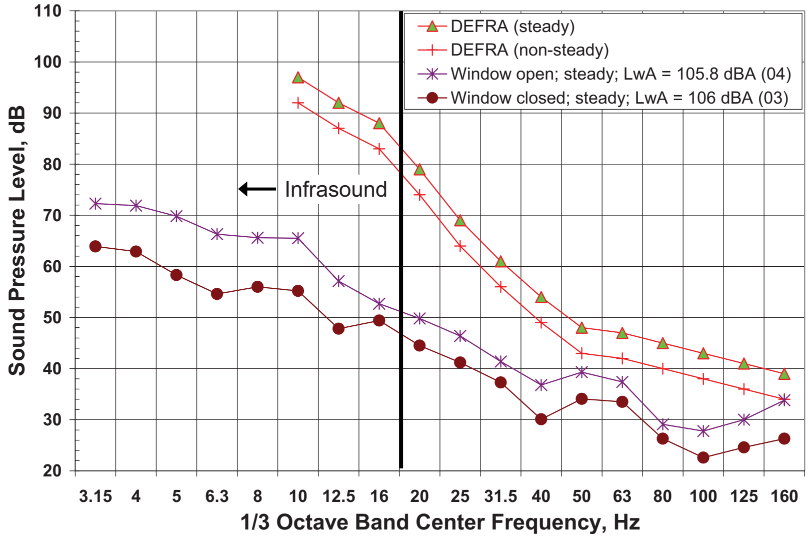

Fig. 15—GE 1.5sle wind turbine indoor sound levels at 290 meters compared to DEFRA criteria (Home "B").

was used in our analysis for obtaining the equivalent outdoor DEFRA criteria, the average of the three homes has a greater noise reduction than assumed in the Appendix and all houses at all frequencies have higher values with one minor exception. Only Home "A" at 25 Hz had a lower noise reduction (3 dB), and this difference is not critical since the measured indoor sounds at 25 Hz at each of these home was significantly lower than the indoor DEFRA criteria and the indoor Japanese criteria. Furthermore, the outdoor measurements for both Siemens and GE wind turbines at 305 meters (1,000 feet) under high output/high noise levels met the equivalent outdoor DEFRA criteria at 25 Hz.

Table 14 presents the measured octave band noise reduction for the three homes with windows closed and open, respectively. Also presented in Table 14 are the octave band noise reductions used in Table 2 of this paper to obtain equivalent outdoor criteria for the indoor ANSI/ASA S12.2 criteria for perceptible vibration and for NC-25 and NC-30. It can be seen that for the window closed condition, the measured noise reductions for all houses were greater than that used in our analysis. For the open window case, the average of the three homes has a greater noise reduction than the values from Table A1, and all houses at all frequencies have higher values with one minor exception. Only Home "A" at 31 Hz (which contains the 25 Hz one-third octave band) had a lower noise reduction (3 dB), and this difference is not critical since the measured indoor sounds at 31 Hz at each of these homes was significantly lower than the indoor ANSI/ASA S12.2 criteria. Furthermore, the outdoor measurements for both Siemens and GE wind

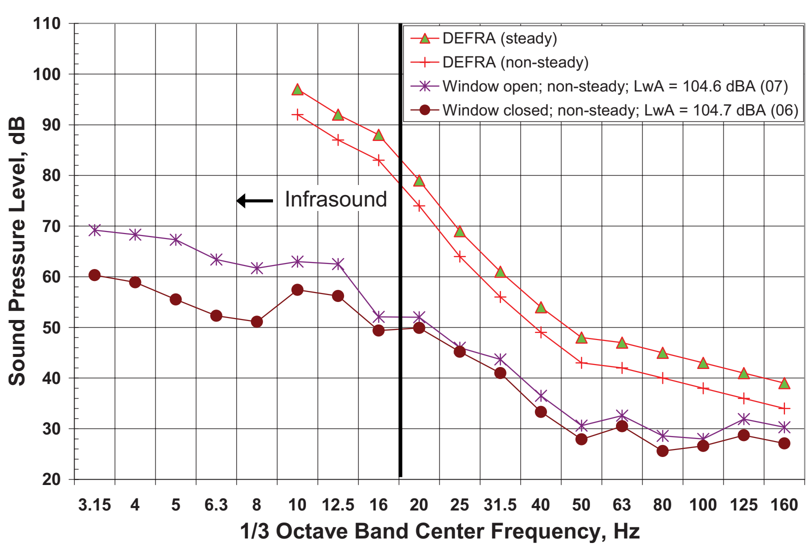

Fig. 16—GE 1.5sle wind turbine indoor sound levels at 312 meters compared to DEFRA criteria (Home "C").

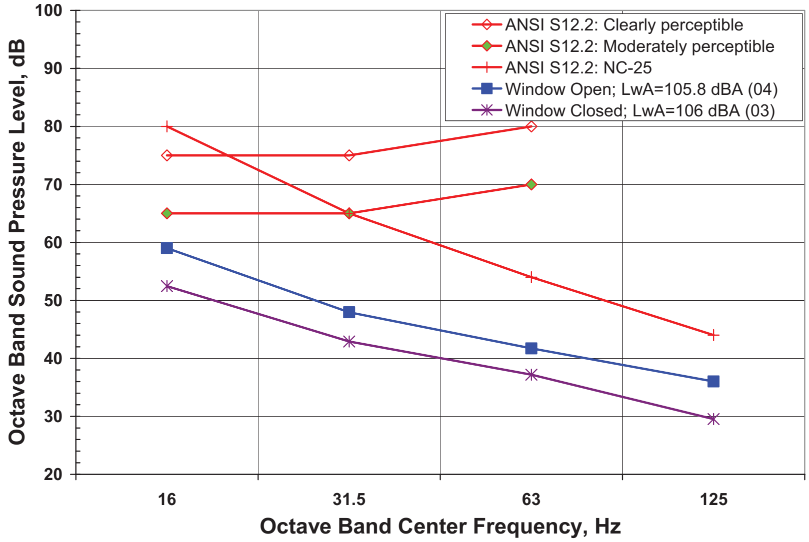

Fig. 17—GE 1.5sle wind turbine indoor sound levels at 290 meters compared to ANSI 12.2 criteria for perceptible vibrations and NC-25 (Home "B").

turbines at 305 meters (1,000 feet) under high output/high noise levels met the equivalent outdoor ANSI/ASA S12.2 criteria at 31 Hz.

6 CONCLUSION

Sound levels from Siemens SWT 2.93-93 and GE 1.5sle wind turbines under maximum noise conditions at a distance more than 305 meters (1,000 feet) from the nearest residence meet the low frequency and infrasound standards and criteria published by several independent agencies and organizations. At this distance the wind farms:

- meet ANSI/ASA S12.2 indoor levels for low frequency sound for bedrooms, classrooms and hospitals;
- meet ANSI/ASA S12.2 indoor levels for moderately perceptible vibrations in light-weight walls and ceilings;
- meet ANSI/ASA S12.2 criteria for balanced spectrum from low frequency sounds;
- meet ANSI S12.9/Part 4 thresholds for annoyance from low frequency sound and beginning of rattles;
- meet UK DEFRA disturbance based guidelines for low frequency sound;
- meet Japan Ministry of Environment Guidance for evaluating complaints of rattling from low frequency noise;
- meet Japan Ministry of Environment Guidance for evaluating complaints of mental and physi-

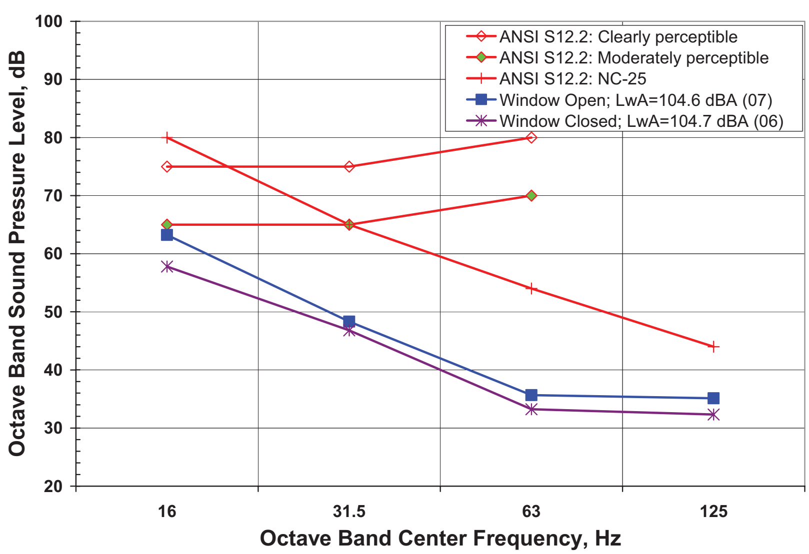

Fig. 18—GE 1.5sle wind turbine indoor sound levels at 312 meters compared to ANSI 12.2 criteria for perceptible vibrations and NC-25 (Home "C").

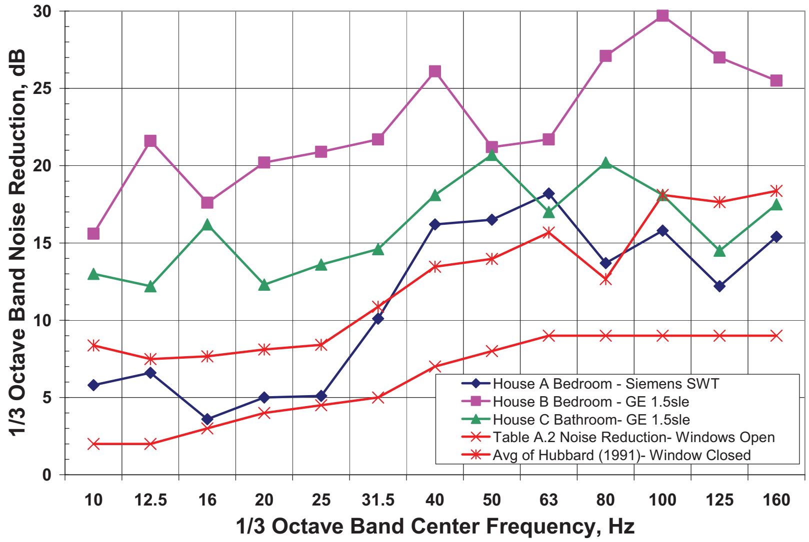

Fig. 19—One-third octave band interior noise reduction—Windows closed.

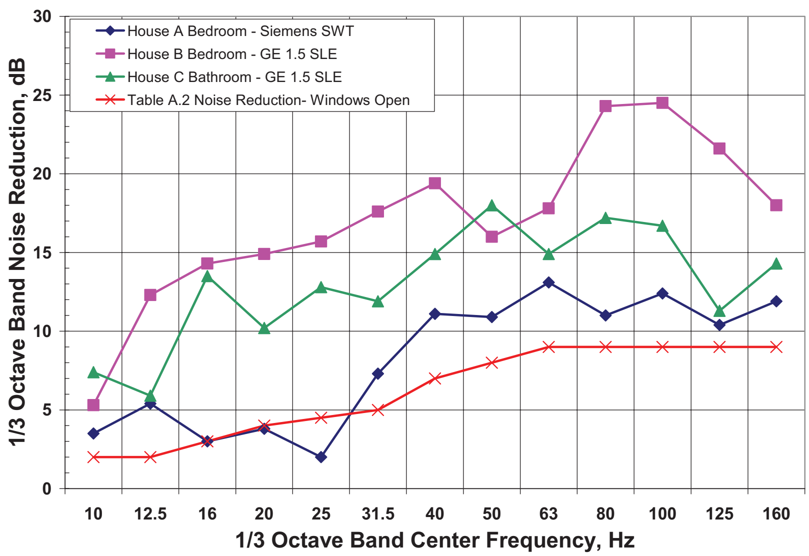

Fig. 20—One-third octave band interior noise reduction—Windows open.

cal discomfort from low frequency noise;

- have no audible infrasound to the most sensitive listeners; and
- might have slightly audible low frequency noise at frequencies at 50 Hz and above depending on other sources of low frequency noises in homes, such as refrigerators or external traffic or airplanes.

In accordance with the above findings, and in conjunction with our extensive literature search of

Table 14—Summary of octave band noise reduction—Interior measurements.

Home	Wind Turbine	Windows	16 Hz	31.5 Hz	63 Hz	125 Hz
A	Siemens SWT-2-3-93	Closed	5	6	16	14
A	Siemens SWT-2-3-93	Open	4	3	12	12
B	GE 1.5sle	Closed	20	22	22	27
B	GE 1.5sle	Open	13	17	18	21
C	GE 1.5sle	Closed	13	14	19	17
C	GE 1.5sle	Open	8	13	17	14
	Table A1 Noise Reduction	Open	3	6	9	9

scientific papers and reports, there should be no adverse public health effects from infrasound or low frequency noise at distances greater than 305 meters (1,000 feet) from the wind turbine types measured: GE 1.5sle and Siemens SWT 2.3-93.

7 ACKNOWLEDGMENTS

Acknowledgement is made to NextEra Energy Resources, LLC ("NextEra"), formerly FPL Energy, for providing financial support for the study, allowing access to the wind farm, and supplying critical operational data. Epsilon determined all means, methods, and the testing protocol without interference or direction from NextEra. No limitations were placed on Epsilon by NextEra with respect to the testing protocol or upon the analysis methods; the conclusions are those of the authors.

8 APPENDIX: HOME NOISE REDUCTION USED TO DETERMINE EQUIVALENT OUTDOOR SOUND PRESSURE LEVEL CRITERIA BASED ON INDOOR CRITERIA

Since indoor measurements are not always possible, for comparison to outdoor sound levels the indoor criteria from ANSI/ASA S12.2 should be adjusted. Outdoor to indoor low frequency noise reductions have been reported by Sutherland for aircraft and highway noise for open and closed windows[9] and by Hubbard and Shepherd for aircraft and wind turbine noise for closed windows[10]. Table A1 presents the average low frequency octave band noise reductions from outdoor to indoors from these two papers for open and closed windows. Sutherland only reported values down to 63 Hz; whereas Hubbard and Shepherd presented values to less than 10 Hz. The closed window conditions of Ref. 10 were used to estimate noise reductions less than 63 Hz by applying the difference between values for open and closed windows from Ref. 9 data at 63 Hz. It should be noted that the attenuation for wind turbines in Ref. 10 is based on only three homes at two different wind farms, whereas the traffic and aircraft data are for many homes. The wind turbine open window values were determined from the wind turbine closed window values by subtracting the difference in values between windows closed and open obtained by Ref. 9.

To be conservative, we use the open window case instead of closed windows except for the adjustments to the Japanese guideline which specifically called for closed windows. To be further conservative, we use the wind turbine noise reduction data in Ref. 10 (adjusted to open windows). However, it should be noted that it is possible for some homes to have some slight amplification at low frequencies with windows open due to possible room resonances.

The average one-third octave band noise reductions used to determine equivalent outdoor one-third octave band criteria were determined in a similar manner. The first row of Table A2 and Fig. 20 present the average one-third octave band noise reductions values for *windows open* that were used to determine the equivalent outdoor one-third octave band criteria levels in Table 7 from the indoor criteria. The second row of Table A2 and Fig. 19 presents the one-third octave band noise reductions for windows closed determined by Ref. 10 for homes exposed to wind turbine sounds—these higher closed window noise reduction values were only used to determine equivalent outdoor levels for determining the equivalent Japanese guidance one-third octave band sound pressure level values for dealing with complaints of mental and physical discomfort from environmental sounds.

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BEFORE THE PUBLIC UTILITIES COMMISSION
OF THE STATE OF SOUTH DAKOTA

IN THE MATTER OF THE APPLICATION OF
CROWNED RIDGE, LLC FOR A FACILITIES PERMIT TO
CONSTRUCTION 300 MEGAWATT WIND FACILITY

Docket No. EL19-003

REBUTTAL TESTIMONY AND EXHIBIT

OF SARAH SAPPINGTON

May 24, 2019

INTRODUCTION

Q. PLEASE STATE YOUR NAME AND BUSINESS ADDRESS.

A. My name is Sarah Sappington. My business address is 116 North 4th Street, Suite 200, Bismarck, North Dakota, 58501.

Q. **BY WHOM ARE YOU EMPLOYED AND IN WHAT CAPACITY?**

A. I am employed by SWCA Environmental Consultants as the Director of the Bismarck SWCA Office.

Q. **WHAT ARE YOUR RESPONSIBILITIES?**

A. My responsibility was to assist Crowned Ridge Wind, LLC ("CRW") regarding cultural and environmental resources.

Q. **ARE YOU THE SAME SARAH SAPPINGTON WHO SUBMITTED DIRECT TESTIMONY IN THIS PROCEEDING ON APRIL 10, 2019?**

A. Yes.

Q. HAS THIS TESTIMONY BEEN PREPARED BY YOU OR UNDER YOUR DIRECT SUPERVISION?

A. Yes.

Q. PLEASE DESCRIBE THE PURPOSE OF YOUR REBUTTAL TESTIMONY.

A. The purpose of my rebuttal testimony is to respond the direct testimonies of Staff witness Paige Olson, Staff witness Tom Kirschenmann, and Intervenors' proposed conditions as set forth in Staff witness Darren Kearney's Direct Testimony, Exhibit DK-8.

State Historic Preservation Office ("SHPO")

Q. STAFF WITNESS OLSON'S DIRECT TESTIMONY AT PAGE 4, LINES 6-8 STATES THAT "I AM WAITING FOR THE ARCHITECTURAL PROPERTIES SURVEY AND THE SURVEY OF THE REMAINING FACILITIES, SUCH AS, ACCESS ROADS, CRANE PATHS, COLLECTION LINES, O&M FACILITIES, CONCRETE BATCH PLANT AND LAYDOWN AREAS." WHAT IS THE STATUS OF PROVIDING SHPO THIS INFORMATION?

A. The architectural properties survey report received SHPO concurrence on May 17, 2019, finding that there are no National Register of Historic Places-listed and no State Register of Historic Places-listed architectural properties within 1 mile of project turbines. Additionally no National Register of Historic Places-listed and no State Register of Historic Places-listed architectural properties occur along any additional facilities, such as access roads, crane paths, collection lines, O&M facilities, concrete batch plant, and laydown areas, that would require further reporting. Cultural (archaeological and tribal) resource survey reports for the remaining facilities, such as, access roads, crane paths, collection lines, O&M facilities, concrete batch plant, and laydown areas will be submitted to SHPO at the end of June 2019.

Q. STAFF WITNESS OLSON'S DIRECT TESTIMONY AT PAGES 5 AND 6 RECOMMENDS THE FOLLOWING CONDITION:

> **THE APPLICANT AGREES TO AVOID DIRECT IMPACTS TO CULTURAL RESOURCES THAT ARE UNEVALUATED, ELIGIBLE FOR OR LISTED IN THE NATIONAL REGISTER OF HISTORIC PLACES (NRHP). WHEN A NRHP UNEVALUATED, ELIGIBLE OR LISTED SITE CANNOT BE AVOIDED, APPLICANT SHALL NOTIFY THE STATE HISTORIC PRESERVATION OFFICE (SHPO) AND THE COMMISSION OF THE REASONS THAT COMPLETE AVOIDANCE CANNOT BE**

ACHIEVED IN ORDER TO COORDINATE MINIMIZATION AND/OR TREATMENT MEASURES.

DO YOU AGREE WITH THIS CONDITION?

A. It is my understanding that CRW is amendable to this condition.

Q. STAFF WITNESS OLSON'S TESTIMONY AT PAGES 7 AND 8 ALSO PROPOSES THE FOLLOWING CONDITION:

THE APPLICANT AGREES TO IMPLEMENT THE AVOIDANCE, MINIMIZATION AND MITIGATION MEASURES IDENTIFIED FOR TCPS:

- **IMPLEMENT STANDARD AVOIDANCE OR RESOURCE PROTECTION PRACTICES (E.G., BARRIER FENCING, CONTRACTOR TRAINING) WHERE FEASIBLE IN COLLABORATION WITH THE SISSETON-WAHPETON OYATE, YANKTON SIOUX, ROSEBUD SIOUX AND SPIRIT LAKE THPOS AND THE APPLICANT.**
- **MAKE BEST EFFORT TO IDENTIFY PARTICIPATING LANDOWNERS WHO MAY BE WILLING TO WORK WITH THE TRIBES ON SITE PRESERVATION, ACCESSIBILITY AND PROTECTION OF TCPS ON THEIR PROPERTY.**
- **CONDUCT SITE REVISITS PRIOR TO CONSTRUCTION.**
- **HELP FACILITATE POST-CONSTRUCTION SITE REVISITS FOR TRIBES WITH THE LANDOWNERS.**
- **IDENTIFY AND IMPLEMENT EDUCATION/INTERPRETATION OPPORTUNITIES REGARDING TRIBAL RESOURCE PRESERVATION AND/OR NATIVE AMERICAN PERSPECTIVES WHICH MAY INCLUDE SENSITIVITY TRAINING WHEN NEEDED.**

A. It is my understanding that CRW is amendable to this condition. It is consistent with the representations set forth in the CRW Application at Section 18.6.3.1.

<u>Wetlands, Grasslands, and Wildlife</u>

Q. STAFF WITNESS KIRSCHENMANN'S TESTIMONY AT PAGE 7, LINE 21 THROUGH PAGE 8, LINE 2 STATES THAT TEMPORARY IMPACTS TO HABITAT AS A RESULT OF CONSTRUCTION OF THE PROPOSED WIND

FACILITY CAN BE ADDRESSED BY RESTORATION OF IMPACTS AREAS THROUGH GRADING AND RESEEDING. WHAT ACTIVITIES WILL CRW CONDUCT TO ADDRESS TEMPORARY IMPACTS TO HABITAT AS A RESULT OF CONSTRUCTION?

A. CRW sets forth in its Application (Section 11.3.2.5) a number of measures it will implement to avoid, minimize, and mitigate potential impacts to habitat. These measures include reseeding and revegetating areas temporarily impacted. The Application (in Section 15.2) also explains that during construction, the Applicant will segregate and stockpile topsoil to be re-spread after construction. Therefore, CRW's approach to addressing temporary impacts to habitat is consistent with Staff witness Kirschenmann's recommendations.

Q. STAFF WITNESS KIRSCHENMANN'S TESTIMONY AT PAGE 8, LINES 4-10 RECOMMENDS THAT PERMANENT LOSS OF GRASSLAND OR WETLAND CAN BE ADDRESSED THROUGH RESTORING THE AREA USING NATIVE SEED SOURCES. DO YOU AGREE?

A. I agree but perhaps differ as to the timing of such activities. e. CRW acknowledges that limited permanent impacts will occur as a result of the Project, as described in Table 11.1.2 of the Application. Permanent impacts include those where newly constructed, impervious surfaces will occur. Therefore, restoring these impacts is not feasible in these areas until such time that the CRW project is decommissioned.

Q. STAFF WITNESS KIRSCHENMANN'S TESTIMONY AT PAGE 8, LINES 4-10 ALSO RECOMMENDS THAT ANY PERMANENT LOSS ACRES OF GRASSLAND AND WETLAND BE REPLACED IN CLOSE PROXIMITY TO THE PROJECT. DO YOU AGREE?

A. CRW acknowledges the merit of off-site mitigation practices, when warranted. However, CRW has not planned an off-site mitigation plan due to the very limited permanent impacts associated with the project. Impacts to wetlands and grasslands were first avoided through siting, then minimized through project design. As stated in the Application, Table 11.1.2, the project is anticipated to result in minimal permanent impacts as shown below:

Table 11.1.2 Temporary and permanent impacts as a result of the Project

Land Cover Type[1]	Temporary Impacts (acres)	Permanent Impacts (acres)
Agricultural	1,504.01	60.40
Grass/Pasture	558.45	21.48
Developed	40.07	2.37
Other Hay/Non Alfalfa	21.86	1.36
Deciduous Forest	6.53	0.39
Herbaceous Wetlands	1.90	0.04
Fallow/Idle Cropland	1.11	0
Open Water	0.41	0
Barren	0.02	0
Total	2,134.4	86.0

Temporary impacts to naturally vegetated areas will be reseeded and revegetated as described in the Application.

Q. STAFF WITNESS KIRSCHENMANN'S TESTIMONY AT PAGE 8, LINES 17-20 CITES THE LOESCH AND SHAFFER/BUHL STUDIES (EXHIBIT TK-2 and EXHIBIT TK-3) AS INDICATING THAT SOME SPECIES WILL NOT USE GRASSLAND AND WETLAND WITHIN A CERTAIN DISTANCE OF A WIND TURBINE. DO YOU AGREE WITH THE FINDINGS IN THESE STUDIES?

A. CRW has not had the opportunity to conduct an independent peer review of the specific studies referenced. However, the Applicant acknowledges that Shaffer and Buhl 2015 study observed that (a) 7 of 9 species were displaced; (b) that one species was unaffected; and (c) that one species exhibited attraction. Likewise, the Applicant acknowledges that Loesch et al. 2012 reported a negative displacement effect where some species showed behavioral avoidance. The Application sets forth the indirect impacts that have potential to occur as a result of the Project. Section 11.1.2, page 51, states "indirect impacts could include the spread of noxious weed species resulting from construction equipment introducing seeds into new areas, or erosion or sedimentation due to ground-clearing in construction areas." Section 11.3.2.3, page 68, states "Impacts to avian species can be direct (e.g., turbine strike mortality) or indirect (e.g., loss [or] degradation of habitat)." Section 11.3.2.4 indicates that "Impacts to bat can be direct (e.g., turbine strike mortality) or indirect (e.g., loss [or] degradation of habitat)." The Applicant currently is preparing a Wildlife Conservation Strategy (WCS) that will discuss indirect effects, including potential for avoidance and displacement, in detail. The WCS will be filed with the Commission prior to start of construction of the Project and will be implemented during Project construction and operation.

Q. STAFF WITNESS KIRSCHENMANN'S TESTIMONY AT PAGE 12, LINES 8-13 RECOMMENDS THAT CRW AVOID UNTILLED NATIVE PRAIRIE TO THE GREATEST EXTENT POSSIBLE. WILL THE CROWNED WIND PROJECT IMPACT UNTILLED NATIVE PRAIRIE?

A. The CRW project will result in permanent impacts to only approximately 22.5 acres of grass/pasture. CRW avoided native prairie to the greatest extent possible in conjunction with consideration of landowner preferences, conflicting environmental constraints, and other local or state requirements or setbacks.

Table 11.1.2 Temporary and permanent impacts as a result of the Project

Land Cover Type[1]	Temporary Impacts (acres)	Permanent Impacts (acres)
Agricultural	1,504.01	60.40
Grass/Pasture	558.45	21.48
Developed	40.07	2.37

Other Hay/Non Alfalfa	21.86	1.36
Deciduous Forest	6.53	0.39
Herbaceous Wetlands	1.90	0.04
Fallow/Idle Cropland	1.11	0
Open Water	0.41	0
Barren	0.02	0
Total	2,134.4	86.0

Untilled native prairie is a subset of the grass/pasture land cover type. The Application, Section 11.3.2.5, describes that CRW sited the project to avoid placing structures, or conducting any activity, on USFWS grassland or USFWS wetland/grassland combination easements. Further, CRW sited the project with overall preference to agricultural areas, disturbed areas, and following landowner preferences. Native prairies were avoided to the extent practical.

Q. STAFF WITNESS KIRSCHENMANN'S TESTIMONY AT PAGE 12, LINE 15 THROUGH PAGE 14, LINE 7 EXPLAINS THAT IT IS CHALLENGING FOR THE CROWNED RIDGE PROJECT TO AVOID AN IMPACT ON GRASSLAND HABITAT. WHAT IS CRW DOING TO AVOID IMPACTING GRASSLAND HABITAT?

A. The Application, Section 11.3.2.5, describes that CRW sited the project to avoid placing structures, or conducting any activity, on USFWS grassland or USFWS wetland/grassland combination easements. Further, CRW sited the project with overall preference to disturbed areas and following landowner preferences.

Q. STAFF WITNESS KIRSCHENMANN'S TESTIMONY AT PAGE 15, LINE 23 THROUGH PAGE 16, LINE 3 EXPLAINS THAT IT IS CHALLENGING FOR

THE CRW PROJECT TO AVOID AN IMPACT ON WETLANDS. WHAT IS CROWNED RIDGE DOING TO AVOID IMPACTING WETLANDS?

A. As described in Section 2.1, the Applicant sited facilities to avoid direct impacts to field-verified wetlands to the extent practical. Generally, wind turbines were sited in higher elevation areas and avoided low-lying areas where wetlands are present. Access roads were located to avoid and minimize potential impacts to identified natural resources to the extent practical, while also minimizing impacts to existing field operations to the extent practical. Further, as stated in Section 10.2.2 of the Application, to the extent practicable, impacts to water bodies, wetlands, and aquatic resources were avoided or minimized through the siting process and will be further avoided and minimized through the use of stormwater best management practices ("BMP") during construction. Impacts to wetlands and waterbodies that may result because of access road construction are minor and will be authorized under United States Army Corps of Engineers ("USACE") Nationwide Permit ("NWP") 12 for utility lines and associated facilities in waters of the U.S. Likewise, as described in the Application (Section 10.2.2), collector lines will be sited to avoid intersecting wetland or other waterbodies to the extent practical. Where collector lines must intersect these resources, the Applicant will bore under these features to the extent practical to minimize impacts to the maximum extent feasible. Where any activity must occur in a wetland area, the Applicant will utilize standard construction BMPs to minimize impacts and has designed the project to keep permanent impacts below USACE NWP thresholds.

Q. STAFF WITNESS KIRSCHENMANN'S TESTIMONY AT PAGE 16, LINE 13 EXPLAINS THAT THE PLACEMENT OF TURBINES ON LAND CURRENTLY UNDER CULTIVATION WILL HELP MINIMIZE CUMULATIVE IMPACTS

TO GRASSLANDS AND WETLANDS FROM THE COMBINATION OF CRW AND OTHER WIND PROJECTS PROPOSED FOR THE AREA. IS CROWNED RIDGE WIND MINIMIZING THE IMPACT ON GRASSLANDS AND WETLANDS IN A MANNER THAT WILL THAT HELP REDUCE CUMULATIVE IMPACTS?

A. Yes. The siting measures described above and in the Application, including avoidance of wetland and grassland habitat to the extent practical, is helping to reduce overall cumulative impacts to these features by avoiding or minimizing impacts to these resources altogether. These approaches also incorporate landowner preferences.

Q. STAFF WITNESS KIRSCHENMANN'S TESTIMONY AT PAGE 17, LINES 10-15 EXPLAINS THAT A STORM WATER POLLUTION PREVENTION PLAN ("SWPPP") AND MITIGATION TO REDUCE OR ELIMINATE SEDIMENTATION SHOULD BE IMPLEMENTED TO NEGATE THE POTENTIAL IMPACT TO THE NORTHERN RIVER OTTERS. HAS CRW AGREED TO IMPLEMENT A SWPPP AND OTHER MITIGATION TO ADDRESS THE POTENTIAL IMPACT ON THE NORTHERN RIVER OTTERS?

A. It is my understanding CRW has agreed. CRW is aware that northern river otters have the potential to occur in the project area. The Application discusses the northern river otter and its potential to occur in the project area in Sections 11.3.1.3.1 and 11.3.2.2. Section 11.3.2.2 of the application states that habitat removal and degradation are the primary potential impacts to the northern river otter, as erosion and siltation can affect water quality, limiting prey availability for northern river otters. Impacts to streams and waterbodies will be avoided to the extent practicable through project design and BMPs, further described in the Application (Section 11.2). As such, impacts to northern river otters are not anticipated to result from the project and therefore, mitigation for impacts to the species is not warranted.

Q. STAFF WITNESS KIRSCHENMANN'S TESTIMONY AT PAGE 17, LINE 19 THROUGH PAGE 18, LINE 2 ASKS THAT CRW ENGAGE THE SOUTH DAKOTA DEPARTMENT OF GAME, FISH AND PARKS ("GFP") IF THE "WALK-IN AREA" IS TEMPORARY DISRUPTED DURING CONSTRUCTION. DOES CROWNED RIDGE WIND AGREE TO ENGAGE GFP AS REQUESTED?

A. Yes.

Q. STAFF WITNESS KIRSCHENMANN'S TESTIMONY AT PAGE 18, LINES 12-20, EXPLAINS THAT THERE ARE NO STATE SET-BACKS FOR THE DISTANCE OF WIND TURBINES FROM GAME PRODUCTION AREAS. WHAT IS THE SETBACK FOR THE CROWNED RIDGE WIND TURBINES FROM THE GAME PRODUCTION AREAS?

A. Table 13.2.1 of the Application indicates there are 8 game production easements in the project area for a total of 3.5 acres. No turbines are located on game production areas. The closest turbines to game production areas are CR-28 located 0.24 mile to the south and CR-26, located 0.35 mile to the southeast.

Q. STAFF WITNESS KIRSCHENMANN'S TESTIMONY AT PAGE 19, LINE 4 STATES THAT IF THE FINAL TURBINE LOCATIONS CHANGE, THAT COULD CHANGE THE CURRENTLY UNDERSTOOD IMPACT TO THE TERRESTRIAL ENVIRONMENT. HAVE THE TURBINE LOCATIONS CHANGED FROM THE LOCATIONS FILED IN THE APPLICATION?

A. While there have been minor shifts in collector lines, access roads, the siting of turbines, and the use of alternative turbines instead of primary turbines (as set forth in the testimony of CRW witness Wilhelm and Massey) none of these moves change the overall project or impact the terrestrial environment. See Exhibit SS-R-1, which includes maps showing the minor adjustments to project infrastructure.

Q. STAFF WITNESS KIRSCHENMANN'S TESTIMONY AT PAGE 20, LINE 1-6 SUGGESTS THAT TWO YEARS OF POST-CONSTRUCTION AVIAN AND BAT MORTALITY MONITORING SHOULD BE CONDUCTED BY CRW. DO YOU AGREE WITH THIS SUGGESTION?

A. Yes. Similar to past cases (Crocker Wind, and Dakota Range 1 and 2), CRW is agreeable to a condition that states:

> Applicant agrees to undertake two years of independently-conducted post-construction avian and bat mortality monitoring for the Project, and to provide a copy of the report to the United States Fish & Wildlife Service (USFWS), the South Dakota Game, Fish, and Parks (SD GF&P), and the Commission. The Applicant will conduct a third year of monitoring independently-conducted post-construction avian and bat mortality monitoring for the Project if results of the first two years exceed other publicly available studies in the region in comparable habitats in coordination with the USFWS and SD GF&P. If the results from the first two years confirm that the Project site is low risk for avian and bat mortality, a third year will not be conducted.

CRW believes it is important to clearly articulate the objective and rationale for a third year of post-construction mortality monitoring. In this case, the purpose of the first two years is to confirm the site is low risk compared to publicly available data in the region and in comparable habitats. If the site is not low risk, then the Applicant agrees to consider a third year of post-construction mortality monitoring in coordination with the wildlife agencies, unless another course of action or remedy is identified and can be addressed.

Q. STAFF WITNESS KIRSCHENMANN'S TESTIMONY AT PAGE 20, LINES 7-14 RECOMMENDS POST-CONSTRUCTION GROUSE LEK MONITORING OF THOSE LEKS THAT ARE LESS THAN 1 MILE FROM THE PROPOSED WIND TURBINES. DO YOU AGREE WITH THIS CONDITION?

A. No. Pre-construction grouse lek surveys were conducted for the project or earlier iterations of the project in 2007-2008 and 2016. The South Dakota Game, Fish and Parks provided lek location data to CRW which was considered during Project siting. The Applicant sited the Project to avoid or minimize impacts to grassland communities, and collocated linear project features, such as access roads, collection lines, and crane paths with existing disturbed corridors (e.g., roads, fence rows) to the extent practical in an effort to reduce fragmentation and impacts to grouse leks. The Applicant will avoid construction activities within 2 miles of known leks during the lekking period (March 1 to June 30) to minimize impacts to the species.

INTERVENORS' PROPOSED CONDITIONS

Q. THE INTERVENORS' PROPOSED CONDITION 8 (KEARNEY EXHIBIT DK-8) THAT REQUIRES "AIR QUALITY MONITORING DURING CONSTRUCTION AND THE MONTHS OF MAY THROUGH OCTOBER AFTER CONSTRUCTION IS COMPLETE, THROUGHOUT THE LIFE OF THE PROJECT." DO YOU AGREE WITH THIS CONDITION?

A. No. As stated in the application in Section 16, the State of South Dakota follows ambient air quality goals and is in attainment for all criteria pollutants, meaning it meets the national standard, as defined under the National Ambient Air Quality Standards

("NAAQS"). The nearest Ambient Air Quality Monitoring Site is located in Watertown in Codington County. The primary emission sources within the Project Area include agricultural-related equipment and vehicles traveling along state highways and county roads. In Section 16.2 of the application, temporary impacts to air quality are expected from construction activities that may result in short-term airborne dust/particulate matter from construction equipment and vehicle emissions. Dust from ROW clearing, hauling, and excavation may be generated. These impacts are temporary, and no long-term impacts are anticipated. The Applicant will use standard BMPs to minimize air quality emissions as required by the project Storm Water Pollution Prevention Plan (SWPPP) and/or county haul route permits. After construction has been completed and disturbed areas reclaimed, air emissions will only be associated with operational vehicles as personnel conduct inspections and perform routine maintenance activities and minor dust generated by those vehicles. Air quality effects during construction and in the months of May through October and throughout the life of the project would not result in NAAQS exceedances; therefore, no monitoring would be needed. Air quality monitoring has not been required in previous cases (Dakota Range I and II, Prevailing Wind, and Crocker Wind).

Q. THE INTERVENORS' PROPOSED CONDITION 10 (KEARNEY EXHIBIT DK-8) IS PREMISED ON COTEAU PRAIRIE BRING AN IMPORTANT ASPECT TO THE EARTH'S OVERALL ECOSYSTEM, PART OF WHICH IS BEING DESTROYED BY THE APPROVAL OF THIS PROJECT." DO YOU AGREE?

A. No. The Project Area lies within three ecoregions, namely the Prairie Coteau Escarpment, the central Prairie Coteau, and the Big Sioux Basin. As shown in the Application, Table

11.1.2, the Project is anticipated to result in permanent impacts to 86 acres, which represents less than 0.16% of the Project Area (approximately 53,186 acres). The Prairie Coteau Escarpment, the central Prairie Coteau, and the Big Sioux Basin ecoregions within the Project Area encompasses approximately 53,186 acres. Therefore, the permanent impact to 86 acres within this total area is equal to 0.16% and will be minimal.

Q. THE INTERVENORS' PROPOSED CONDITION 10 (KEARNEY EXHIBIT DK-8) WOULD REQUIRE CRW TO "SUBMIT AND FOLLOW A 3 YEAR GRASSLAND RECLAMATION PLAN FOR ANY PASTURE, GRASS AND/OR NATIVE UNDISTURBED LAND THAT IS DISTURBED DURING THE CONSTRUCTION OF THIS PROJECT. DO YOU AGREE WITH THIS PROPOSED CONDITION?

A. No. In Table 11.1.2 of the application, temporary impacts to grass/pasture lands is 558.45 acres and permanent impacts to grass/pasture lands is 21.48 acres. Temporary impacts will be mitigated through the use of BMPs as described in the project (SWPPP) and the stormwater permit will remain open until all disturbed lands achieve final stabilization and a Notice of Termination is filed with the South Dakota Department of Environment and Natural Resources ("SDDENR"). For example, in temporarily impacted areas that were previously natural (i.e., non-cropland), the Applicant will use native vegetation (weed-free) seed mixes to revegetate disturbed areas to preconstruction conditions where feasible and pending landowner preferences. Where temporary impacts occur, the land will be returned to pre-construction conditions.

Also, in past cases (Dakota Range I and II, Prevailing Wind, and Crocker Wind) required the following condition:

> Applicant will repair and restore areas disturbed by construction or maintenance of the Project. Except as otherwise agreed to by the landowner, restoration will include replacement of original pre-construction topsoil or equivalent quality topsoil to its original elevation, contour, and compaction and re-establishment of original vegetation as close thereto as reasonably practical. In order to facilitate compliance with this Permit Condition, Applicant shall:
>
> a) Strip topsoil to the actual depth of the topsoil, or as otherwise agreed to by the landowner in writing (e-mail is sufficient), in all areas disturbed by the Project; however, with respect to access roads, Applicant may remove less than the actual depth of topsoil to ensure roads remain low-profile and the contours align with the surrounding area;
>
> b) Store topsoil separate from subsoil in order to prevent mixing of the soil types;
>
> c) All excess soils generated during the excavation of the turbine foundations shall remain on the same landowner's land, unless the landowner requests, and/or agrees, otherwise; and
>
> d) When revegetating non-cultivated grasslands, Applicant shall use a seed mix that is recommended by the Natural Resource Conservation Service (NRCS), or other land management agency, unless otherwise agreed upon with the landowner in writing.

This condition already protects grasslands by establishing additional control if not already addressed in the Applicant's SWPPP and permit. Therefore, no additional condition is needed to protect grasslands.

Q. THE INTERVENORS' PROPOSED CONDITION 10 (KEARNEY EXHIBIT DK-8) WOULD REQUIRE CRW TO PROVIDE A DETAILED WEED CONTROL PLAN. DO YOU AGREE WITH THIS PROPOSED CONDITION?

A. No. As stated in the Application (Section 11.1.1.2), noxious weeds are regulated by State and Federal rules and regulations (SDCL 38-22 and 7 U.S.C. 2801 et seq.; 88 Stat.

2148). In previous cases (e.g., Crocker Wind, Prevailing Wind, and Dakota I and II), the Commission conditioned approval on the following: "Applicant shall work closely with landowners or land management agencies, such as the NRCS, to determine a plan to control noxious weeds." This condition is sufficient, and will ensure CRW coordinates with the appropriate land management agencies to develop a site-specific and effective noxious weed control plan. Therefore, the Commission should not adopt the Intervenors condition requiring a detailed weed control plan at this time.

Q. THE INTERVENORS' PROPOSED CONDITION 10 (KEARNEY EXHIBIT DK-8) REQUIRES CRW TO PROVIDE SEED MIX DETAILS THAT WILL BE USED TO RECLAIM THE DISTURBANCE. DO YOU AGREE WITH THIS CONDITION?

A. No. In past cases (e.g., Crocker Wind, Prevailing Wind, and Dakota I and II), the Commission conditioned approval on the following or similar to the following: "When revegetating non-cultivated grasslands, Applicant shall use a seed mix that is recommended by the Natural Resource Conservation Service ("NRCS"), or other land management agency, unless otherwise agreed upon with the landowner in writing." Accordingly, the seed mix details will be available in the future, after coordinating with the NRCS, other land management agencies, and landowners. Therefore, the Commission should not adopt the Intervenors condition requiring seed mix details at this time.

Q. THE INTERVENORS' PROPOSED CONDITION 10 (KEARNEY EXHIBIT DK-8) WOULD REQUIRE CRW TO WRITE AN ANNUAL REPORT THAT IS AVAILABLE TO THE PUBLIC INCLUDING

PHOTOS OF EACH LOCATION AND A STATUS OF THE RECLAMATION PROGRESS. DO YOU AGREE WITH THIS PROPOSED CONDITION?

A. No. Reclamation of disturbed lands will be addressed in the SWPPP and the stormwater permit will remain open until all disturbed lands achieve final stabilization and a Notice of Termination is filed with the SDDENR. Annual reports are not required; however, reports detailing the results of each inspection and any necessary corrective actions have to be prepared and retained for three years. Reports can be inspected/viewed by SDDENR at any time.

Q. THE INTERVENORS' PROPOSED CONDITION 11 (KEARNEY EXHIBIT DK-8) WOULD REQUIRE "ALL OIL OR HAZARDOUS MATERIAL SPILLS DURING PRE-CONSTRUCTION, CONSTRUCTION, MAINTENANCE, OPERATION AND DECOMMISSIONING SHALL BE REPORTED TO THE PUC WITHIN 20 DAYS IN ADDITION TO ANY REQUIRED REPORTING TO THE DENR." DO YOU AGREE WITH THIS PROPOSED CONDITION?

A. No. The SWPPP has requirements for oil and hazardous materials spill prevention, response, and reporting during construction and the SPCCP includes preparedness, response, and reporting requirements for oil and hazardous materials spills throughout the active life of the Project. Both plans specify local, state, and federal agencies that have to be notified in the event of a spill or release that could adversely impact surface water, groundwater, human health, or the environment. While the Commission has jurisdiction over pipeline safety and hazardous materials transportation, jurisdiction for releases of oil and hazardous materials to waters of the United States lies with the U.S. EPA, SDDENR, and local emergency management offices.

Q. THE INTERVENORS' PROPOSED CONDITION 16 (KEARNEY EXHIBIT DK-8) WOULD REQUIRE:

> **PARTNER WITH THE SOUTH DAKOTA DENR TO IMPLEMENT AND MONITOR TEST WELLS THROUGHOUT THE PROJECT WHICH MUST BE TESTED BEFORE ANY CONSTRUCTION IS COMMENCED AND THEN TESTED MONTHLY DURING CONSTRUCTION AND ANNUALLY THEREAFTER FOR THE LIFE OF THE PROJECT. RESULTS MUST BE MADE AVAILABLE TO THE PUBLIC. WELL TESTING MUST BE COMPLETED BY A THIRD PARTY ORGANIZATION SELECTED BY THE DENR. THE PROJECT AREA IS LOCATED IN A SHALLOW AQUIFER REGION AND IS THEREFORE PRONE TO CONTAMINATION.**

DO YOU AGREE WITH THIS PROPOSED CONDITION?

A. No. Potential impacts to surface water and groundwater are mitigated by the use of BMPs during construction, spill prevention procedures, physical controls, and spill response procedures, materials, equipment, and, personnel during operation of the facility as specified in the Project SWPPP and the facility SPCC plans. The SPCC Plan that will be developed for the Project will also specify secondary containment structures, operational requirements, and response procedures and equipment to comply with US EPA regulations for oil pollution prevention (40CFR112).

The SDDENR has information available online for the public to access regarding water quality throughout the state. The SDDNER maintains an extensive surface water quality monitoring network of South Dakota Streams including 11 water quality monitoring stations in streams in Codington, Grant, and Deuel Counties. The SDDENR also has a monitoring network to examine the quality of shallow groundwater in 26 aquifers across the state, including the Big Sioux aquifer in Codington and Grant Counties and the Antelope Valley aquifer in Grant County. Groundwater Protection Overlay Districts Ordinances exist in Codington, Grant, and Deuel Counties to protect groundwater within those specific counties. This network regularly and systematically assesses nonpoint source pollution, the current ground water quality, short-term water-quality changes and long-term trends in water.

Requiring development, administration, and implementation of a groundwater monitoring program that would provide an assessment of pre-construction groundwater conditions, measure groundwater quality changes during construction, monitor long-term changes in groundwater quality and quantity, and could be used to assess groundwater quality changes throughout the life of the Project is not needed as the State of South Dakota and the counties currently maintain public information on water quality and aquifers in the project area.

Q. THE INTERVENORS' PROPOSED CONDITION 17 (KEARNEY EXHIBIT DK-8) REQUIRES CRW TO:

> **OFFER EACH NON-PARTICIPATING LANDOWNER WITHIN 2 MILES OF THE BOUNDARY FOOTPRINT A FREE WATER WELL TEST FOR EACH WATER WELL ON THEIR PROPERTY UP TO $2,500 PER LANDOWNER. THIS TEST SHALL COVER BUT NOT LIMITED TO TURBIDITY, PARTICULATES AND BACTERIA. THIS MUST BE COMPLETED BEFORE ANY CONSTRUCTION IS COMMENCED AND REIMBURSEMENT SHALL BE MADE BY THE APPLICANT WITHIN 30 DAYS OF SUBMISSION OF THE RECEIPT TO THE PUC.**

DO YOU AGREE WITH THIS CONDITION?

A. No. The SDDENR has online information regarding water quality throughout the state readily available for the public to access. The SDDNER maintains an extensive surface water quality monitoring network of South Dakota Streams including 11 water quality monitoring stations in streams in Codington, Grant, and Deuel Counties. The SDDENR also has a monitoring network to examine the quality of shallow groundwater in 26 aquifers across the state, including the Big Sioux aquifer in Codington and Grant Counties and the Antelope Valley aquifer in Grant County. This network regularly and systematically assesses nonpoint source pollution, the current ground water quality, short-term water-quality changes and long-term trends in water. Groundwater Protection Overlay Districts Ordinances exist in Codington, Grant and Deuel Counties to protect groundwater within those specific counties.

Because the SDDENR maintains publicly available information regarding water quality and aquifers in the project, area, an additional groundwater monitoring program is not necessary.

Q. THE INTERVENORS' PROPOSED CONDITION 24 (KEARNEY EXHIBIT DK-8) WOULD REQUIRE:

> **THE PUC FOR THE LIFE OF THE PROJECT, SHALL REQUIRE THE APPLICANT TO MONITOR 24/7 AND REPORT THE DUST PARTICULATE MATTER, OZONE AND AIR CARBON DATA FOR THE LIFE OF THE PROJECT. THIS REPORT SHALL BE COMPILED QUARTERLY THE FINDINGS SHALL BE PUBLISHED WITHIN 3 MONTHS OF COMPLETION OF THE DUST PARTICULATE REPORT IN THE FOLLOWING PUBLIC PUBLICATIONS, FOR THE LIFE OF THE PROJECT: PUBLIC OPINION NEWSPAPER IN WATERTOWN, SD, SOUTH SHORE GAZETTE IN SOUTH SHORE, SD AND THE GRANT COUNTY REVIEW IN MILBANK, SD. THE APPLICANT ADMITS THERE IS SOIL DISTURBANCE, OVER 41 MILES OF NEW DIRT ROADS, VEHICLES AND EQUIPMENT INVOLVED WITH THIS PROJECT.**

DO YOU AGREE WITH THIS PROPOSED CONDITION?

A. No. Exhaust emissions and dust generated from construction equipment and contractor vehicles will be elevated slightly elevated during construction but will diminish to pre-construction levels after construction ends. Dust control BMPs on gravel/soil roads during construction may include enforcing lowered vehicle speed and the use of water and/or soil stabilizers (e.g., magnesium chloride) to suppress dust generation from equipment and vehicles. After construction has been completed and disturbed lands have achieved final stabilization, vehicles will periodically have to access wind turbine tower locations for operational and maintenance activities, but the frequency of these activities and the number of vehicles involved will be minimal. Wind turbines do not emit particulates or other chemicals that could adversely impact air quality within the Project Area.

Q. THE INTERVENORS' PROPOSED CONDITION 29 (KEARNEY EXHIBIT DK-8) WOULD REQUIRE THE APPLICANT TO DEVELOP A PREDATOR AND RODENT MANAGEMENT PLAN. DO YOU AGREE WITH THIS CONDITION?

A. No. The Applicant is developing a WCS for the Project, which as described in the Application will be provided to the SDPUC prior to the start of construction. The Applicant is developing and implementing the WCS in its continued efforts to demonstrate due diligence in avoiding and minimizing impacts to wildlife in association with the development, construction, and operation of the Project. This WCS describes CRW's strategy to address wildlife conservation in all phases of Project development. Therefore, the Commission should not adopt the Intervenors condition requiring development of a separate predator and rodent management plan.

Q. **THE INTERVENORS' PROPOSED CONDITION 30 (KEARNEY EXHIBIT DK-8) WOULD REQUIRE:**

> **THE APPLICANT SHALL DEVELOP A PLAN TO RENDER AND COMPILE A REPORT THE BIRDS AND BATS KILLED BY TURBINES OR EQUIPMENT OPERATED BY OR CONTRACTED FOR THE APPLICANT. THIS REPORT SHALL CONTAIN BUT NOT LIMITED TO, TIME AND DATE OF DISCOVERY, THE BREED OF BIRD, AND THE SIZE. THIS REPORT SHALL BE REPORTED ANNUALLY AND PUBLISHED IN THE FOLLOWING PUBLIC PUBLICATIONS, FOR THE LIFE OF THE PROJECT: PUBLIC OPINION NEWSPAPER IN WATERTOWN, SD, SOUTH SHORE GAZETTE IN SOUTH SHORE, SD AND THE GRANT COUNTY REVIEW IN MILBANK, SD.**

DO YOU AGREE WITH THIS PROPOSED CONDITION?

A. No. Similar to past cases (Crocker Wind, Prevailing Winds, Dakota I and II), the Applicant generally is agreeable to a condition that states:

> Applicant agrees to undertake two years of independently-conducted post-construction avian and bat mortality monitoring for the Project, and to provide a copy of the report to the United States Fish & Wildlife Service (USFWS), the South Dakota Game, Fish, and Parks (SD GF&P), and the Commission. The Applicant will conduct a third year of independently-conducted post-construction avian and bat mortality monitoring for the Project if results of the first two years exceed other publicly available studies in the region in comparable habitats in coordination with the USFWS and SD GF&P. If the results from the first two years confirm that the Project site is low risk for avian and bat mortality, a third year will not be conducted.

The Applicant believes it is important to clearly articulate the objective and rationale for a third year of post-construction mortality monitoring. In this case, the purpose of the first two years is to confirm the site is low risk compared to publicly available data in the region and in comparable habitats. If the site is not low risk, then the Applicant agrees to consider a third year of post-construction mortality monitoring in coordination with the wildlife agencies, unless another course of action or remedy is identified and can be addressed.

Also, past cases (Crocker Wind, Prevailing Wind and Dakota Range 1 and 2) have required the applicant to file a Bird and Bat Conservation Strategy prior to beginning construction of the project. CRW will do this through preparation of a WCS. The WCS describes CRW's strategy to address wildlife conservation in all phases of Project development. As described in the Application, the WCS will be submitted to the SDPUC prior to the start of construction, and will be implemented during construction and operation of the Project." Therefore, the Intervenors' condition is not necessary because the Commission's typical conditions which already appropriately address avian and bat mortality monitoring will be met.

Q. THE INTERVENORS' PROPOSED CONDITION 33 (KEARNEY EXHIBIT DK-8) WOULD REQUIRE:

> **THE APPLICANT, FOR THE LIFE OF THE PROJECT, SHALL MONITOR AND REPORT ON CHANGES IN SOIL HEALTH INCLUDING BUT NOT LIMITED TO CHANGES IN ORGANIC MATTER, VEGETATION, MOISTURE, MICROBES, BURYING INSECTS, AND MAMMALS. THIS REPORT SHALL BE COMPILED ANNUALLY AND SHALL BE REPORTED ANNUALLY AND PUBLISHED IN THE FOLLOWING PUBLIC PUBLICATIONS, FOR THE LIFE OF THE PROJECT: PUBLIC OPINION NEWSPAPER IN WATERTOWN, SD, SOUTH SHORE GAZETTE IN SOUTH SHORE, SD AND THE GRANT COUNTY REVIEW IN MILBANK, SD.**

> **DO YOU AGREE WITH THIS PROPOSED CONDITION?**

A. No. The Application describes multiple environmental studies that have been completed by the Applicant to document baseline conditions and to accurately assess potential impacts of the Project on the environment in accordance with the South Dakota Codified Laws Title 49-41B-11 (11) and South Dakota Administrative Rules Chapter 20:10:22:13. The Applicant has determined that only 86 acres of permanent impacts will result from the Project. This represents less than 0.2% of the 53,186-acre Project Area. Within the Project Area, the Project will result in minimal impacts to soil particularly when compared to existing land uses.

In temporarily impacted areas, the Applicant will implement a SWPPP and SPCC Plan to ensure that potential impacts to soil resulting from erosion, sedimentation, spills, or releases are minimized and promptly remediated.

Q. INTERVENOR WITNESS THOMPSON SUBMITTED TESTIMONY EXPLAINING THAT HE IS NOT PARTICIPATING IN THE PROJECT. DID REMOVAL OF THE THOMPSON PROPERTIES IMPACT THE ENVIRONMENTAL MAPS AND IMPACTS?

A. I have included as Exhibit SS-R-1 the following maps that show the collector lines no longer located on the Thompson's properties.

Figure 2 Map – State and Federal Lands
Figure 6 Map – Environmental Constraints
Figure 7 Map – Constraints
Figure 9 Maps a and b -- Surficial Geology and Geology Cross Sections
Figure 10 Map – Bedrock
Figure 11 Map – Soils
Figure 12 Map –Water Resources
Figure 13 Map Land Cover

These are the same maps submitted in the docket on May 23, 2019 that show the re-route of the collector lines off of the Thompson properties. As the maps indicate the re-route does not show any additional environmental impacts associated with the new route for the collector lines.

Q. DOES THIS CONCLUDE YOUR REBUTTAL TESTIMONY?

A. Yes, it does.

STATE OF NORTH DAKOTA)
) ss
COUNTY OF [INSERT])
Burleigh

I, Sarah Sappington, being duly sworn on oath, depose and state that I am the witness identified in the foregoing prepared testimony and I am familiar with its contents, and that the facts set forth are true to the best of my knowledge, information and belief.

Sarah Sappington

Subscribed and sworn to before me this 23 th day of May, 2019.

SEAL

CHRIS KRAUSE
Notary Public
State of North Dakota
My Commission Expires July 28, 2023

Notary Public

My Commission Expires July 28, 2023

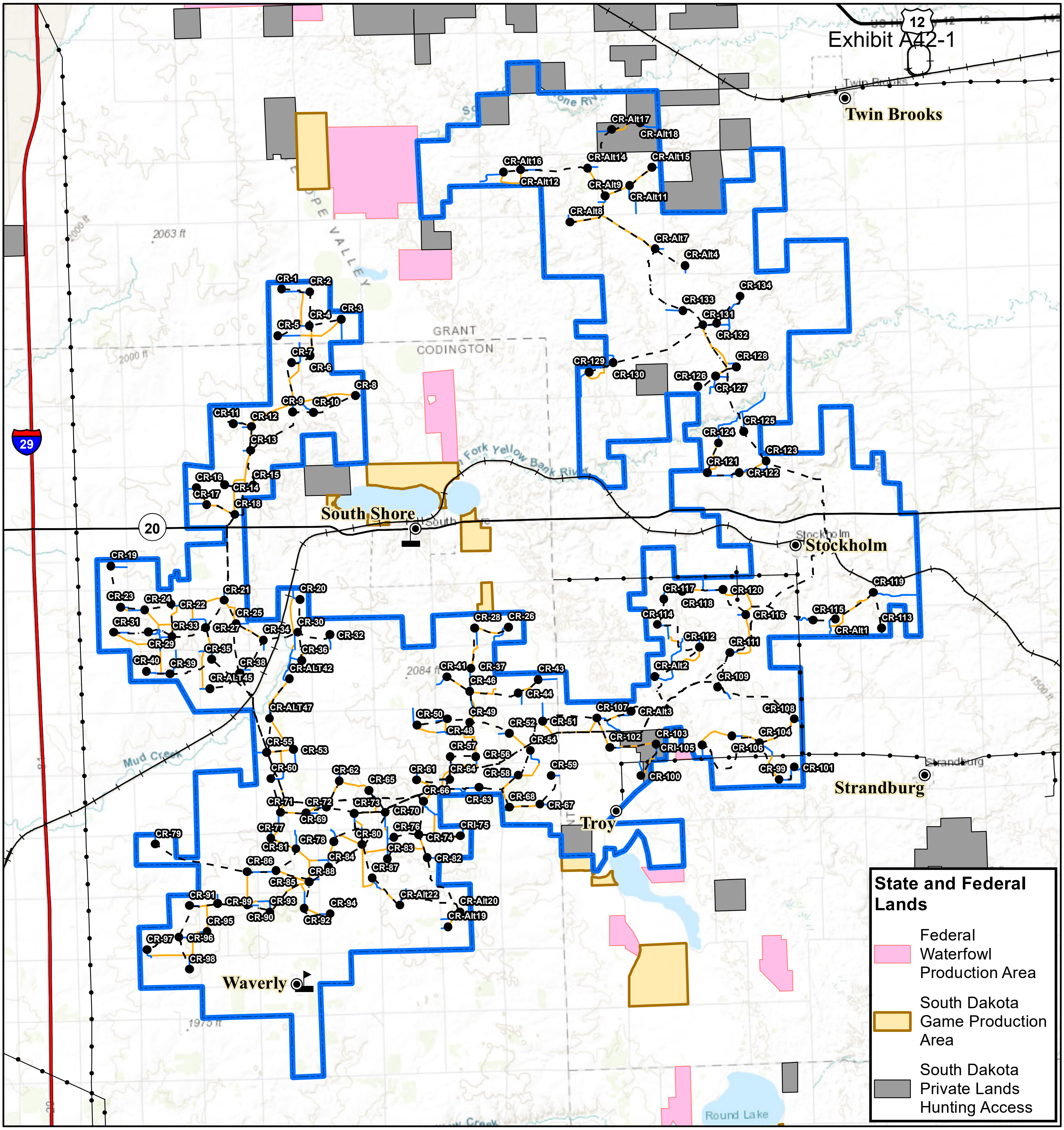

Figure 2. Public Land and Facilities

Crowned Ridge Wind Farm

- City
- School
- Turbine
- Collector Line
- Access Road
- Crane Path
- Electrical Line
- Railroad
- Interstate Highway
- U.S. Highway
- State Highway
- Project Boundary

Kilometers: 0 5 10

Miles: 0 2.5 5

Base Map: World Topographic Map
Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community
Codington and Grant Counties, South Dakota

Projection: NAD 1983 UTM Zone 14N

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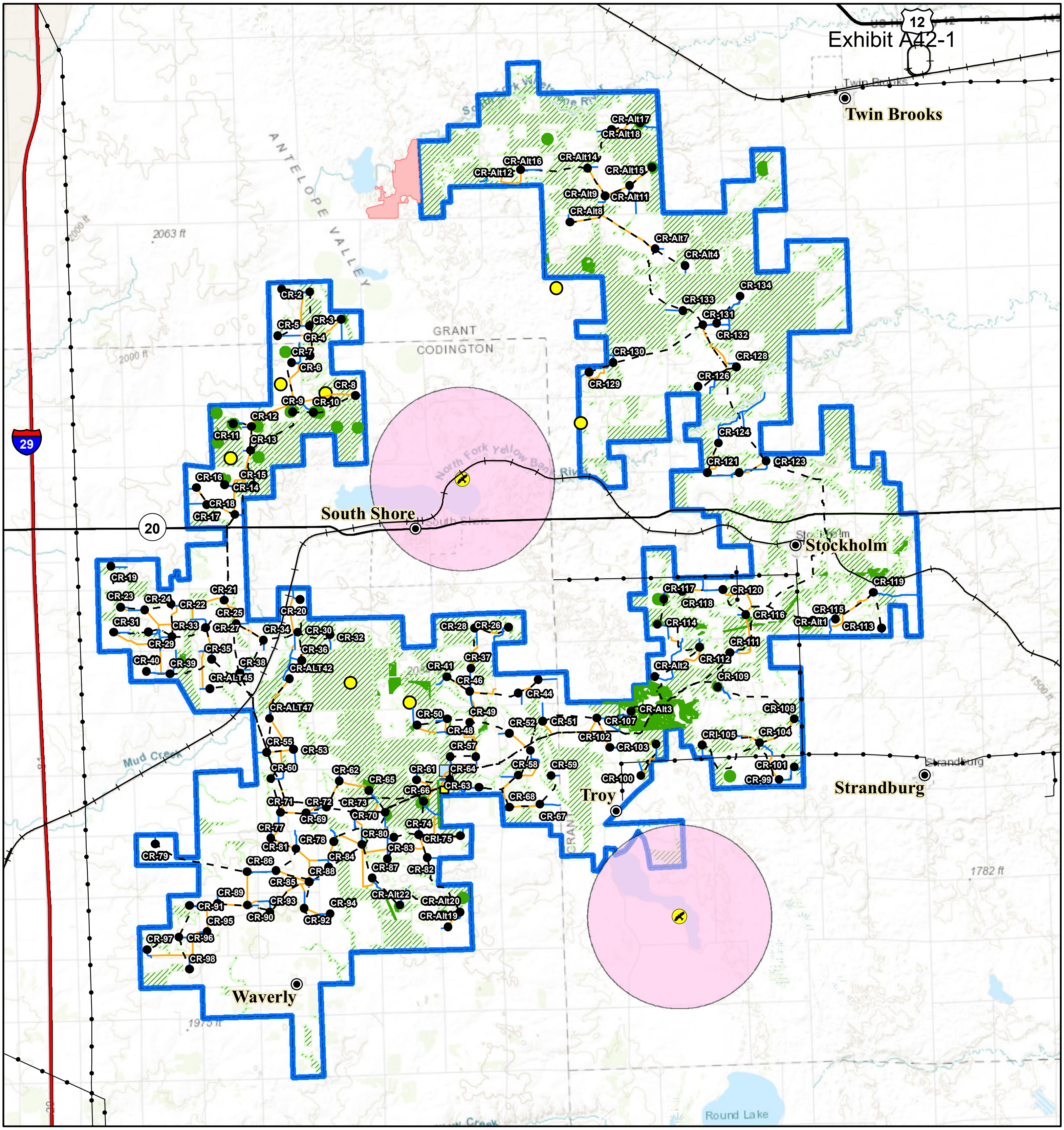


Figure 6. Environmental Constraints

Crowned Ridge Wind Farm

- Bald Eagle Nest Location
- Turbine
- Lek Location
- City
- Access Road
- Collector Line
- Crane Path
- Electrical Line
- Railroad
- Interstate Highway
- U.S. Highway
- State Highway
- O&M Facility/ Substation
- Laydown Yard
- Field Assessed Dakota Skipper Habitat
- 1.5-mile Bald Eagle Nest Buffer
- USFWS Critical Habitat
- Undisturbed Native Grasslands (Bauman 2013)
- Project Boundary

Kilometers: 0 5 10

Miles: 0 2.5 5

N W E S

Base Map: World Topographic Map
Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community
Codington and Grant Counties, South Dakota

Projection: NAD 1983 UTM Zone 14N

SWCA ENVIRONMENTAL CONSULTANTS

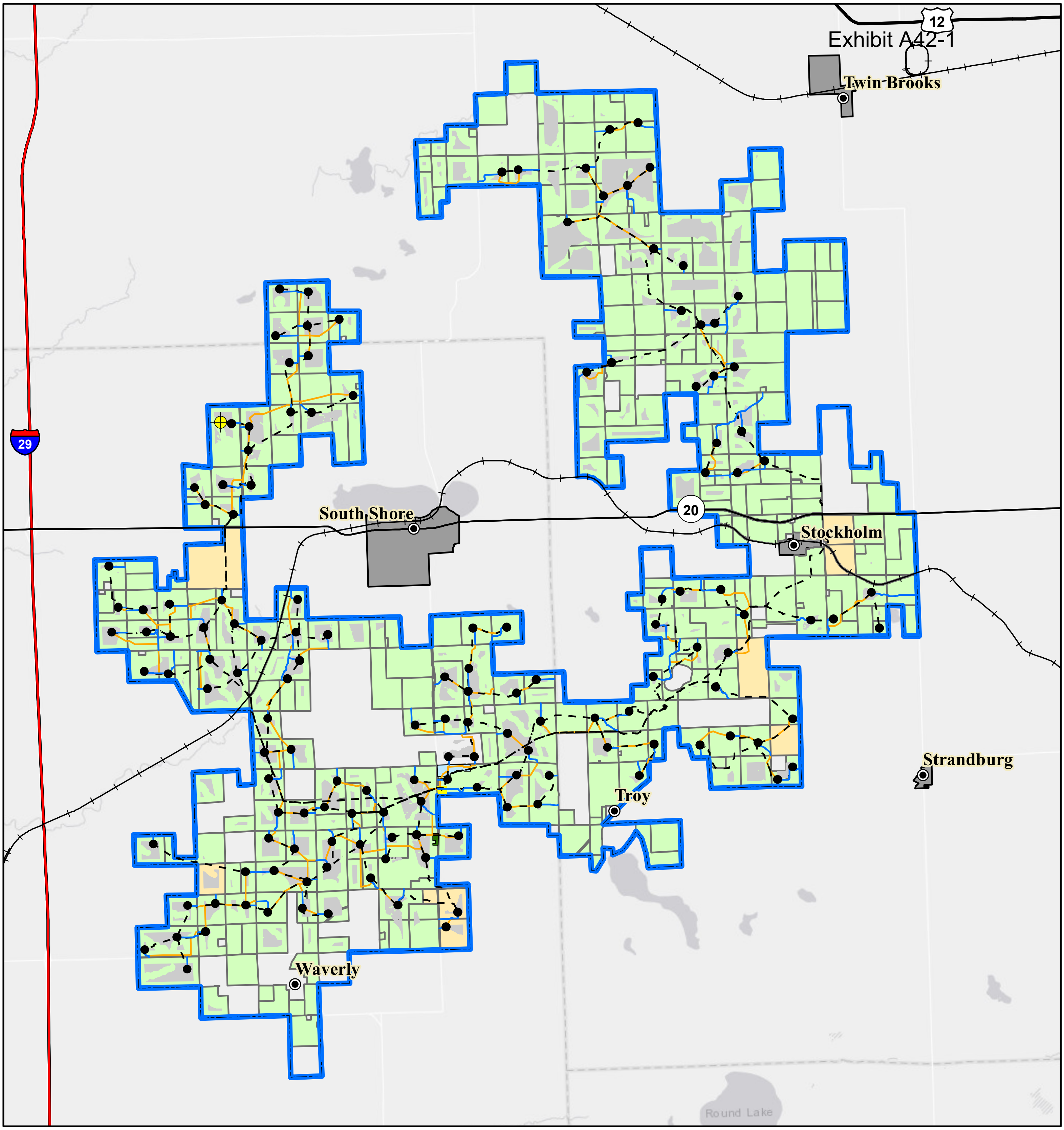
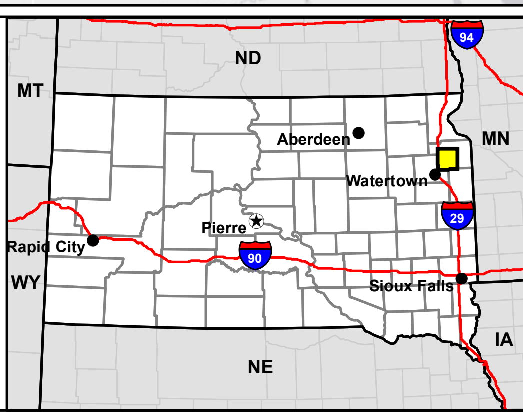


Figure 7. Constraints Map

Crowned Ridge Wind Farm

MET Tower	Batch Plant
Turbine	Laydown Yard
City	O & M Facility/ Substation
Railroad	Available Land
Access Road	Town Boundary
Collector Line	Project Boundary
Crane Path	**Lease Status**
Interstate Highway	Leased, Signed
U.S. Highway	Pending Approval
State Highway	



Kilometers
0 2.5 5

Miles
0 2.5 5

Base Map: World Light Gray Canvas Base
Sources: Esri, HERE, Garmin, © OpenStreetMap contributors, and the GIS user community
Codington and Grant Counties, South Dakota

Page 000003

Projection: NAD 1983 UTM Zone 14N

017202

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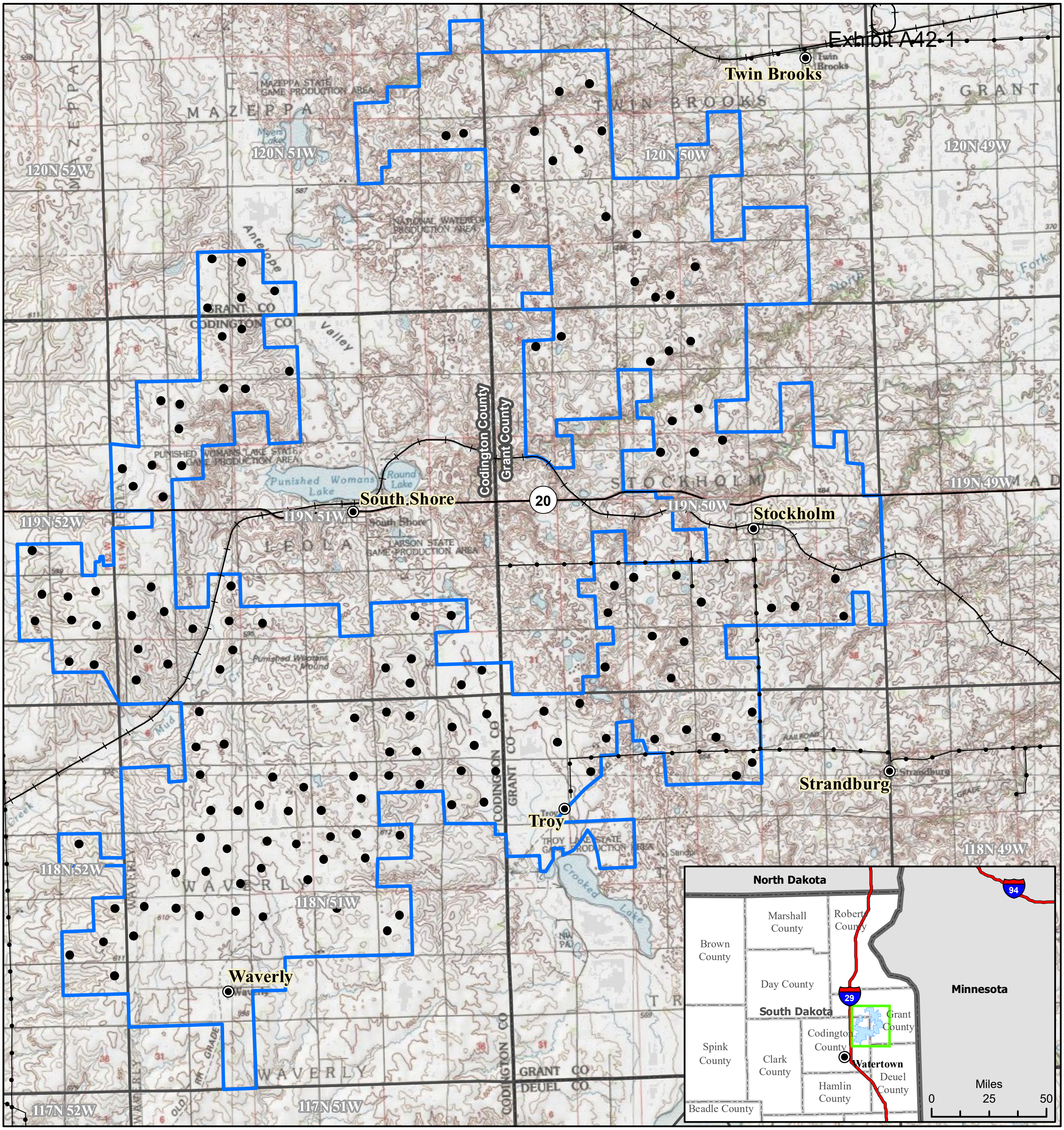

Figure 8. Topographic Map

Crowned Ridge Wind Farm

- Turbine
- City
- Railroad
- Electrical Line
- State Highway
- Project Boundary
- County Boundary
- Township/Range Boundary

Kilometers: 0 5 10

Miles: 0 2.5 5

N S E W

Base Map: USGS 7.5' Topographic Map
Source: Copyright: ©2014 National Geographic Society, i-cubed
Codington and Grant Counties, South Dakota

Projection: NAD 1983 UTM Zone 14N

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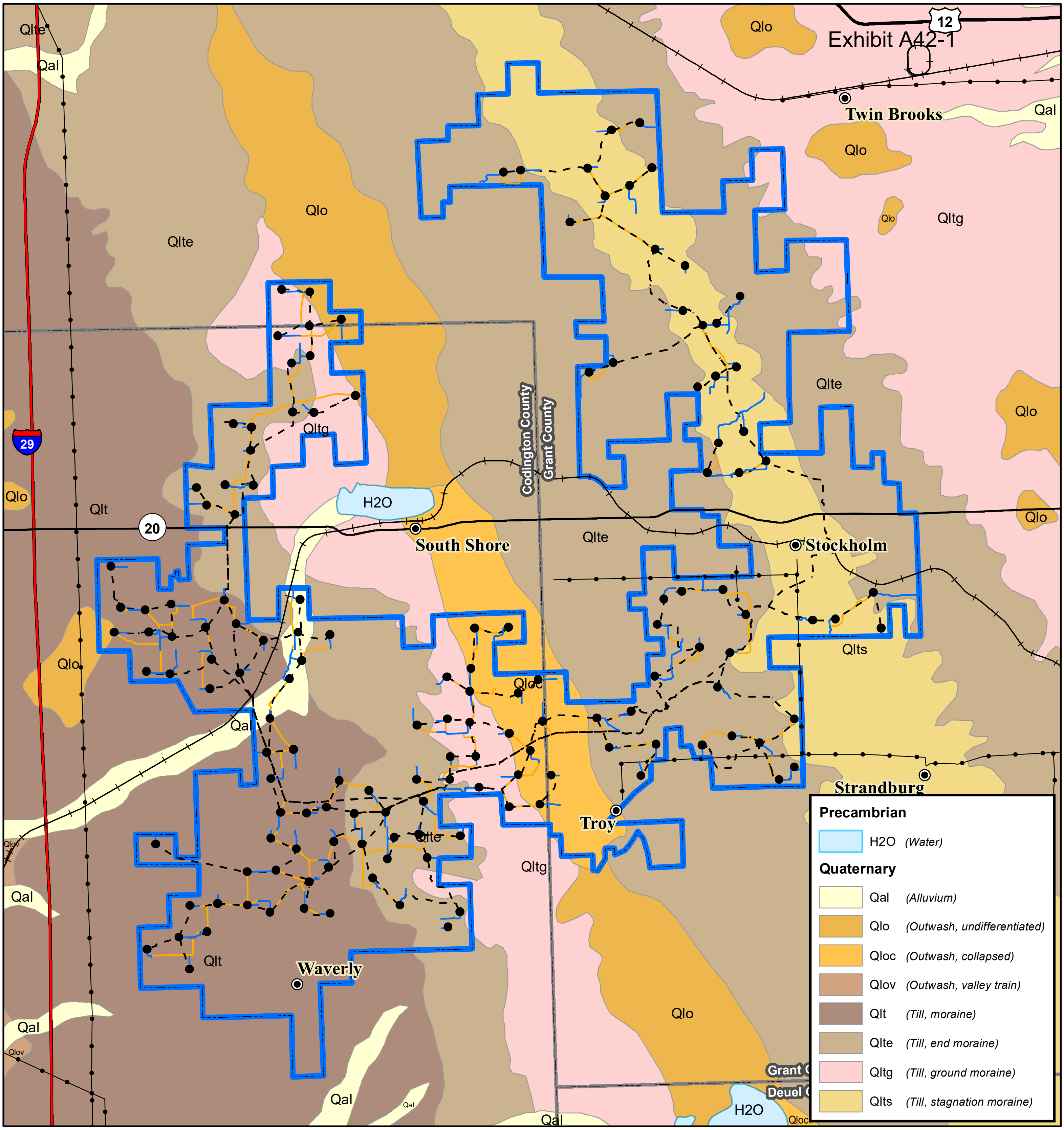

Figure 9a. Surficial Geology

Crowned Ridge Wind Farm

City
Turbine
Access Road
Collector Line
Crane Path
Electrical Line
Railroad
Interstate Highway
U.S. Highway
State Highway
Project Boundary
County Boundary

Kilometers: 0, 5, 10

Miles: 0, 2.5, 5

Base Map: Surficial Geology
Source: South Dakota Geological Survey via
State of South Dakota GIS
Codington and Grant Counties, South Dakota

Projection: NAD 1983 UTM Zone 14N

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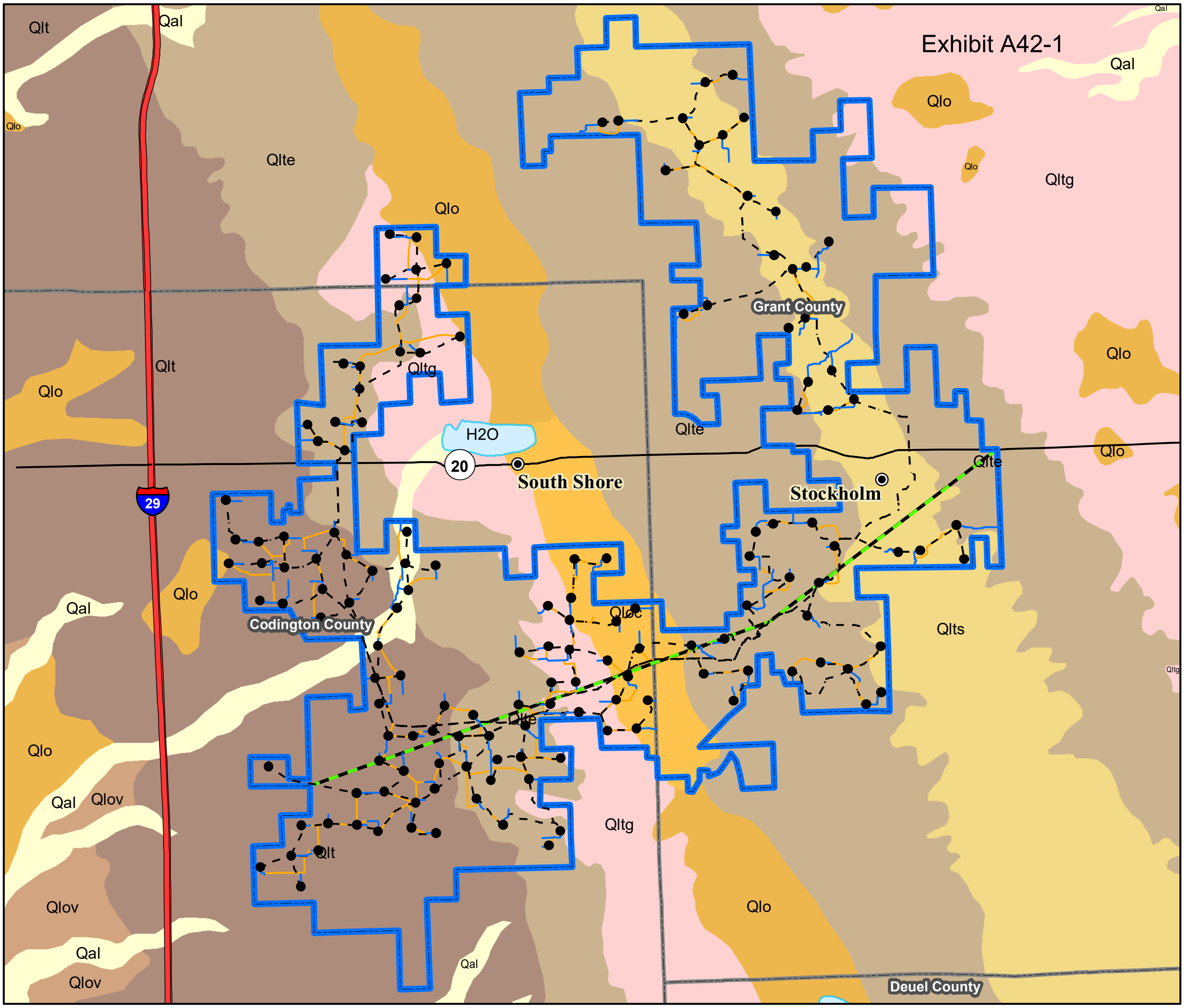
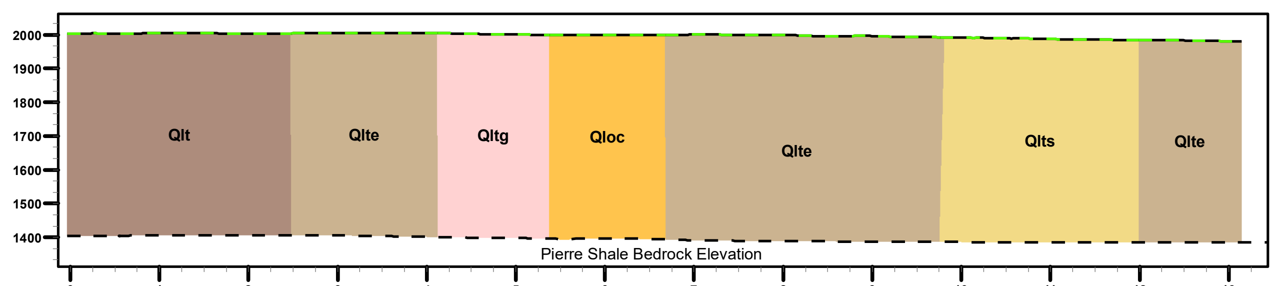
Exhibit A42-1





*Vertical axis in feet above sea level; Horizontal axis in miles

Figure 9b. Geology Cross Sections

Crowned Ridge Wind Farm

- City
- Turbine
- Access Road
- Collector Line
- Crane Path
- Cross Section
- Interstate Highway
- State Highway
- Project Boundary
- County Boundary

Surficial Geology

Precambrian

- H2O *(Water)*

Quaternary

- Qal *(Alluvium)*
- Qlo *(Outwash, undifferentiated)*
- Qloc *(Outwash, collapsed)*
- Qlov *(Outwash, valley train)*
- Qlt *(Till, moraine)*
- Qlte *(Till, end moraine)*
- Qltg *(Till, ground moraine)*
- Qlts *(Till, stagnation moraine)*

Kilometers
0 5 10

Miles
0 2.5 5

N W E S

Base Map: Surficial Geology
Source: South Dakota Geological Survey via
State of South Dakota GIS
Codington and Grant Counties, South Dakota

Page 000006

Projection: NAD 1983 UTM Zone 14N

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Exhibit A42-1

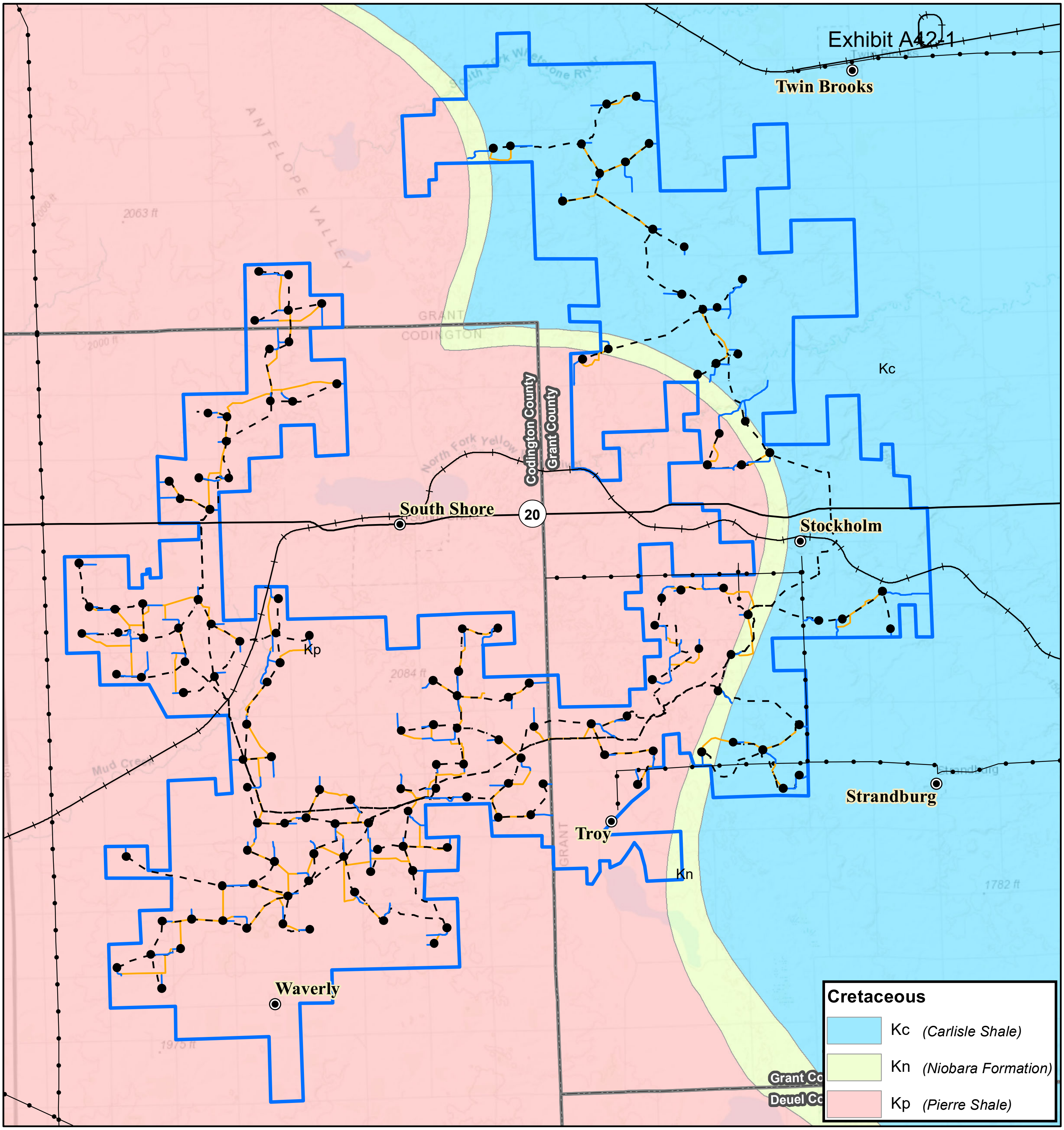

Figure 10. Bedrock Geology

Crowned Ridge Wind Farm

- City
- Turbine
- Access Road
- Collector Line
- Crane Path
- Railroad
- Electrical Line
- State Highway
- Project Boundary
- County Boundary

Kilometers: 0, 5, 10

Miles: 0, 2.5, 5

N E S W

Base Map: World Topographic Map
Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community
Codington and Grant Counties, South Dakota

Projection: NAD 1983 UTM Zone 14N

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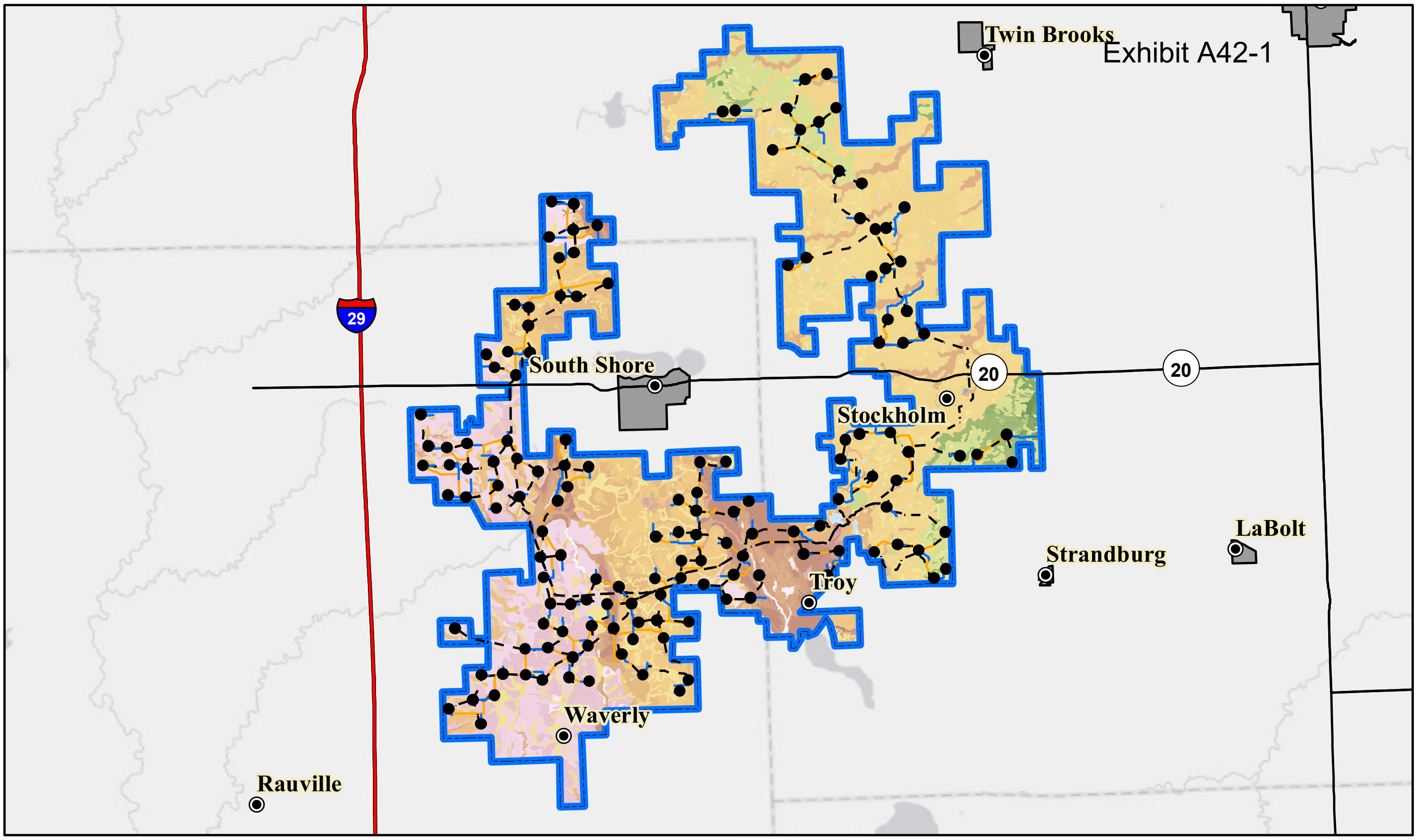

MUSYM (Soil Type)

BeF	(Buse-Forman loams, 25-40% slopes)
BfD	(Buse-Forman-Aastad loams, 4-15% slopes)
Fa	(Flom Clay loam)
FdB	(Forman-Aastad loams, 1-6% slopes)
FdC	(Forman-Aastad loams, 3-9% slopes)
FdD	(Forman-Aastad loams, 4-15% slopes)
FgC	(Forman-Buse loams, 6-9% slopes)
FgE	(Forman-Buse loams, 15-25% slopes)
FhE	(Forman-Buse extremely stony loams, 9-40% slopes)
HaD	(Hattie clay loam, 9 to 15% slopes)
HaE	(Hattie clay loam, 15 to 40% slopes)
J119E	(Buse-Sioux complex, 9 to 40% slopes)
J136A	(Great Bend-Beotia silt loams, 0 to 2% slopes)
J225B	(Forman-Aastad complex)
Lb	(LaDelle silt loam, channeled)
Lc	(Ludden silty clay)
M-W	Miscellaneous Water
Pa	(Parnell silty clay loam)
Pb	(Southam silty clay loam, 0 to 1% slopes)
PcA	(Peever clay loam, coteau, 0 to 2% slopes)
PcB	(Peever clay loam, coteau, 2 to 6% slopes)
PcC	(Peever clay loam, 6 to 9% slopes)
PeB	(Peever clay loam, 2 to 6% slopes)
Ph	(Playmoor silty clay loam)
Ta	(Tonka silty clay loam, 0 to 1% slopes)
Vb	(Vallers-Parnell complex)
W	(Water)
Z101A	(Tonka silty clay loam, 0 to 1% slopes)
Z102A	(Badger-Tonka silty clay loam, 0 to 1% slopes)
Z105A	(Oldham silty clay loam, coteau, 0 to 1% slopes)
Z106A	(Southam silty clay loam, 0 to 1% slopes)
Z107A	(Parnell silty clay loam, coteau, 0 to 1% slopes)
Z110A	(Vallers loam, coteau, 0 to 1% slopes)
Z112A	(Vallers-Hamerly loams, coteau, 0 to 2% slopes)
Z113A	(Vallers-Parnell complex, coteau, 0 to 2% slopes)
Z114A	(Hamerly-Tonka complex, coteau, 0 to 2% slopes)
Z115A	(Hamerly-Badger complex, coteau, 0 to 2% slopes)
Z116A	(McKranz-Hidwood, frequently flooded, silty clay loams, 0 to 2% slopes)
Z117A	(McKranz-Badger silty clay loams, 0 to 2% slopes)
Z119A	(Hamerly-Balaton loams, coteau, 0 to 3% slopes)
Z128B	(Hetland silty clay loam, 2 to 6% slopes)
Z131A	(Forman-Aastad loams, coteau, 0 to 2% slopes)
Z131B	(Forman-Aastad loams, coteau, 1 to 6% slopes)
Z132B	(Forman-Buse-Aastad loams, coteau, 1 to 6% slopes)
Z132C	(Forman-Buse-Aastad loams, coteau, 2 to 9% slopes)
Z132D	(Forman-Buse-Aastad loams, coteau, 2 to 15% slopes)
Z135D	(Forman-Buse loams, very stony, 2 to 15% slopes)
Z136F	(Buse-Langhei complex, very stony, 9 to 40% slopes)
Z137F	(Buse-Forman loams, very stony, 15 to 40% slopes)
Z140F	(Buse-Langhei complex, coteau, 15 to 40% slopes)
Z141A	(Barnes-Svea loams, coteau, 0 to 2% slopes)
Z141B	(Barnes-Svea loams, coteau, 1 to 6% slopes)
Z142B	(Barnes-Buse-Svea loams, coteau, 1 to 6% slopes)
Z142C	(Barnes-Buse-Svea loams, coteau, 2 to 9% slopes)
Z143C	(Barnes-Buse loams, coteau, 6 to 9% slopes)
Z144E	(Buse-Barnes loams, coteau, 9 to 20% slopes)
Z145D	(Buse-Barnes loams, coteau, very stony, 2 to 15% slopes)
Z145F	(Buse-Barnes loams, coteau, very stony, 9 to 40% slopes)
Z146F	(Buse-Lamoure, channeled, frequently flooded, complex, 0 to 40% slopes)
Z148F	(Buse very stony-Lamoure, channeled, frequently flooded, complex, 0 to 40% slopes)
Z149F	(Buse-Langhei, very stony-La Prairie, channeled, occasionally flooded, complex, 0 to 60% slopes)
Z150A	(Rauville silty clay loam, coteau, frequently flooded, 0 to 1% slopes)
Z152A	(Lamoure silty clay loam, coteau, occasionally flooded, 0 to 1% slopes)
Z153A	(Lamoure-Rauville silty clay loams, channeled, frequently flooded, 0 to 2% slopes)
Z157A	(Fairdale loam, channeled, frequently flooded, 0 to 2% slopes)
Z158A	(Marysland loam, occasionally flooded, 0 to 1% slopes)
Z159A	(Divide loam, occasionally flooded, 0 to 2% slopes)
Z160A	(Moritz, occasionally flooded-Lamoure, frequently flooded, complex, 0 to 2 % slopes)
Z161A	(Spottswood loam, occasionally flooded, 0 to 2% slopes)
Z162A	(La Prairie loam, coteau, occasionally flooded, 0 to 2% slopes)
Z166A	(Fordtown loam, rarely flooded, 0 to 2% slopes)
Z167A	(Renwash loam, rarely flooded, 0 to 2% slopes)
Z171A	(Renshaw-Fordville loams, coteau, 0 to 2% slopes)
Z171B	(Renshaw-Fordville loams, coteau, 2 to 6% slopes)
Z172A	(Renshaw loam, coteau, 0 to 2% slopes)
Z172B	(Renshaw loam, coteau, 2 to 6% slopes)
Z173B	(Renshaw-Sioux complex, coteau, 2 to 6% slopes)
Z173C	(Renshaw-Sioux complex, coteau, 6 to 9% slopes)
Z174D	(Sioux-Renshaw complex, coteau, 9 to 15% slopes)
Z174F	(Sioux-Renshaw complex, coteau, 15 to 40% slopes)
Z175D	(Renshaw-Sioux complex, very stony, 2 to 15% slopes)
Z176C	(Arvilla-Sandberg sandy loams, coteau, 6 to 9% slopes)
Z177	(Udorthents, coteau (gravel pits))
Z178A	(Rentill loam, coteau, 0 to 2% slopes)
Z179F	(Sioux-Renshaw complex, very stony, 15 to 40% slopes)
Z184E	(Maddock loamy fine sand, 9 to 25% slopes)
Z185A	(Egeland-Embden complex, coteau, 0 to 2% slopes)
Z185B	(Egeland-Embden complex, coteau, 2 to 6% slopes)
Z186B	(Maddock-Egeland sandy loams, coteau, 2 to 6% slopes)
Z186C	(Maddock-Egeland sandy loams, coteau, 6 to 9% slopes)
Z190A	(Brookings silty clay loam, 0 to 2% slopes)
Z192A	(Vienna-Brookings complex, coteau, 0 to 2% slopes)
Z192B	(Vienna-Brookings complex, coteau, 1 to 6% slopes)
Z193C	(Vienna-Buse complex, coteau, 6 to 9% slopes)
Z194A	(Barnes clay loam, coteau, 0 to 2% slopes)
Z194B	(Barnes clay loam, coteau, 2 to 6% slopes)
Z198A	(Vienna-Forestville loams, coteau, 0 to 2% slopes)
Z199B	(Vienna-Barnes-Forestville loams, 1 to 6% slopes)
Z205B	(Mauvais clay loam, occasionally ponded, extremely stony, 2 to 6% slopes)
Z217A	(McKranz silty clay loam, 0 to 2% slopes)
Z250A	(Rauville mucky silty clay loam, ponded, frequently flooded, 0 to 1% slopes)
Z252A	(Hidewood silty clay loam, frequently flooded, 0 to 2% slopes)

Figure 11. Soil Types

Crowned Ridge Wind Farm

- City
- Turbine
- Access Road
- Collector Line
- Crane Path
- Interstate Highway
- State Highway
- Town Boundary
- Project Boundary

Kilometers
0 5 10

Miles
0 5 10

N W E S

Base Map: World Light Gray Canvas Base
Sources: Esri, HERE, Garmin, © OpenStreetMap contributors, and the GIS user community
Codington and Grant Counties, South Dakota

Projection: NAD 1983 UTM Zone 14N

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Exhibit A42-1

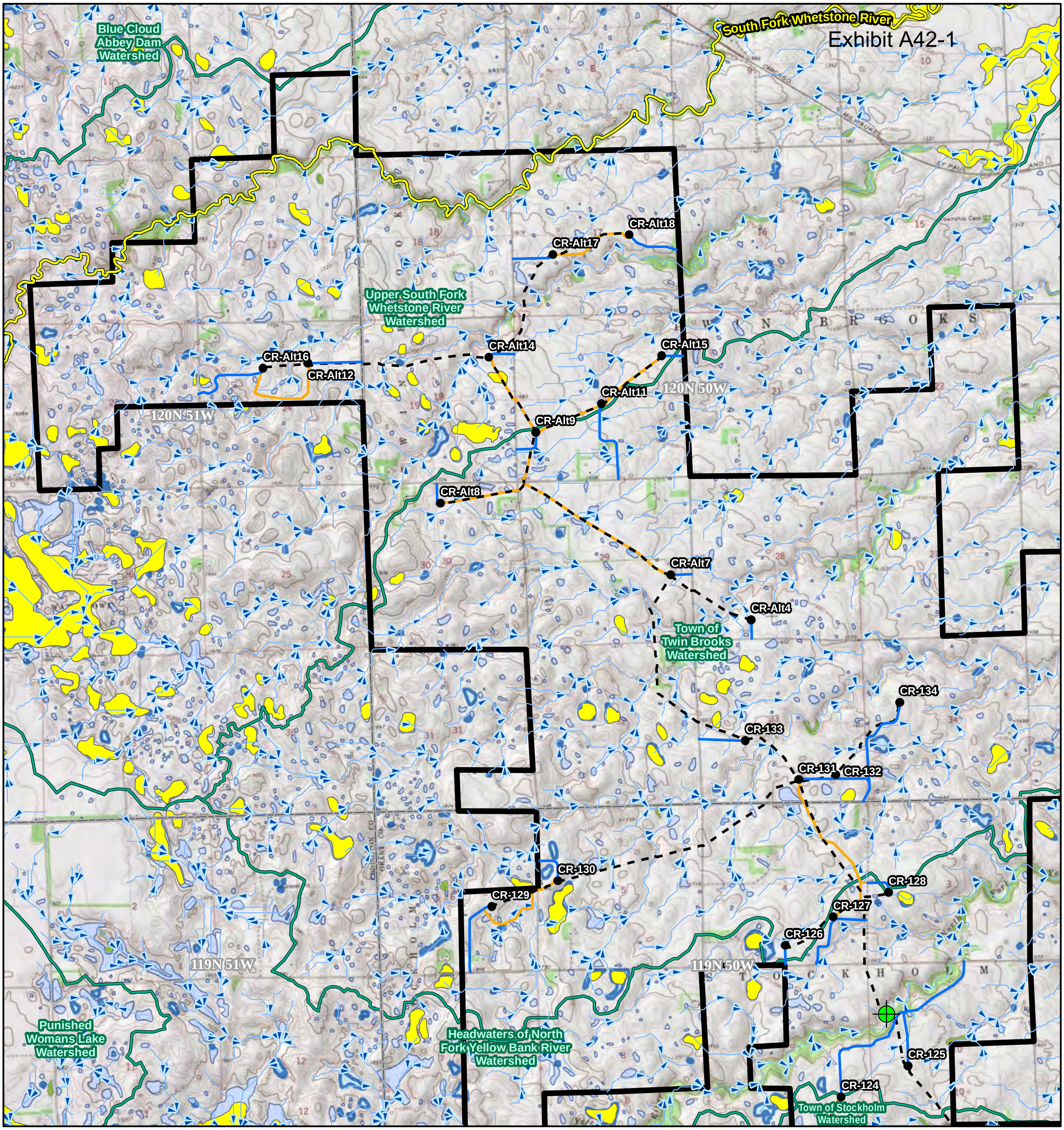


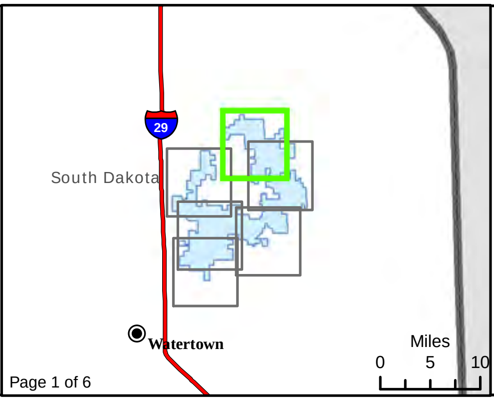
Figure 12. Water Resources

Crowned Ridge Wind Farm

- City
- Intersection of Floodplain and Project Infrastructure
- Turbine
- Access Road
- Collector Line
- Crane Path
- Flow Direction
- South Dakota Beneficial Use Stream
- South Dakota Beneficial Use Lake
- Watershed Boundary (HUC12)
- Project Boundary
- County Boundary
- Township/Range Boundary
- Freshwater Emergent Wetland
- Freshwater Forested/Shrub Wetland
- Lake, Pond, or Riverine Wetland

FEMA Flood Zone

- A



Page 1 of 6

Kilometers 0 1 2

Miles 0 1 2

Base Map: USGS 7.5' Topographic Map
Source: Esri ArcGIS Online service
Quadrangle: Antelope Valley (1973), Twin Brooks (1973), Stockholm (1973)
Township/Range: T120N, R51W & T120N, R50W & T119N, R50W
Grant County, South Dakota

Projection: NAD 1983 UTM Zone 14N

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Exhibit A42-1

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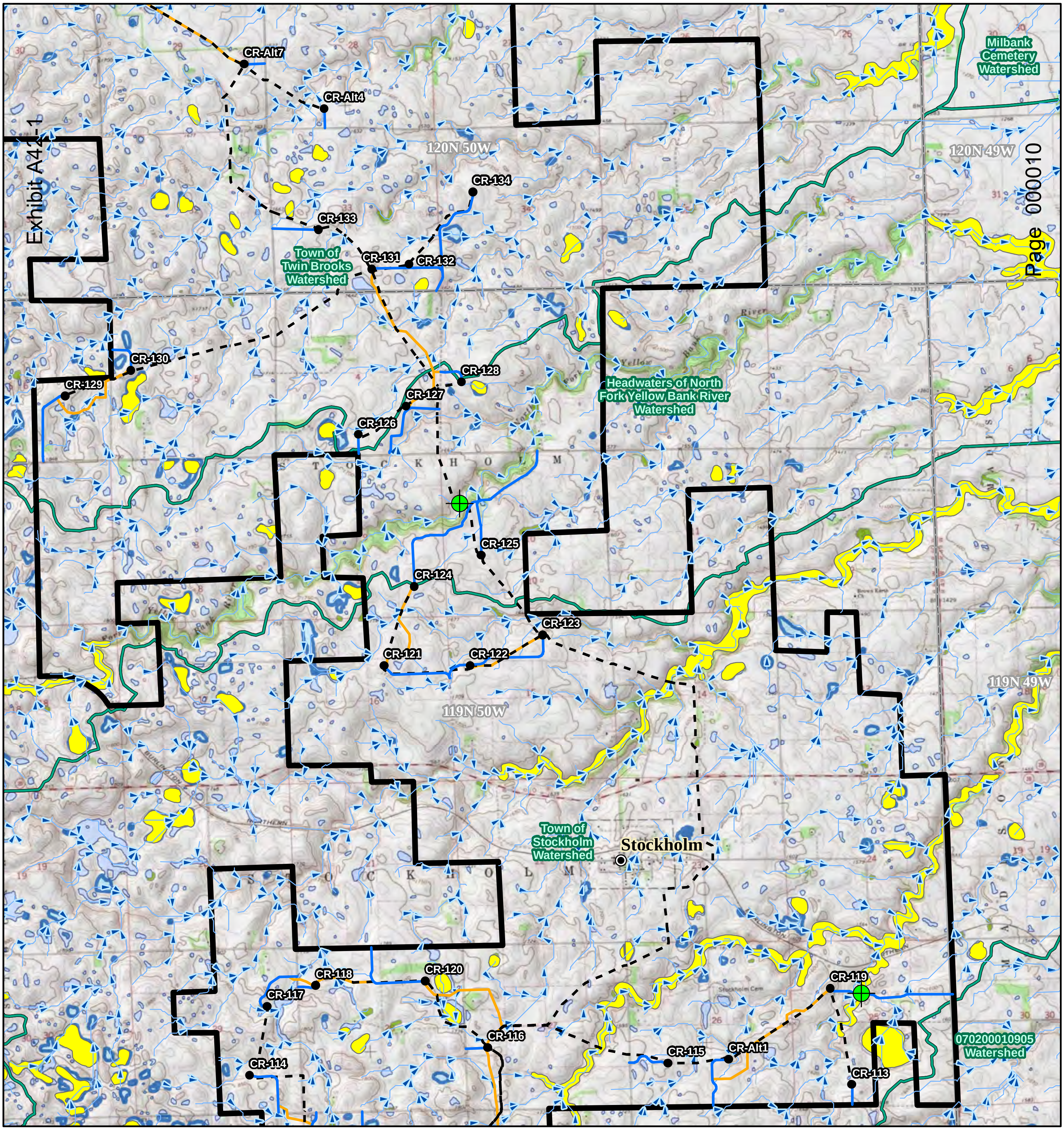
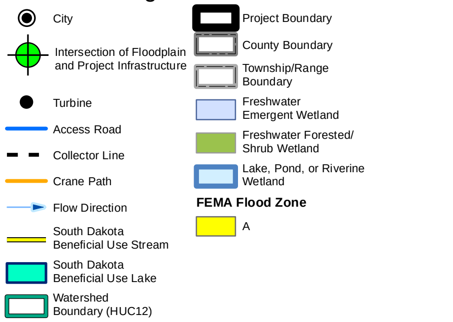
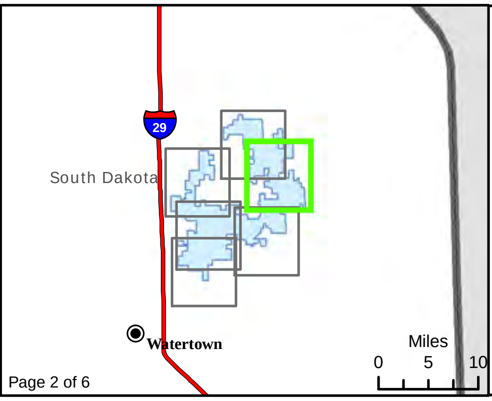


Figure 12. Water Resources

Crowned Ridge Wind Farm





Base Map: USGS 7.5' Topographic Map
Source: Esri ArcGIS Online service
Quadrangle: Twin Brooks (1973), Stockholm (1973)
Township/Range: T120N, R50W & T119N, R50W
Grant County, South Dakota

Projection: NAD 1983 UTM Zone 14N

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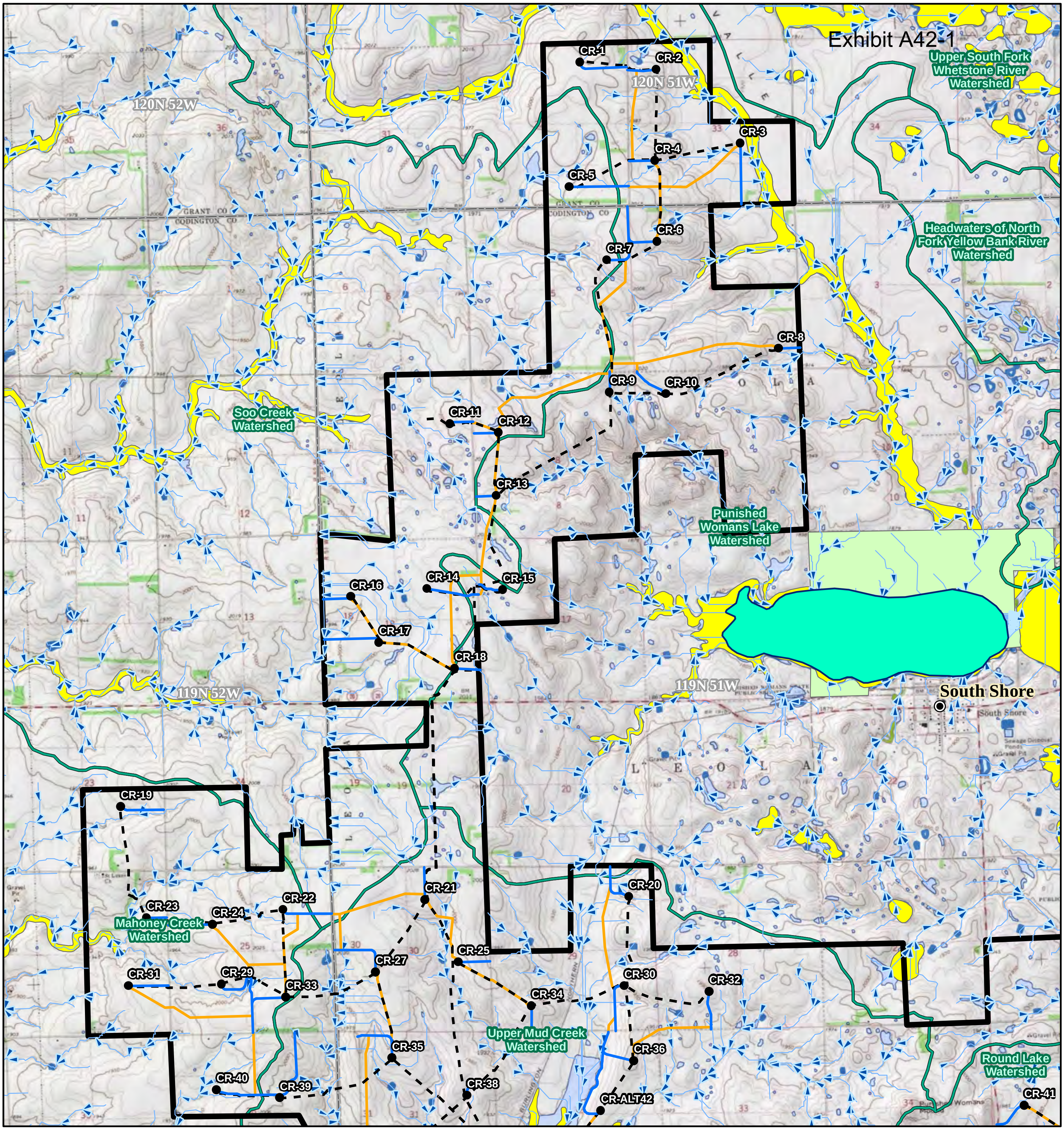


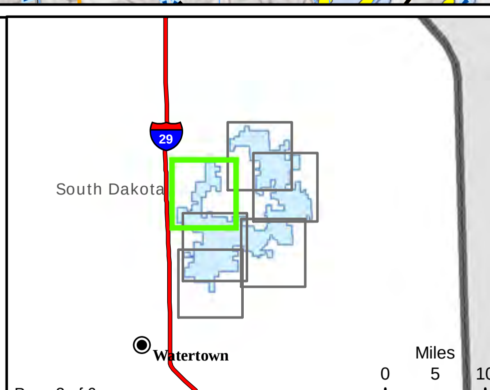
Figure 12. Water Resources

Crowned Ridge Wind Farm

- City
- Intersection of Floodplain and Project Infrastructure
- Turbine
- Access Road
- Collector Line
- Crane Path
- Flow Direction
- South Dakota Beneficial Use Stream
- South Dakota Beneficial Use Lake
- Watershed Boundary (HUC12)
- Project Boundary
- County Boundary
- Township/Range Boundary
- Freshwater Emergent Wetland
- Freshwater Forested/Shrub Wetland
- Lake, Pond, or Riverine Wetland

FEMA Flood Zone

- A
- D



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Kilometers 0 1 2

Miles 0 1 2

Base Map: USGS 7.5' Topographic Map
Source: Esri ArcGIS Online service
Quadrangle: Antelope Valley (1973), Still Lake SE (1970), South Shore (1973)
Township/Range: T120N, R51W & T119N, R52W & T119N, R51W
Codington and Grant Counties, South Dakota

Projection: NAD 1983 UTM Zone 14N

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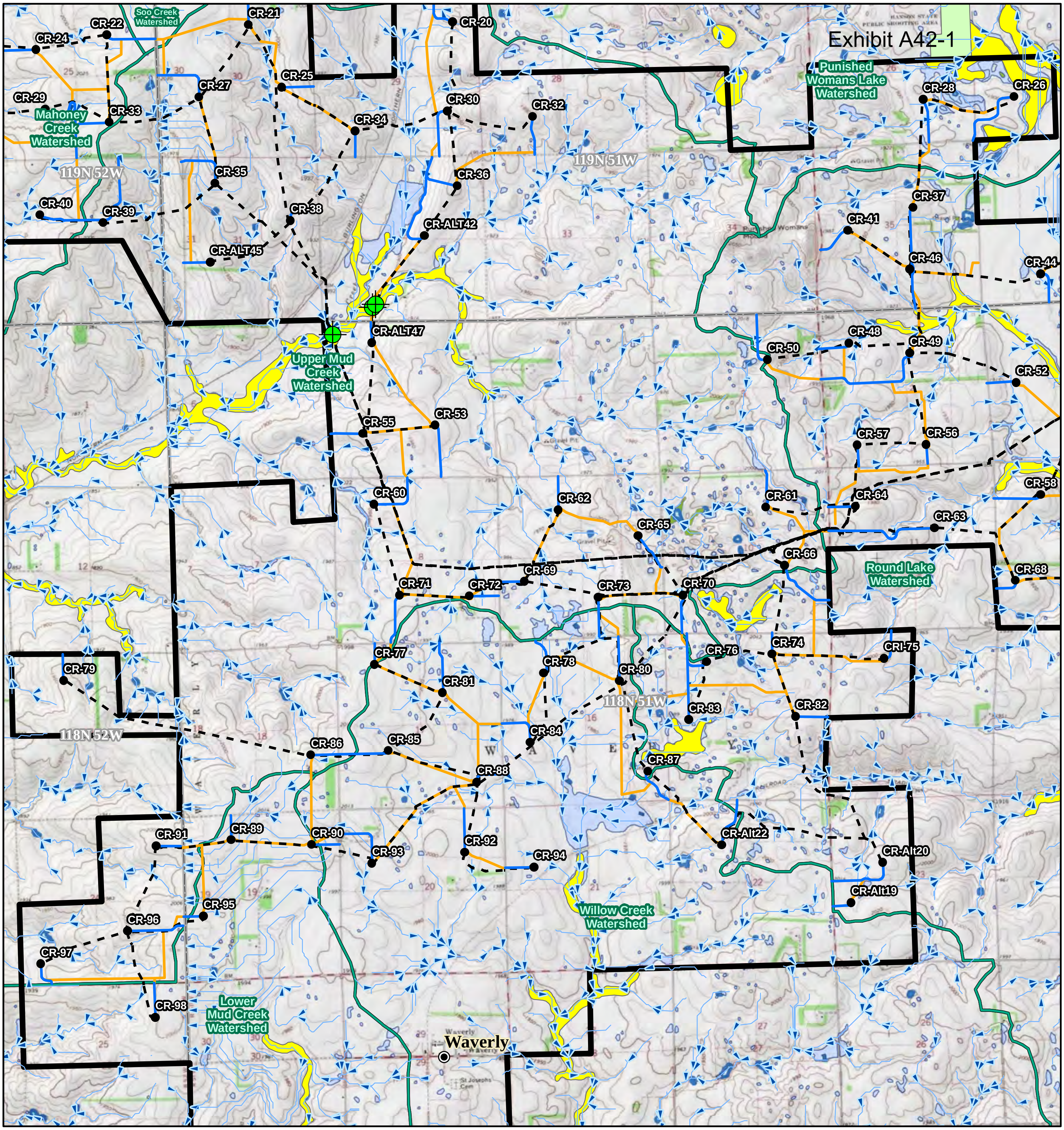

Figure 12. Water Resources

Crowned Ridge Wind Farm

- City
- Intersection of Floodplain and Project Infrastructure
- Turbine
- Access Road
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- Flow Direction
- South Dakota Beneficial Use Stream
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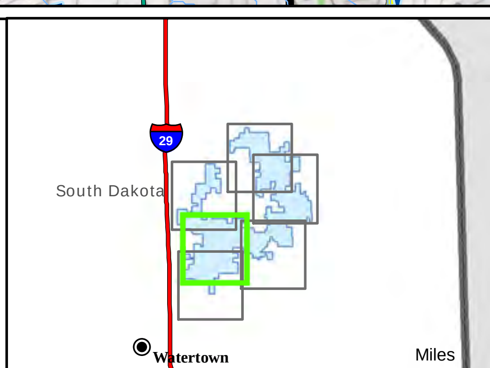
- Project Boundary
- County Boundary
- Township/Range Boundary
- Freshwater Emergent Wetland
- Freshwater Forested/Shrub Wetland
- Lake, Pond, or Riverine Wetland

FEMA Flood Zone

- A
- D



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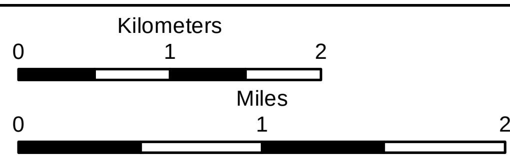

Base Map: USGS 7.5' Topographic Map
Source: Esri ArcGIS Online service
Quadrangle: Still Lake SE (1970), South Shore (1973), Watertown East (1969), Kranzburg (1970)
Township/Range: T119N, R52W & T119N, R51W & T118N, R52W & T118N, R51W
Codington County, South Dakota

Projection: NAD 1983 UTM Zone 14N

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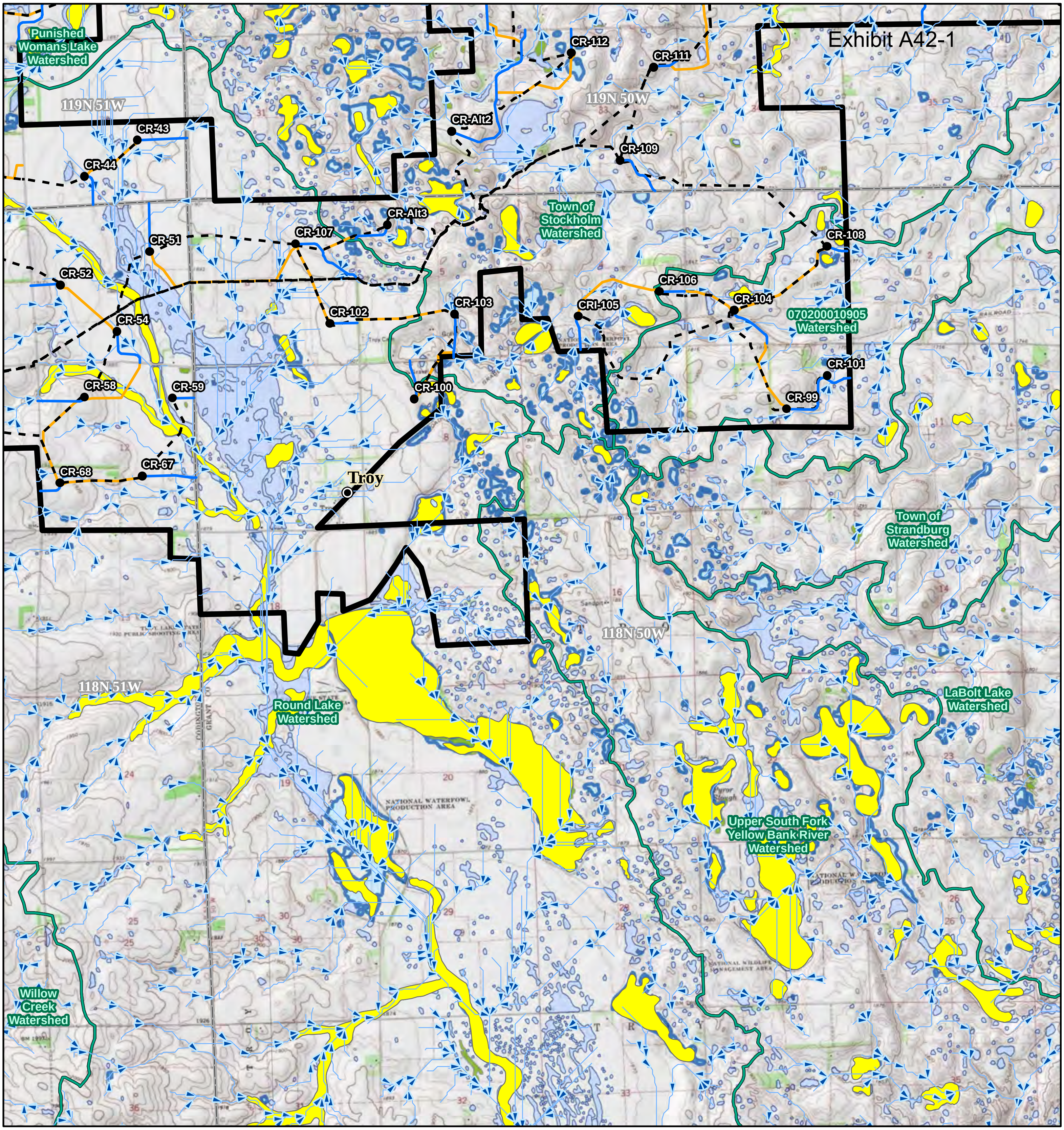
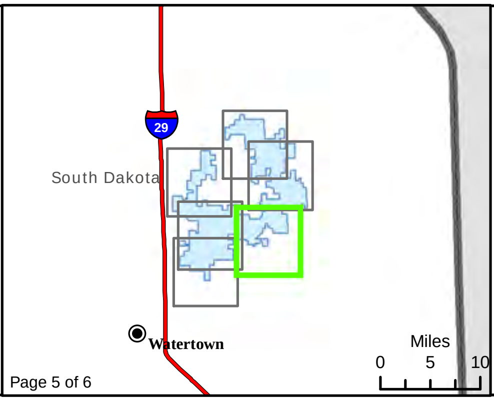


Figure 12. Water Resources

Crowned Ridge Wind Farm

City
Intersection of Floodplain and Project Infrastructure
Turbine
Access Road
Collector Line
Crane Path
Flow Direction
South Dakota Beneficial Use Stream
South Dakota Beneficial Use Lake
Watershed Boundary (HUC12)
Project Boundary
County Boundary
Township/Range Boundary
Freshwater Emergent Wetland
Freshwater Forested/Shrub Wetland
Lake, Pond, or Riverine Wetland
FEMA Flood Zone
A



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Kilometers
0 1 2
Miles
0 1 2

Base Map: USGS 7.5' Topographic Map
Source: Esri ArcGIS Online service
Quadrangle: South Shore (1973), Stockholm (1973)
Township/Range: T119N, R51W & T119N, R50W & T118N, R51W & T118N, R50W
Codington and Grant Counties, South Dakota

Projection: NAD 1983 UTM Zone 14N

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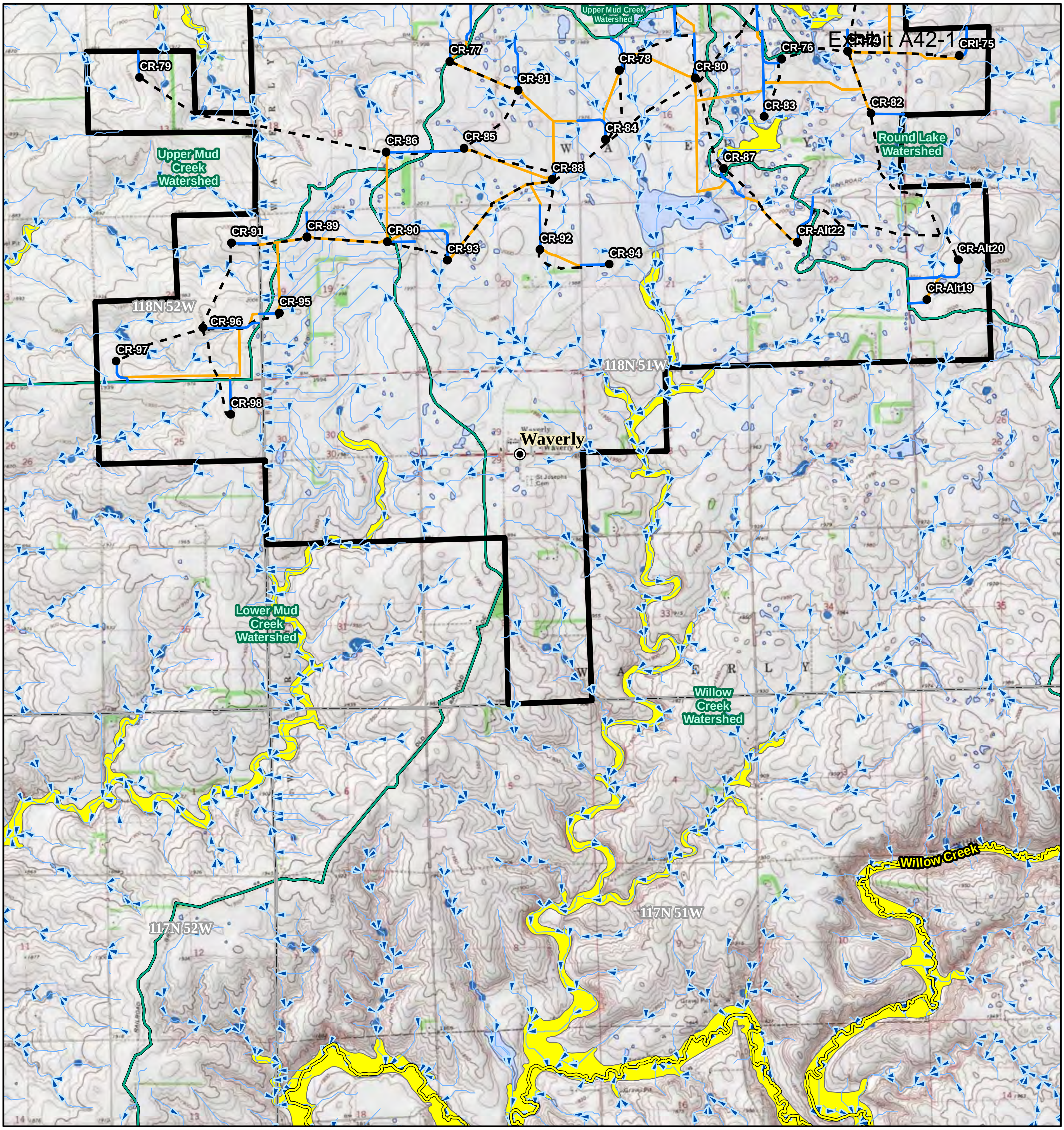

Figure 12. Water Resources

Crowned Ridge Wind Farm

- City
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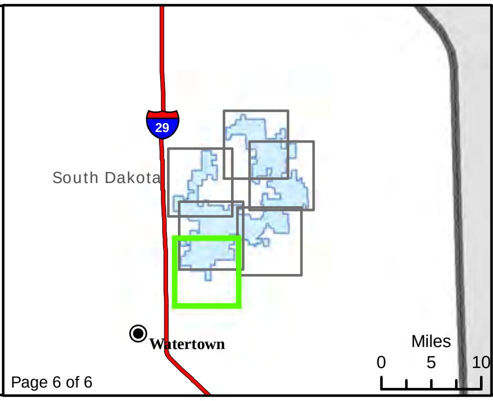
- Lake, Pond, or Riverine Wetland

FEMA Flood Zone

- A



Page 6 of 6

Kilometers 0 1 2

Miles 0 1 2

Base Map: USGS 7.5' Topographic Map
Source: Esri ArcGIS Online service
Quadrangle: Still Lake SE (1970), South Shore (1973), Watertown East (1969), Kranzburg (1970)
Township/Range: T118N, R52W & T118N, R51W
Codington County, South Dakota

Projection: NAD 1983 UTM Zone 14N

SWCA ENVIRONMENTAL CONSULTANTS

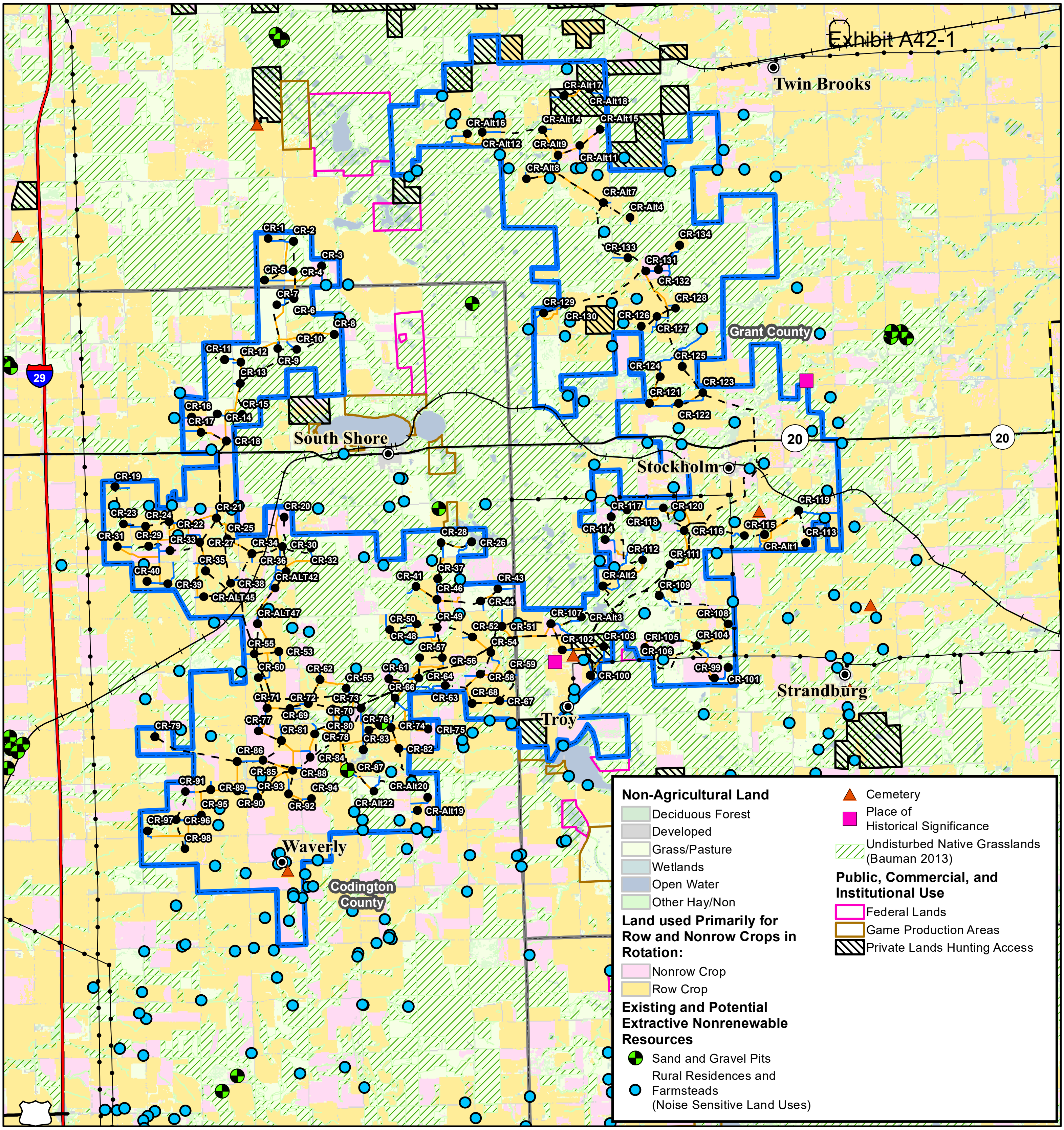


Figure 13. Land Use

Crowned Ridge Wind Farm

City	Railroad
Turbine	Interstate Highway
Access Road	U.S. Highway
Collector Line	State Highway
Crane Path	Project Boundary
Electrical Line	County Boundary
Natural Gas Line	

Kilometers: 0, 5, 10
Miles: 0, 2.5, 5

Base Map: 2017 South Dakota Cropland Data Layer | NASS/USDA
Source: United States Department of Agriculture (USDA),
National Agricultural Statistics Service (NASS),
Research and Development Division (RDD),
Geospatial Information Branch (GIB),
Spatial Analysis Research Section (SARS); 2017 Edition
Codington, Deuel, and Grant Counties, South Dakota

Projection: NAD 1983 UTM Zone 14N

SWCA ENVIRONMENTAL CONSULTANTS

BEFORE THE PUBLIC UTILITIES COMMISSION
OF THE STATE OF SOUTH DAKOTA

IN THE MATTER OF THE APPLICATION OF
CROWNED RIDGE, LLC FOR A FACILITIES PERMIT TO
CONSTRUCTION 300 MEGAWATT WIND FACILITY

Docket No. EL19-003

REBUTTAL TESTIMONY AND EXHIBITS

OF JAY HALEY

May 24, 2019

INTRODUCTION

Q. PLEASE STATE YOUR NAME AND BUSINESS ADDRESS.

A. My name is Jay Haley. My business address is 3100 DeMers Ave., Grand Forks, ND, 58201.

Q. **BY WHOM ARE YOU EMPLOYED AND IN WHAT CAPACITY?**

A. I am a Partner in EAPC Wind Energy and work as a Wind Engineer.

Q. **WHAT ARE YOUR RESPONSIBILITIES?**

A. My responsibility was to conduct the sound and shadow/flicker studies for Crowned Ridge Wind, LLC ("CRW").

Q. **ARE YOU THE SAME JAY HALEY WHO SUBMITTED DIRECT TESTIMONY IN THIS PROCEEDING ON JANUARY 30, 2019 AND SUPPLEMENTAL DIRECT TESTIMONY ON APRIL 1, 2019?**

A. Yes.

Q. HAS THIS TESTIMONY BEEN PREPARED BY YOU OR UNDER YOUR DIRECT SUPERVISION?

A. Yes.

Q. PLEASE DESCRIBE THE PURPOSE OF YOUR REBUTTAL TESTIMONY.

A. The purpose of my rebuttal testimony is to response to the direct testimony of Staff witness Darren Kearney, Staff witness David Hessler, Intervenor witness John Thompson, and Intervenors' proposed conditions as set forth in Staff witness Darren Kearney's Direct Testimony, Exhibit DK-8.

Shadow Flicker Modeling

Q. STAFF WITNESS KEARNEY'S TESTIMONY AT PAGE 10, LINES 16-18 REQUESTS THAT CRW FILE UPDATED FIGURES FROM APPENDIX D OF THE SHADOW FLICKER STUDY TO SHOW THE TOTAL EXPECTED LEVELS OF SHADOW FLICKER ON RECEPTORS FROM ALL TURBINES, WHETHER THOSE TURBINES ARE PROPOSED TO BE CONSTRUCTED BY CROWNED RIDGE WIND OR ANOTHER PROJECT. DO AGREE WITH THIS REQUEST?

A. Yes. Let me start by pointing out that I did explain the cumulative impacts from all turbines, whether they be proposed by CRW, Crowned Ridge Wind II, or Dakota Range Wind I and II, in my supplemental testimony on page 6. The tables in Exhibit 3 of the supplemental testimony show the cumulative results from all turbines in CRW, Crowned Ridge Wind II, and Dakota Range Wind I and II. Also, attached is the Iso-line map book for cumulative shadow flicker to my testimony as Exhibit JH-R-1. This document has also been updated to the most current land status.

Q. STAFF WITNESS KEARNEY'S TESTIMONY AT PAGE 10, LINES 22-33 STATES THAT IF CRW CANNOT OBTAIN A WAIVER FOR NON-PARTICIPATING RECEPTOR (CR1-C61-NP), WHO IS EXPECTED TO EXPERIENCE 49 HOURS AND 6 MINUTES OF SHADOW FLICKER PER YEAR, THAT CRW SHOULD ELIMINATE THE USE OF THE WIND TURBINE CAUSING THE SHADOW/FLICKER IR AUTOMATICALLY CONTROL THE TURBINE SO THAT THE RECEPTOR DOES NOT EXPERIENCE OVER 30 HOURS OF SHADOW/FLICKER PER YEAR. HE ALSO REQUESTS THAT CROWNED RIDGE PROVIDE IN REBUTTAL TESTIMONY THE FINAL PLAN FOR LIMITING SHADOW/FLICKER AT RECEPTOR (CR1-C61-NP). WHAT

IS YOUR UNDERSTANDING OF CRW'S FINAL PLAN FOR THIS RECEPTOR?

A. The final plan for this receptor is set forth in the rebuttal testimony of witnesses Wilhelm and Massey. If CR1-16 is curtailed by 20 hours per year, this reduces the shadow-flicker at receptor CR1-C61-NP to less than 30 hours of shadow flicker per year, with 21:33 hours contributed by Dakota Range turbines. This was determined by running the model with all turbines from CRW, Crowned Ridge Wind II and Dakota Range I and II, and then with and without turbine CR1-16.

Sound Modeling

Q. STAFF WITNESS KEARNEY'S TESTIMONY AT PAGE 12, LINES REQUESTS THAT CROWNED RIDGE WIND UPDATE THE FIGURES FOR APPENDIX D TO 5 THE SOUND STUDY THAT PROVIDE THE ISO-LINES FOR SOUND LEVELS THAT ACCOUNT FOR THE CROWNED 6 RIDGE, DAKOTA RANGE, AND CROWNED RIDGE II WIND TURBINE ARRAYS? DO AGREE WITH THIS REQUEST?

A. Yes, and I have attached a sound Iso-line map book to my testimony as Exhibit JH-R-2. This document has been updated to the most current land participation status.

Q. STAFF WITNESS HESSLER'S TESTIMONY AT PAGE 3, LINES 11-20 CLAIMS THAT THE CRW SOUND STUDY SHOULD HAVE EVALUATED OR ASSESSED THE POTENTIAL NOISE IMPACT FOR THE PROJECT ON THE COMMUNITY THROUGH A BASELINE SOUND SURVEY. DO YOU AGREE?

A. No, I do not. In my years of performing these studies, I have not been asked or required to assess community perception based on the difference between the turbine noise and the background noise. For the Crowned Ridge project, I was hired to perform the noise study pertaining to the noise emissions from the turbines. There was no requirement to perform background noise measurements, as there was no regulatory requirement to do so.

Q. STAFF WITNESS HESSLER'S TESTIMONY AT PAGE 6, LINES 17-19 RECOMMENDS THAT THE ENTIRE CRW PROJECT SHOULD ADOPT THE GRANT COUNTY ORDINANCE LEVEL OF NO MORE THAT 45 DBA AT ALL NON-PARTICIPATING RESIDENCES. DO YOU AGREE?

A. I have modeled the entire project using the Grant County Ordinance. The results show that with turbines CR-40 and CR-17 being removed and replaced by turbines CR1-Alt42 and CR1-Alt45, all Codington non-participating residences are at or below 45 dBA, and the highest noise level at a Codington participating residence is 47.9 dBA. For Grant County, all non-participants are below 45 dBA and all but 3 participants are below 45 dBA except for three, with the highest of those being 45.3 dBA. The results of this model rule is in Exhibit JH-R-3.

Q. STAFF WITNESS HESSLER'S TESTIMONY AT PAGE 5 LINES 17 TO PAGE 6 LINE 5 CLAIMS THAT CRW SHOULD MOVE 16 PRIMARY TURBINE LOCATIONS TO ALTERNATIVE LOCATIONS TO REDUCE THE DBA FOR NON-PARTICIPANTS FROM A RANGE OF 43-45 DBA TO 41 OR 42 DBA. DID YOU MODEL STAFF WITNESS HESSLER'S RECOMMENDATION?

A. Yes. The results are attached as Exhibit JH-R-4. As these results show, only 13 Receptors of the 50 that were above 42 dBA were lowered to a level of 42 dBA or less by eliminating the 16 suggested turbines.

Non-Participant

Q. INTERVENOR WITNESS THOMPSON SUBMITTED TESTIMONY EXPLAINING THAT HE IS NOT PARTICIPATING IN THE PROJECT. DOES IS NON-PARTICIPATION CHANGE YOUR STUDY RESULTS?

A. No, since there is no occupied structure on the property, it does not change any of the study results.

Q. WHERE THERE OTHER PROPERTY STATUS CHANGES THAT IMPACTED YOUR SOUND AND SHADOW/FLICKER STUDY RESULTS?

A. Yes, I have confirmed with Tyler Wilhelm, the Project Manager, that the data that was provided to me is accurate and complete with respect to who is a participant and who is a non-participant. I have attached a shadow flicker Iso-line map book to my testimony as Exhibit JH-R-2. This document has also been updated to the most current land participation status.

Q. GIVEN THE CONSIDERATION OF CUMULATIVE IMPACTS FROM DAKOTA RANGE AND LAND STATUS CHANGES ARE THERE RECEPTORS THAT ARE NO LONGER IN COMPLIANCE WITH EITHER THE GRANT COUNTY OR CODINGTON COUNTY ORDINANCE?

A. Yes, those receptors are CRI-C46-NP and CRI-C58-NP.

Q. HAS CRW ELIMINATED PRIMARY TURBINES AND ACTIVATED ALTERNATIVE TURBINES IN RESPONSE TO THE SOUND RESULTS?

A. Yes, it is my understanding that CRW will not use primary turbines CRI-40 and CRI-17 and will activate alternative turbines CRI-Alt42 and CRI-Alt45.

Q. BASED ON THESE CHANGES TO TURBINES ARE THE SOUND LEVELS IN COMPLIANCE WITH THE GRANT AND CODINGTON COUNTY ORDINANCES?

A. Yes, this is shown in Exhibit JH-R-5.

Q. DOES THE ENTIRE CRW PROJECT ALSO MEET THE STANDARD THAT ALL NON-PARTICIPANTS ARE BELOW 45 DBA AND ALL PARTICIPANTS ARE BELOW 50 DBA WHEN MEASURED 25 FEET FROM THEIR RESIDENCE?

A. Yes, this is shown in Exhibit JH-R-3.

<u>Intervenors Proposed Conditions</u>

Q. THE INTERVENORS' PROPOSED CONDITION 2 (KEARNEY EXHIBIT DK-8) WOULD REQUIRE A 2 MILE SETBACK OF WIND TURBINES FROM WAVERLY SCHOOL. BASED ON YOUR MODELING, WHAT LEVEL OF SOUND WILL BE EXPERIENCED AT THE SCHOOL?

A. The distance from the school to the nearest wind turbine is 5,892 feet, which is a Crowned Ridge II turbine. The nearest Crowned Ridge turbine is 6,208 feet away from the school. The sound pressure level at the school would be 39.4 dBA.

Q. BASED ON YOUR MODELING, WHAT LEVEL OF SHADOW/FLICKER WILL BE EXPERIENCED AT THE SCHOOL?

A. The distance from the school to the nearest wind turbine is 5,892 feet, which is a Crowned Ridge II turbine. The nearest Crowned Ridge turbine is 6,208 feet away from the school. There would be 46 minutes per year of shadow flicker at the school.

Q. THE INTERVENORS' PROPOSED CONDITION 18 (KEARNEY EXHIBIT DK-8) WOULD REQUIRE "NO FLICKER SHALL BE ALLOWED TO CROSS NON-PARTICIPATING LANDOWNER'S PROPERTY LINE." BASED ON YOUR EXPERIENCE MODELING WHAT AMOUNT OF SHADOW AND FLICKER IS CROSSING A NON-PARTICIPATING LANDOWNER'S PROPERTY LINE?

A. Shadow flicker occurs when a moving shadow passes over a constrained opening such as a window or doorway of a building. A moving shadow out in an open field is not considered to be "flicker". The specialized software programs that calculate shadow flicker are designed to calculate flicker that would occur inside of a building by modeling the size and location of windows because the shadow flicker impacts occur inside the buildings. They do not calculate shadow movement across property lines.

Q. DO YOU AGREE WITH THE CONDITION THAT NO FLICKER SHALL BE ALLOWED TO CROSS NON-PARTICIPATING LANDOWNER'S PROPERTY LINE?

A. No, I do not agree with this condition. A moving shadow crossing a property line is not shadow flicker. Shadow flicker occurs when the shadow moves across a window in a room. The shadow in that case causes the light intensity level in the room to fluctuate, causing a flickering sensation. This does not happen out in an open field.

Q. DOES THIS CONCLUDE YOUR SUPPLEMENTAL TESTIMONY?

A. Yes, it does.

STATE OF NORTH DAKOTA)
) ss
COUNTY OF GRAND FORKS)

I, Jay Haley, being duly sworn on oath, depose and state that I am the witness identified in the foregoing prepared testimony and I am familiar with its contents, and that the facts set forth are true to the best of my knowledge, information and belief.

Jay Haley

Jay Haley

Subscribed and sworn to before me this 24rd day of May, 2019.

SEAL

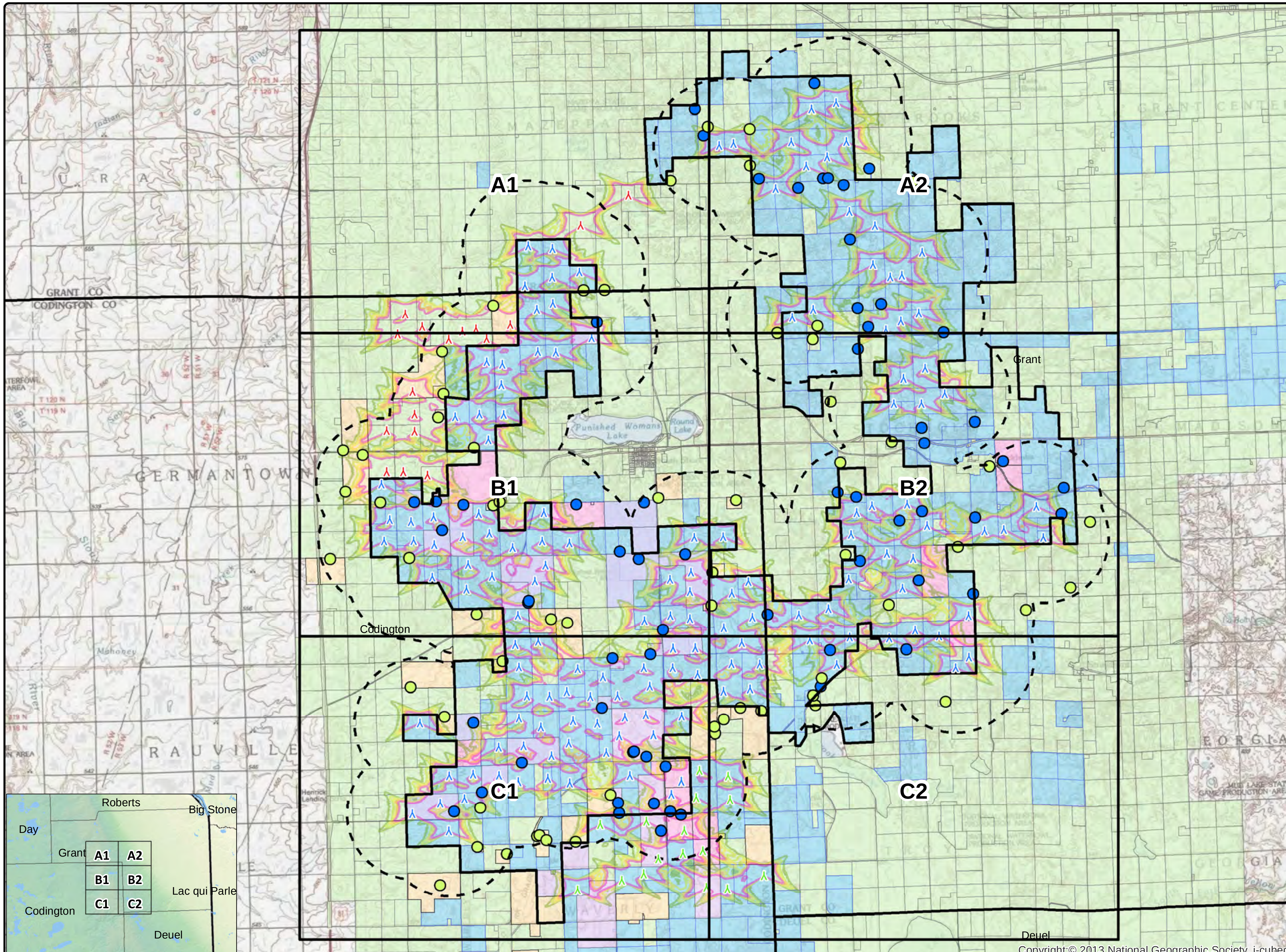
CAROL ENGLUND
Notary Public
State of North Dakota
My Commission Expires April 11, 2023

Carol Englund

Notary Public

My Commission Expires April 11, 2023

Exhibit A43-1



0 0.75 1.5 3 Mile

EAPC
WIND ENERGY

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Crowned Ridge Wind Farm Shadow Flicker Iso-Lines Overview Map

Client

SWCA Environmental Consultants

Project Description

Wind turbine layout with occupied structures within 2 km.

Predicted shadow flicker levels at existing residences.

Location: *Watertown, SD*

Project #: 20174431

Issue Dates

#	Description	Date
1	Original	2019.05.24

Drawn By: *AS* *Checked By:* *JH*

Legend

- Crowned Ridge Wind Turbines
- Crowned Ridge II Wind Turbines
- Dakota Range Wind Turbines
- 2 km Turbine Buffer
- County Lines
- CR1 Project Boundary
- Non Participants
- Participants

Shadow Flicker (hr/yr)

- 10
- 15
- 20
- 25
- 30
- Non-Participating Codington Parcels
- Participating Codington Parcels
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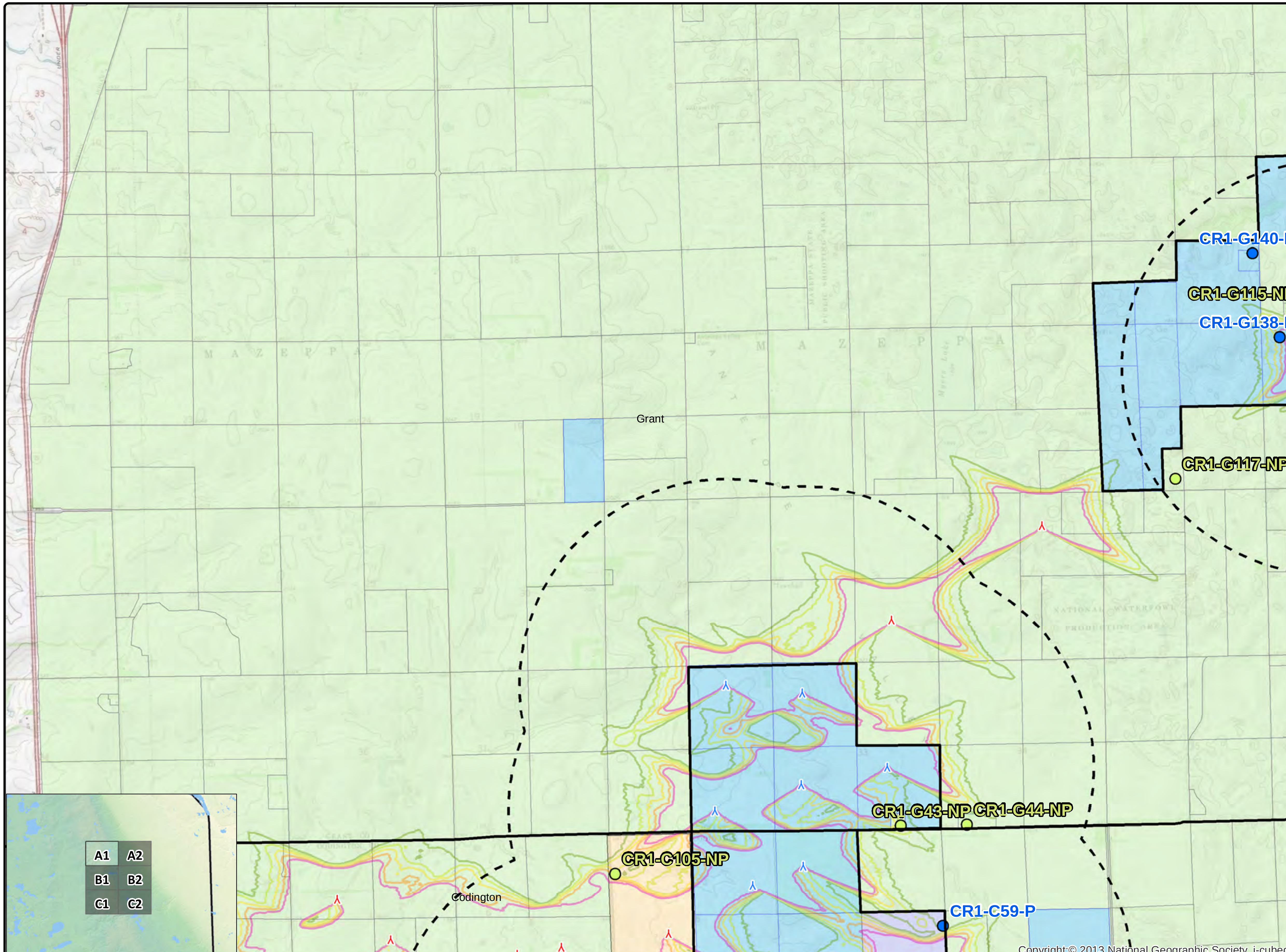
N W E S

Exhibit A43-1



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Crowned Ridge Wind Farm
Shadow Flicker Iso-Lines

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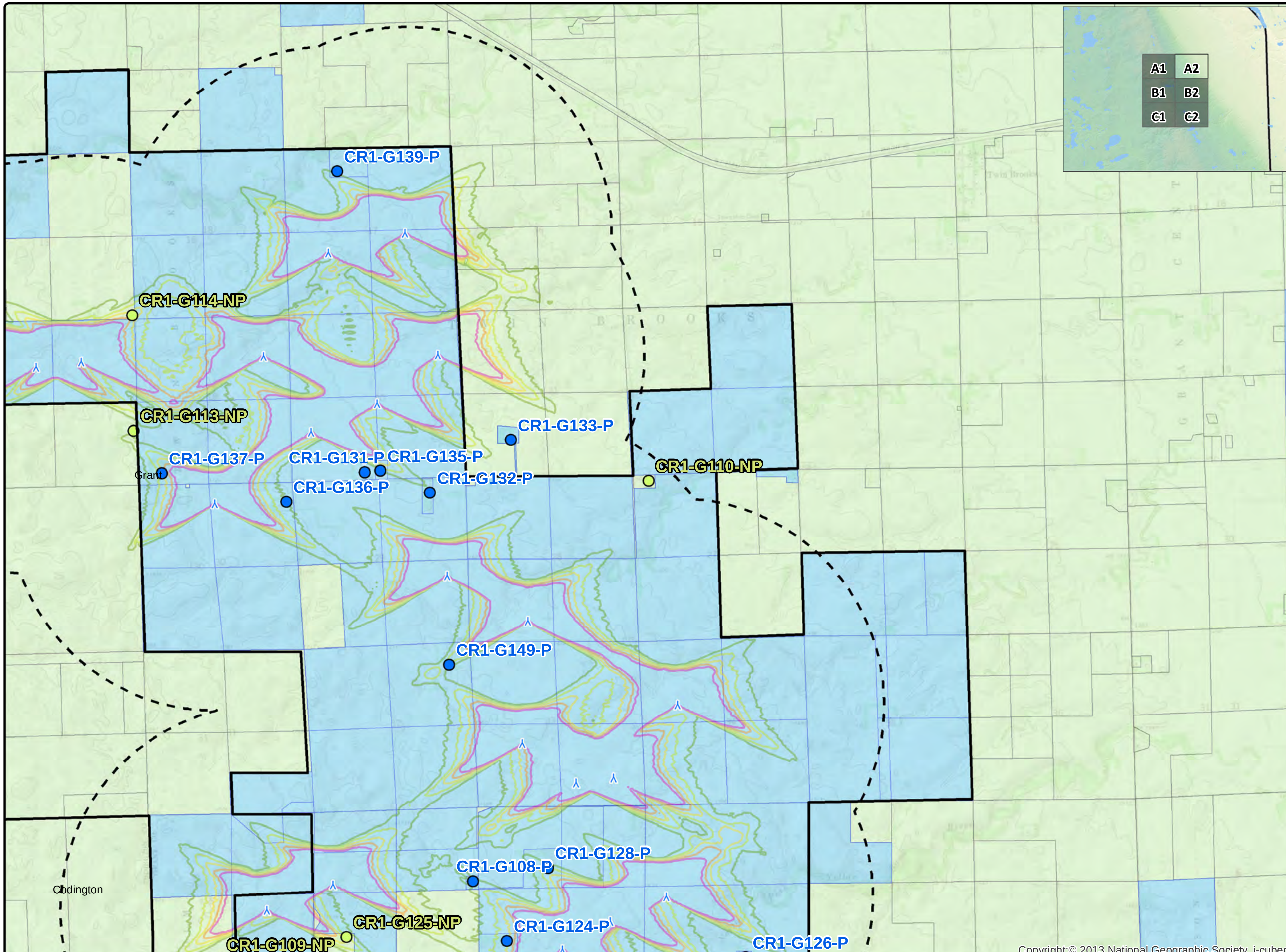
N W E S

0 0.25 0.5 1 Mile

Exhibit A43-1



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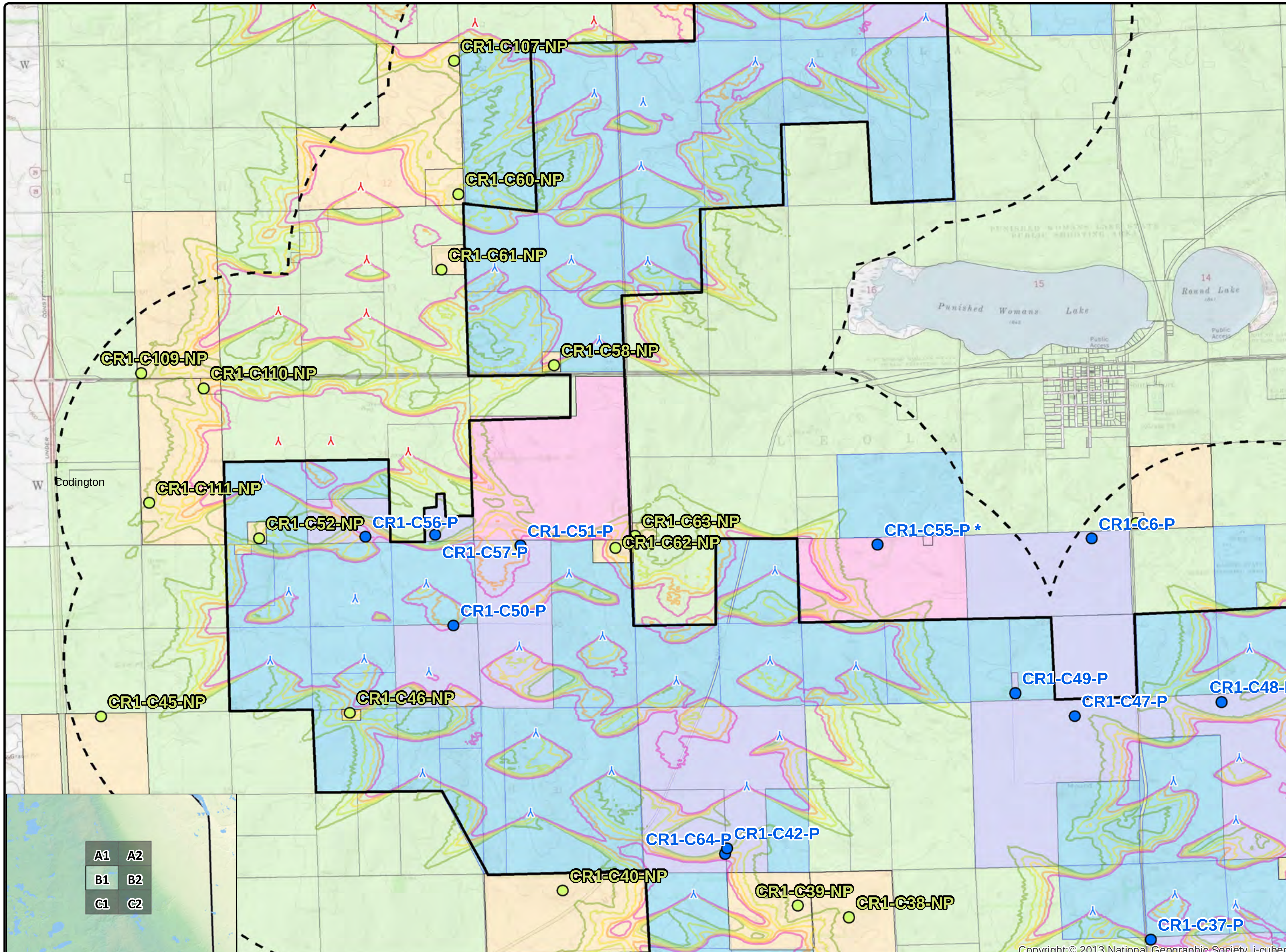

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Crowned Ridge Wind Farm
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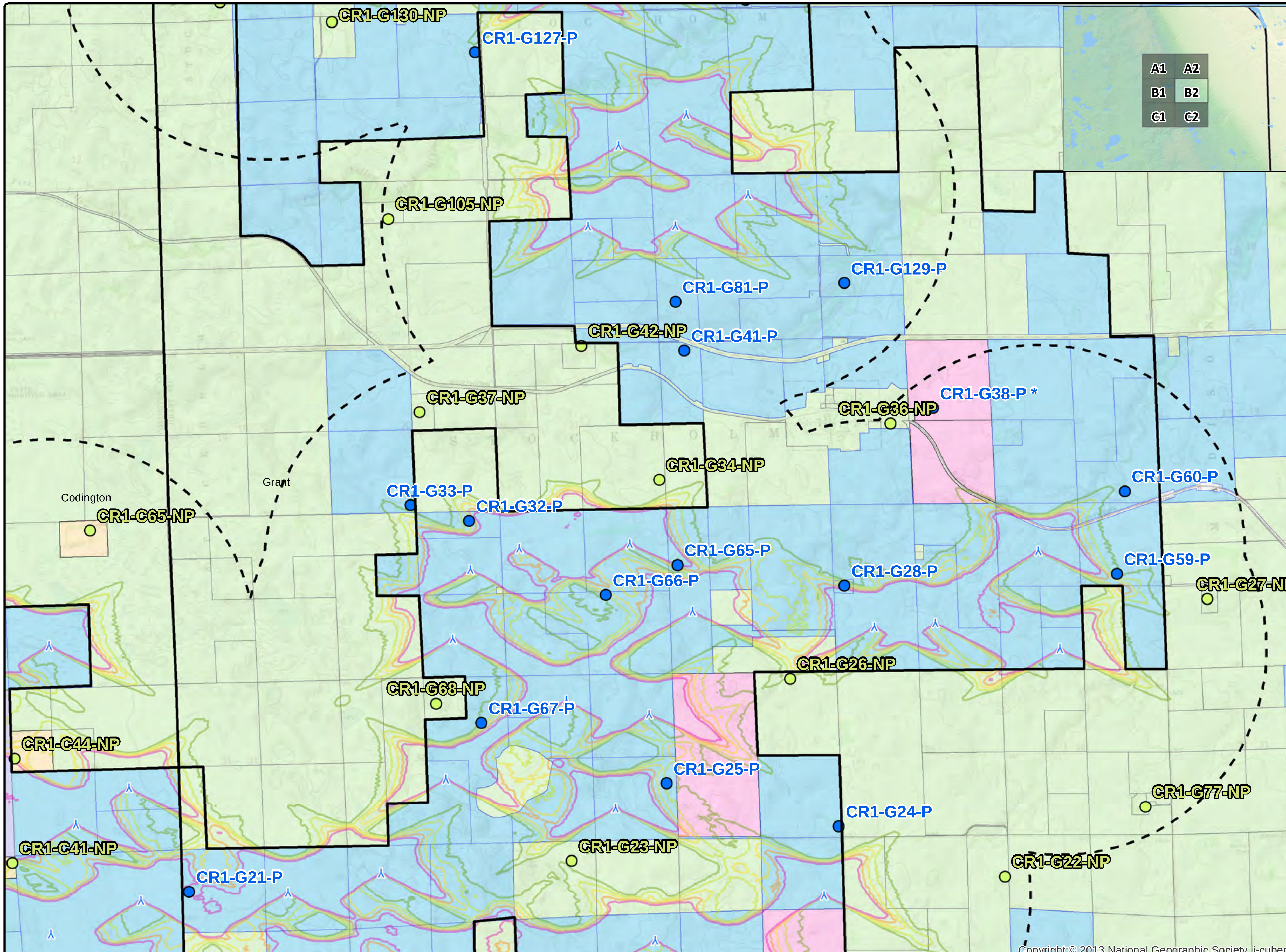

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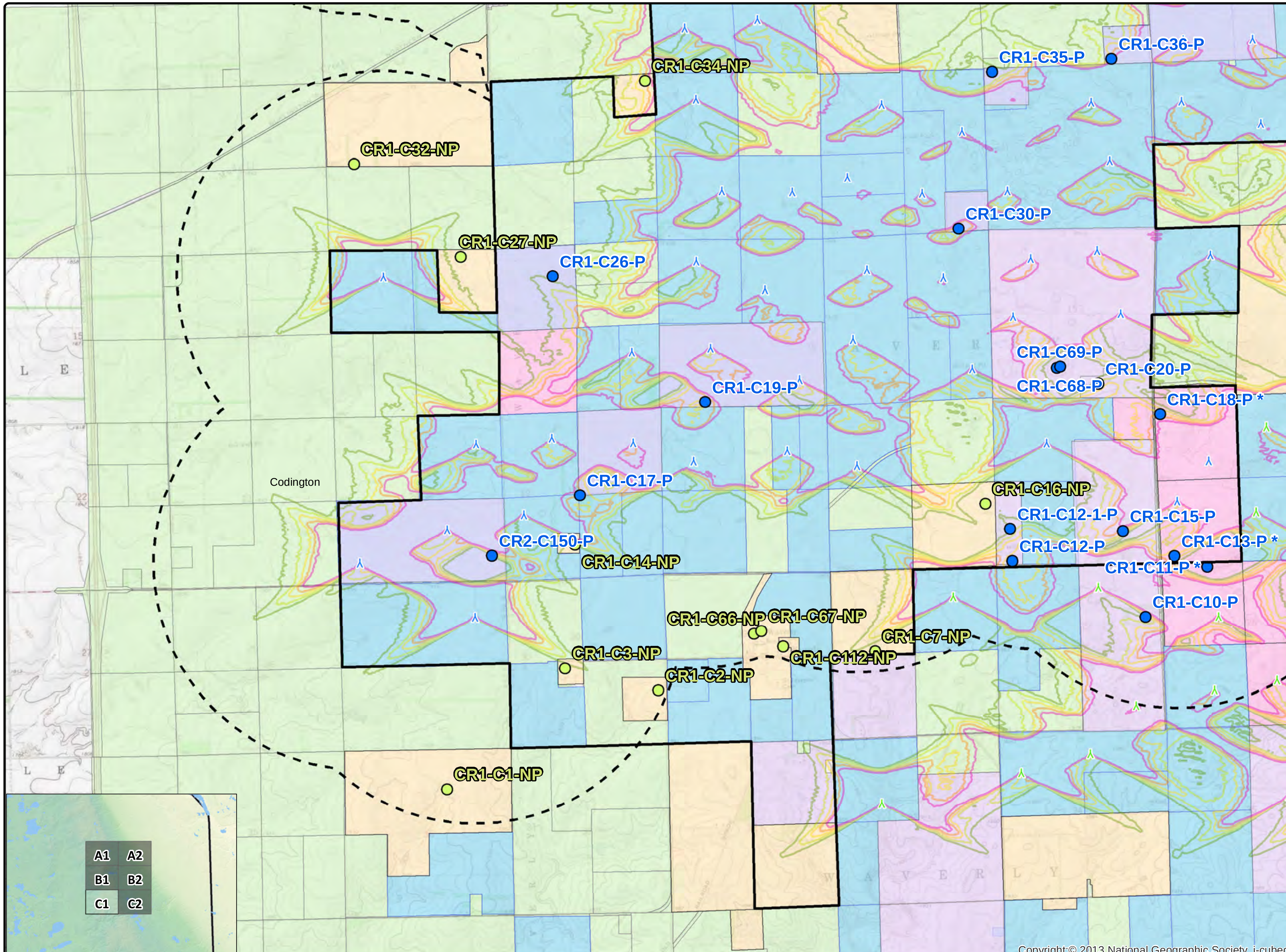

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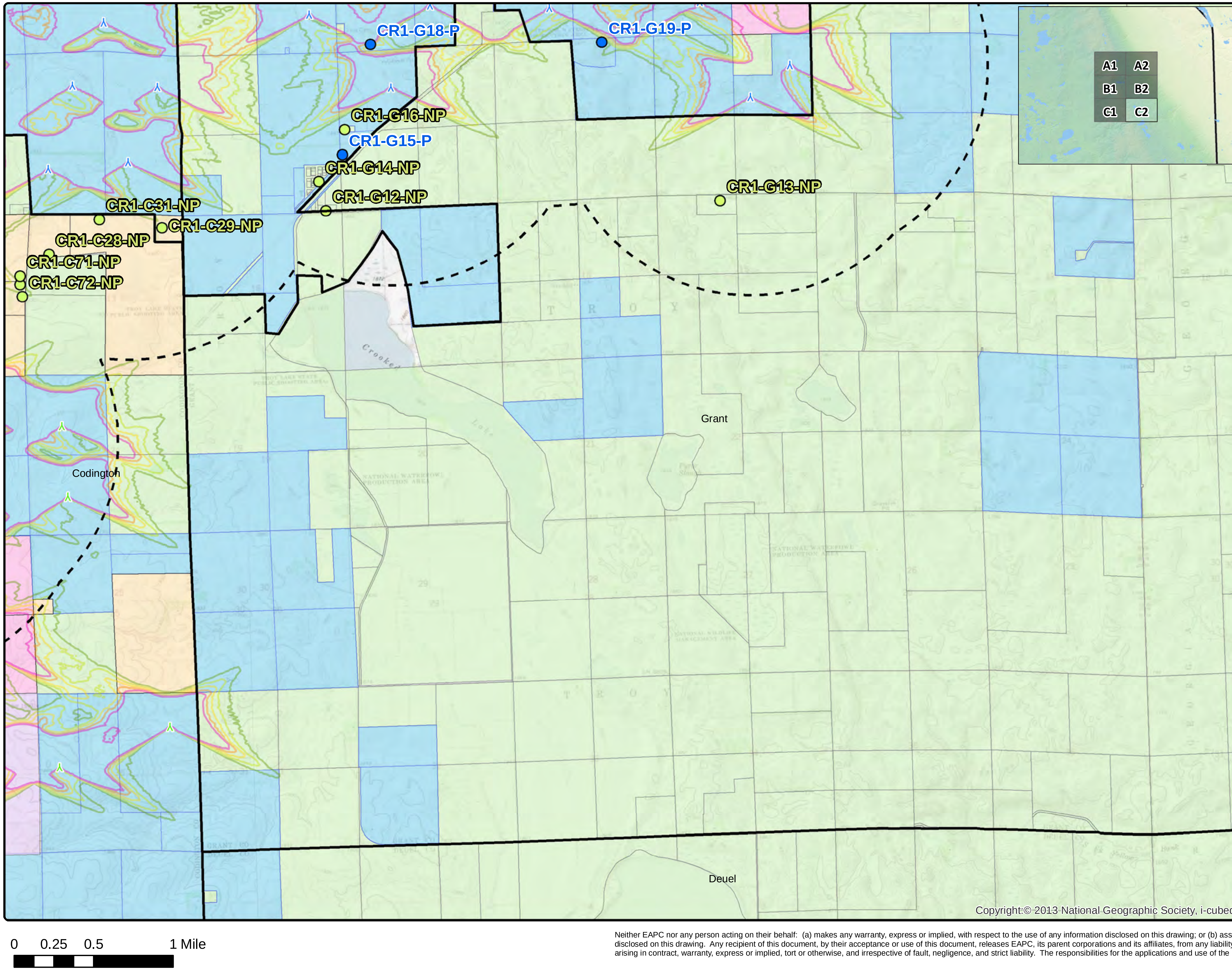

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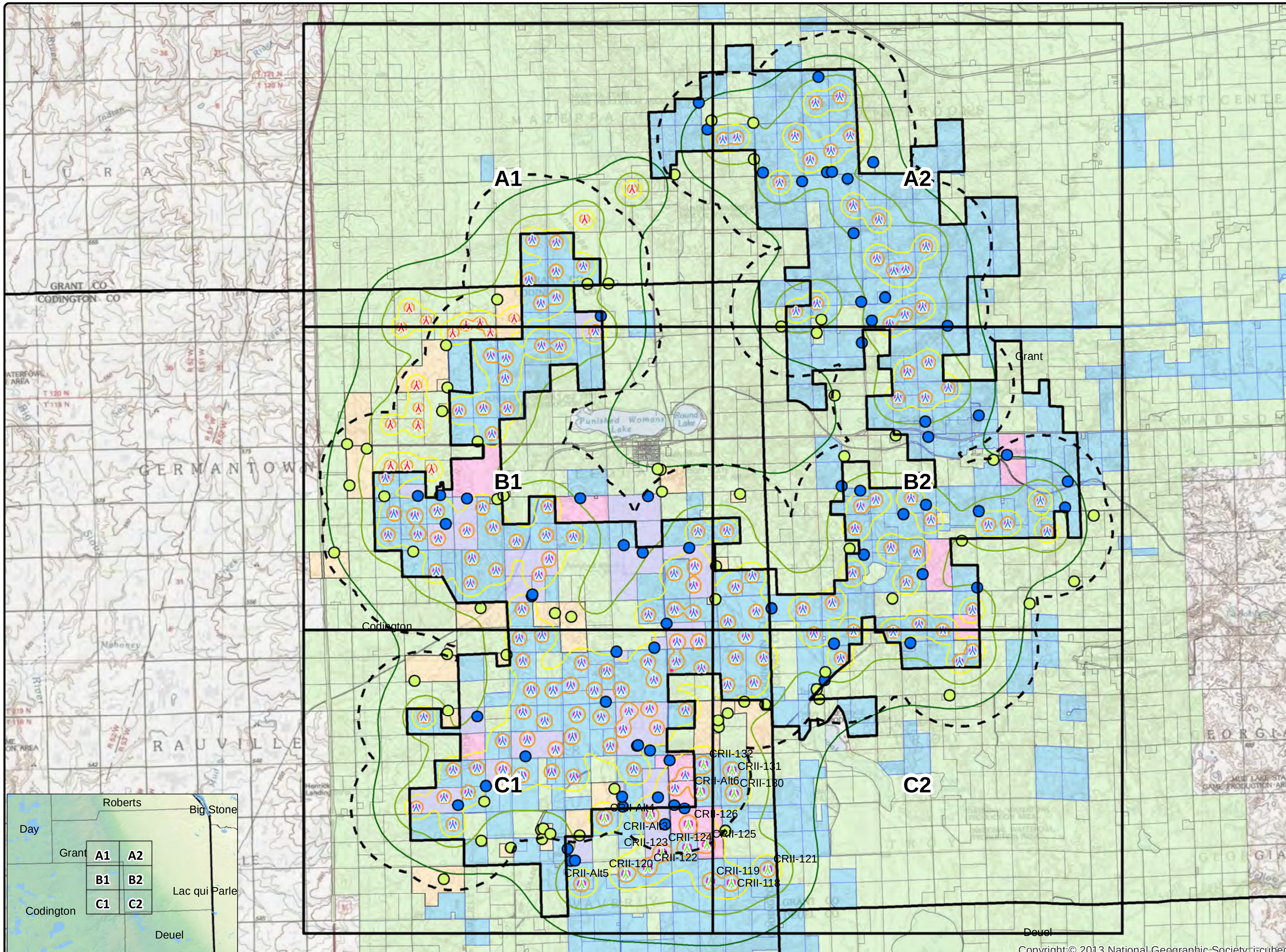
N W E S

Exhibit A43-2



0 0.75 1.5 3 Mile

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Crowned Ridge Wind Farm
Sound Pressure Iso-Lines
Overview Map

Client

SWCA Environmental Consultants

Project Description

Wind turbine layout with occupied structures within 2 km as well as parcel boundaries.

Predicted sound pressure levels at existing residences and land parcel boundaries.

Additional 2 dBA added.

Location: Watertown, SD

Project #: 20174431

Issue Dates

#	Description	Date
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Drawn By: AS *Checked By:* JH

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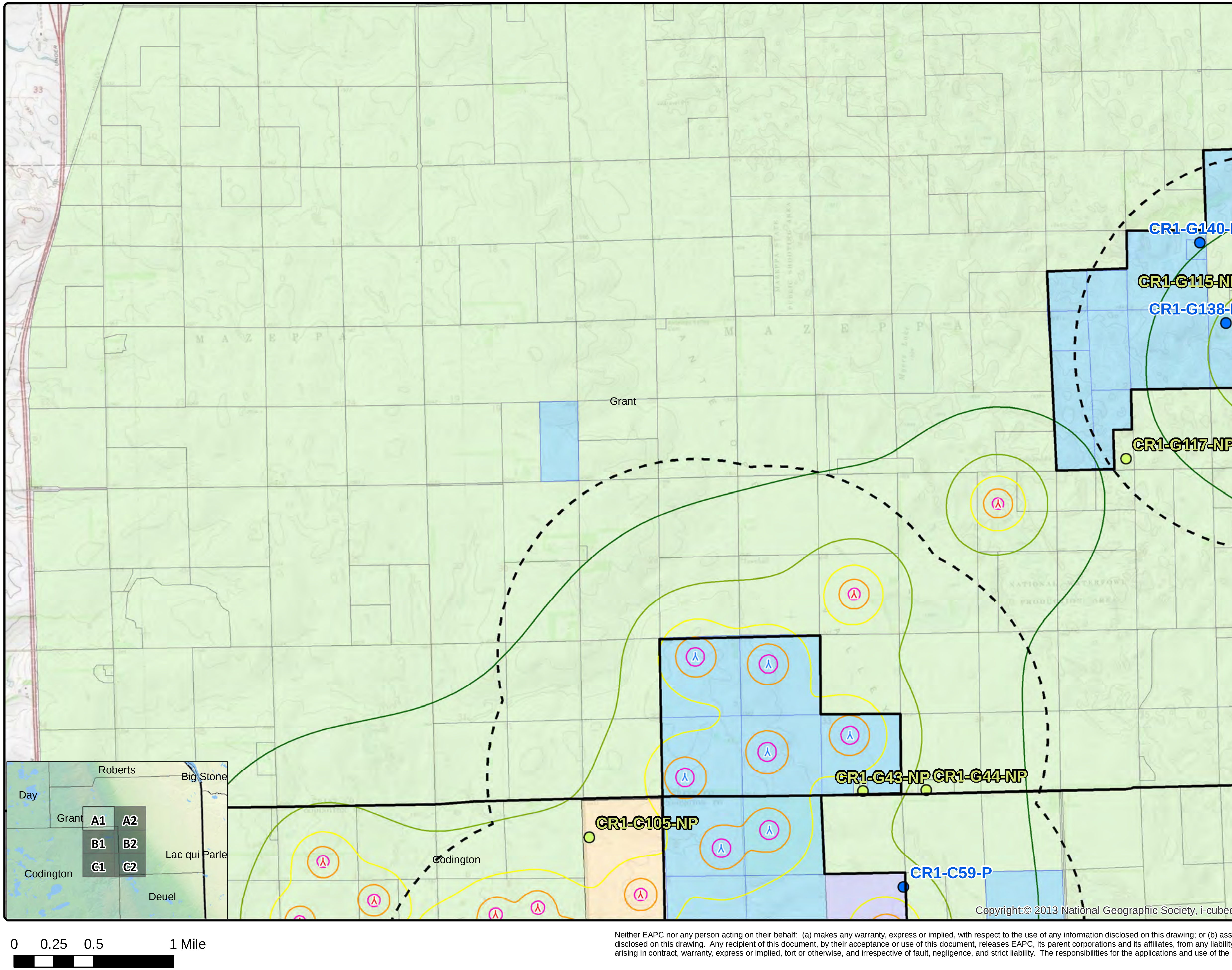
- Participants
- <all other values>

Sound Pressure (dBA)

- 35
- 40
- 45
- 50
- 55
- Participating Codington Parcels
- Non-Participating Codington Parcels
- Participating Parcels
- Pending Parcels
- Non-Participating Parcels

N E S W

Exhibit A43-2



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Crowned Ridge Wind Farm
Sound Pressure Iso-Lines

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N W E S

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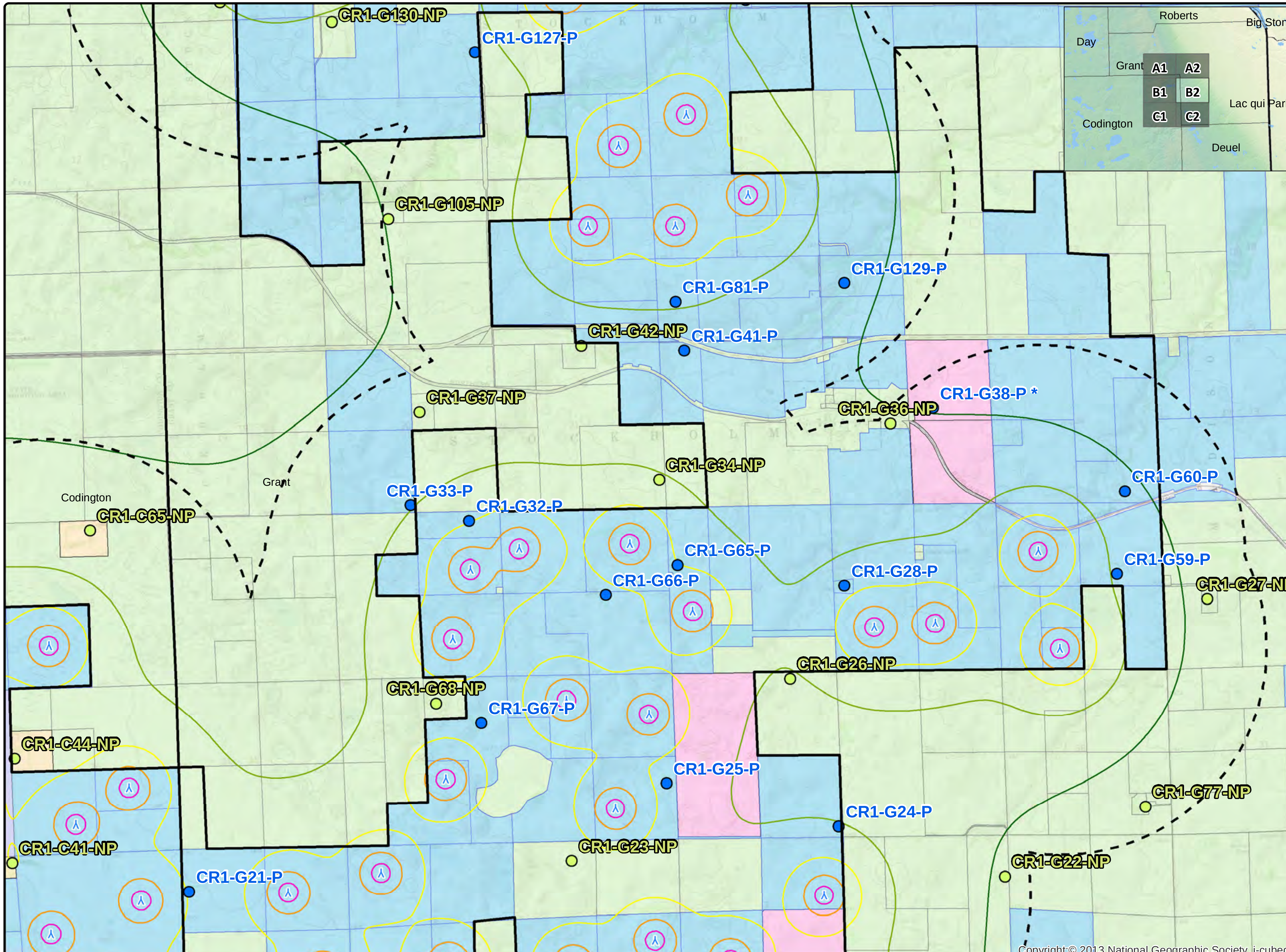

0 0.25 0.5 1 Mile

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Crowned Ridge Wind Farm
Sound Pressure Iso-Lines

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SWCA Environmental Consultants

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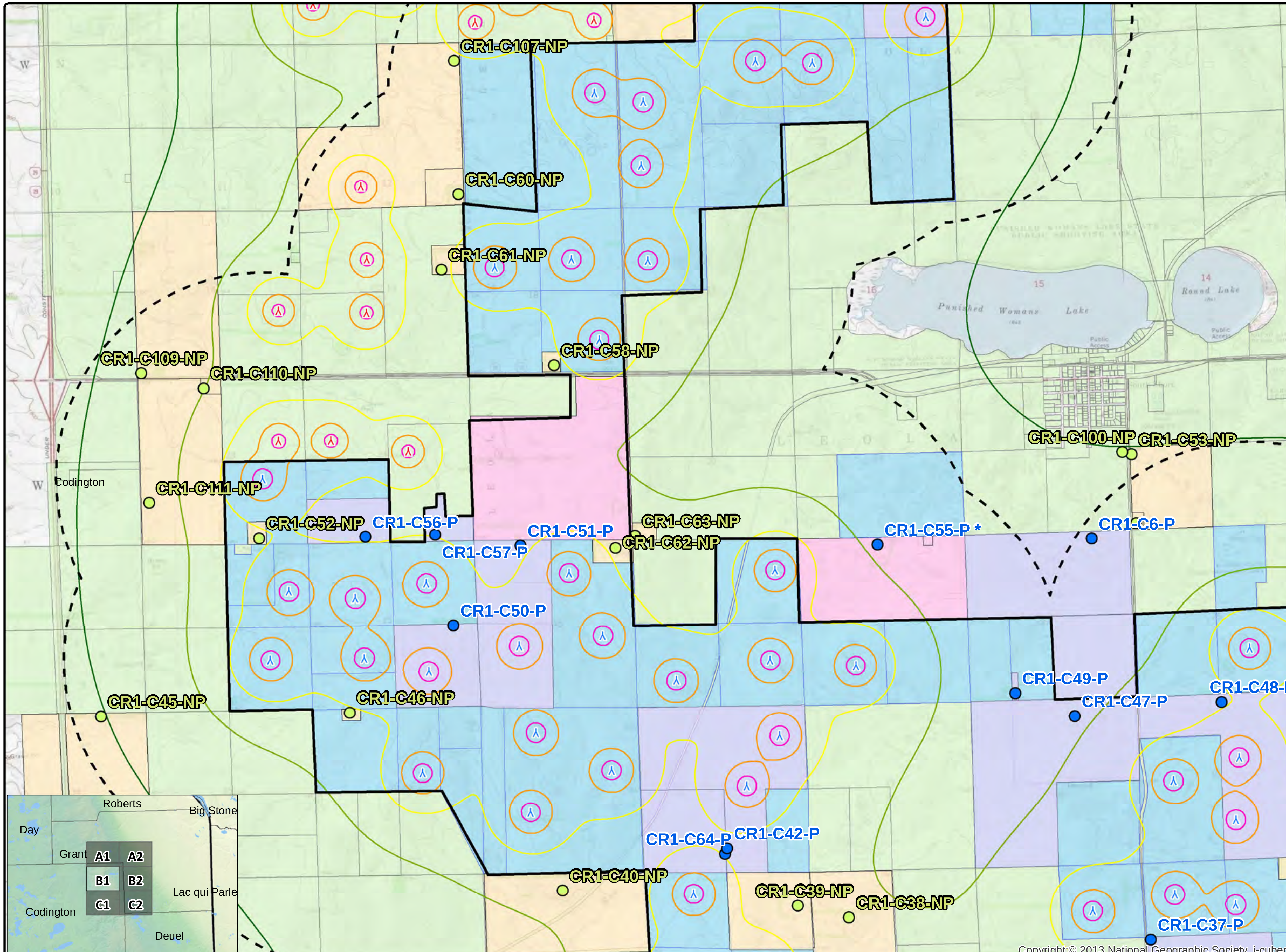
Exhibit A43-2



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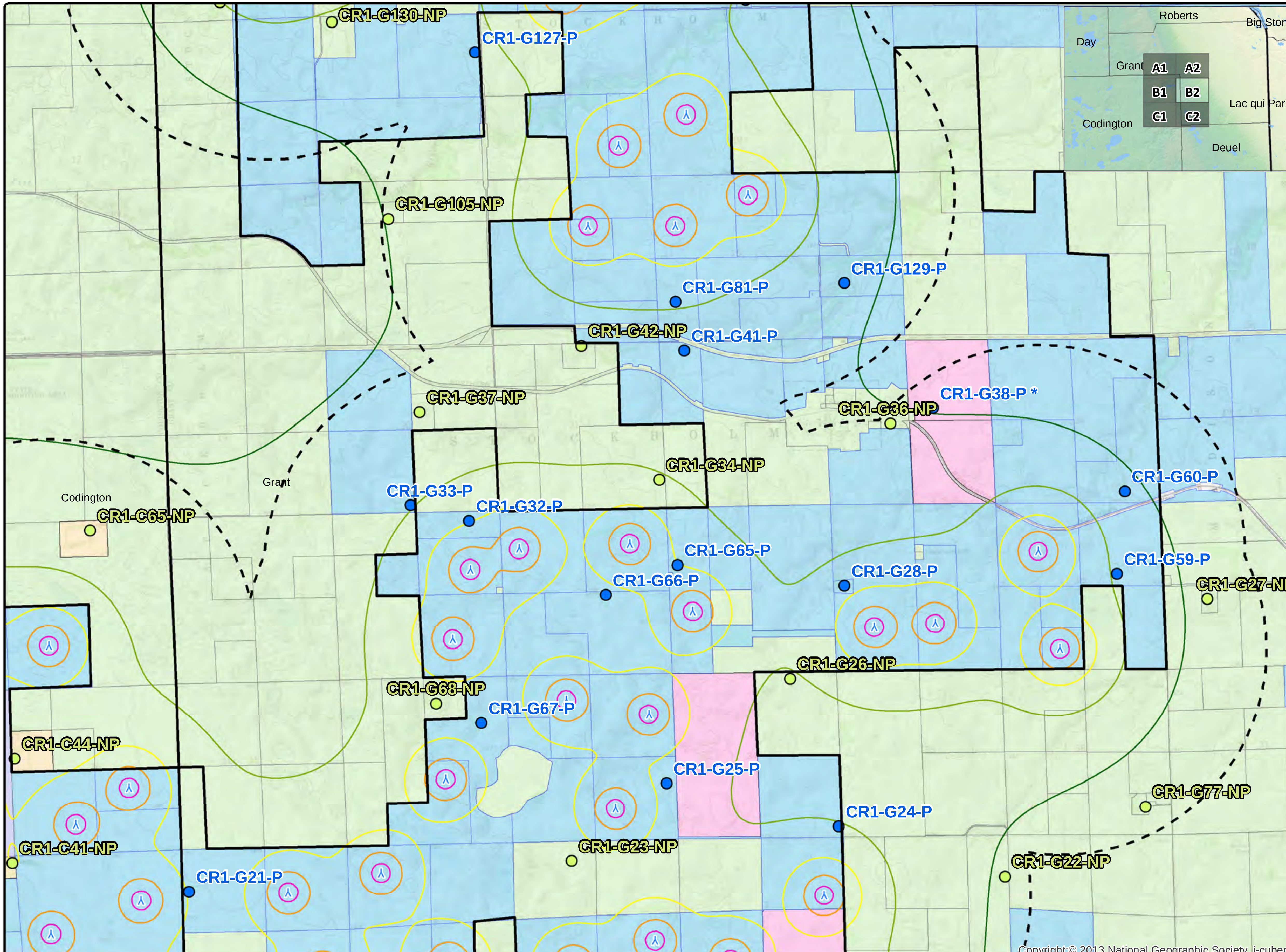
N W E S

Exhibit A43-2



0 0.25 0.5 1 Mile

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Crowned Ridge Wind Farm
Sound Pressure Iso-Lines

Client

SWCA Environmental Consultants

Project Description

Wind turbine layout with occupied structures within 2 km as well as parcel boundaries.

Predicted sound pressure levels at existing residences and land parcel boundaries.

Additional 2 dBA added.

Location: *Watertown, SD*

Project #: *20174431*

Issue Dates

#	Description	Date
1	Original	2019.05.24

Drawn By: AS *Checked By:* JH

Legend

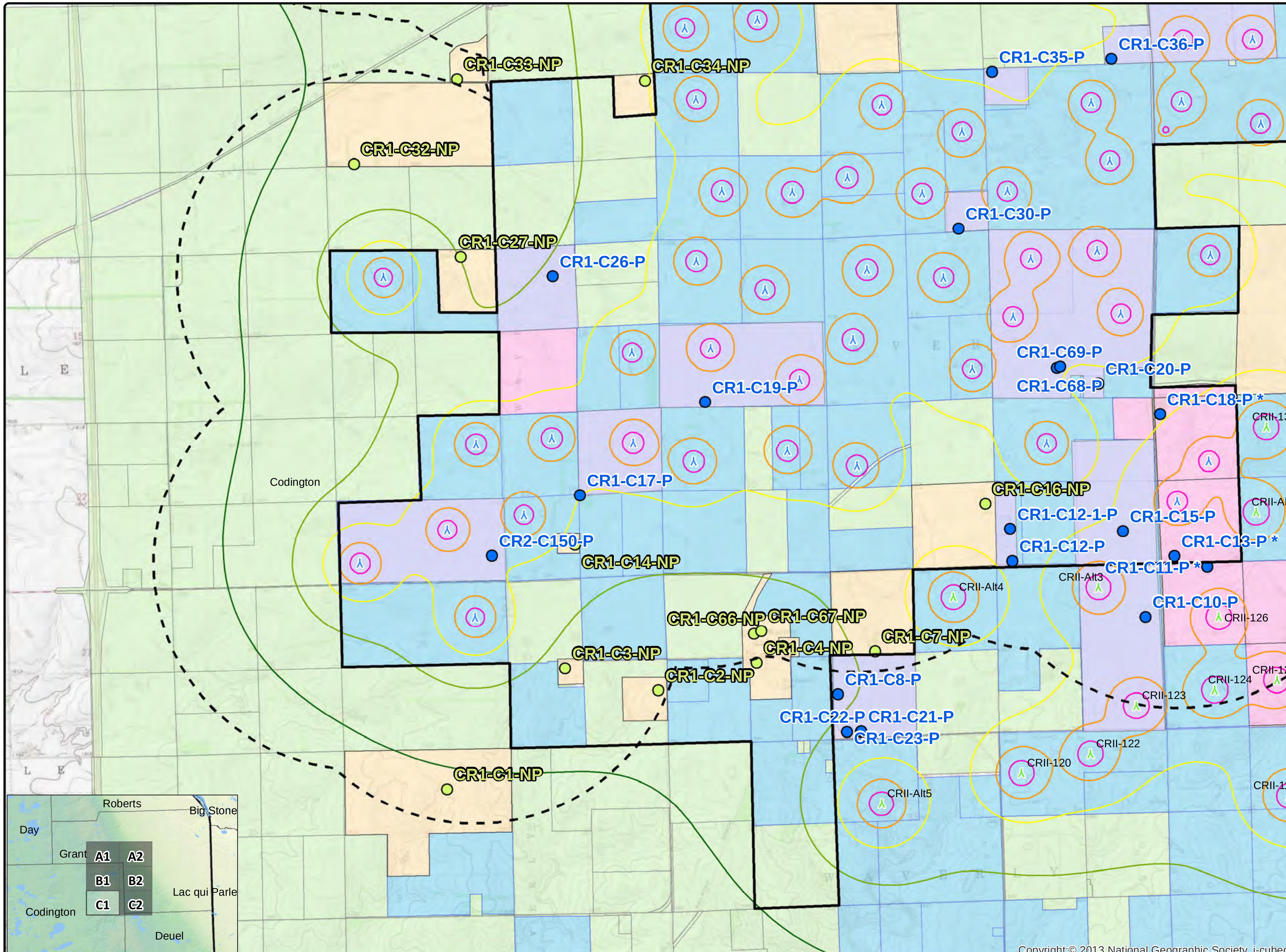
- Crowned Ridge Wind Turbines
- Crowned Ridge II Wind Turbines
- Dakota Range Wind Turbines
- 2 km Turbine Buffer
- County Lines
- CR1 Project Boundary
- Non Participants
- Participants
- <all other values>

Sound Pressure (dBA)

- 35
- 40
- 45
- 50
- 55
- Participating Codington Parcels
- Non-Participating Codington Parcels
- Participating Parcels
- Pending Parcels
- Non-Participating Parcels

N W E S

Exhibit A43-2



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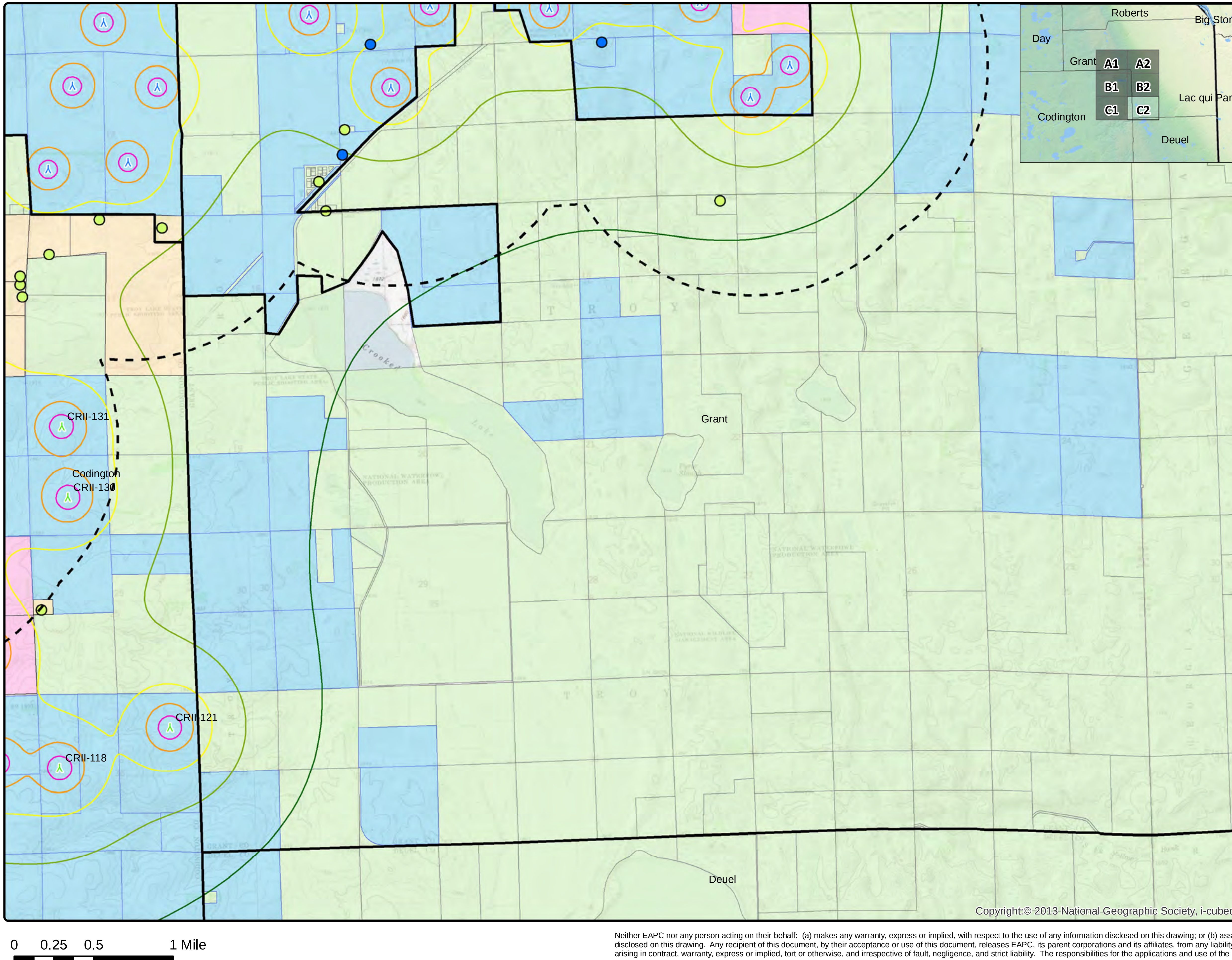
N W E S

Exhibit A43-2



EAPC WIND ENERGY

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Crowned Ridge Wind Farm Sound Pressure Iso-Lines Overview Map

Client

SWCA Environmental Consultants

Project Description

Wind turbine layout with occupied structures within 2 km as well as parcel boundaries.

Predicted sound pressure levels at existing residences and land parcel boundaries.

Additional 2 dBA added.

Location: Watertown, SD

Project #: 20174431

Issue Dates

#	Description	Date
1	Original	2019.05.24

Drawn By: AS *Checked By: JH*

Legend

- Crowned Ridge Wind Turbines
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- 2 km Turbine Buffer
- County Lines
- CR1 Project Boundary
- Non Participants
- Participants
- <all other values>

Sound Pressure (dBA)

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- Participating Codington Parcels
- Non-Participating Codington Parcels
- Participating Parcels
- Pending Parcels
- Non-Participating Parcels

N W E S

Table C-4: Crowned Ridge Sound Level Tabular Results Sorted by Sound Level
Realistic case sound results 25 ft from occupied structures perimeter
Results using GE 2.3-116-90 m HH, GE 2.3-116-80 m HH WTG's
UTM NAD83 Zone 14
Codington County

Receptor ID	Participation Status	Easting (m)	Northing (m)	Elevation AMSL (m)	Real Case Sound (dB(A))	Distance to Nearest Turbine (ft)
CR1-C41-NP	Non-P	665,053	4,992,084	576.1	45.0	2,359
CR1-C34-NP	Non-P	658,661	4,990,389	589.1	44.7	1,726
CR1-C52-NP	Non-P	654,924	4,995,231	603.0	44.7	1,883
CR1-C46-NP	Non-P	655,802	4,993,540	609.7	44.6	1,680
CR1-C9-NP	Non-P	665,352	4,985,004	609.0	44.5	1,621
CR1-C61-NP	Non-P	656,690	4,997,831	612.0	44.3	1,686
CR1-C107-NP	Non-P	656,811	4,999,855	598.8	44.1	1,401
CR1-C62-NP	Non-P	658,375	4,995,138	615.0	44.1	1,676
CR1-C44-NP	Non-P	665,076	4,993,095	578.2	44.0	2,155
CR1-C58-NP	Non-P	657,781	4,996,906	615.0	43.9	1,647
CR1-C14-NP	Non-P	657,982	4,985,894	609.0	43.5	1,880
CR1-C31-NP	Non-P	665,939	4,988,950	585.4	43.5	2,126
CR1-C16-NP	Non-P	661,960	4,986,288	606.0	43.3	2,736
CR1-C39-NP	Non-P	660,144	4,991,670	588.0	42.3	2,605
CR1-C105-NP	Non-P	658,372	5,001,257	601.5	42.2	2,549
CR1-C63-NP	Non-P	658,566	4,995,254	612.6	42.2	2,408
CR1-C28-NP	Non-P	665,429	4,988,598	590.8	42.1	2,831
CR1-C60-NP	Non-P	656,855	4,998,565	613.5	42.1	2,592
CR1-C70-NP	Non-P	665,135	4,988,293	595.7	42.1	3,540
CR1-C71-NP	Non-P	665,137	4,988,378	594.6	42.1	3,448
CR1-C72-NP	Non-P	665,158	4,988,170	595.2	42.1	3,776
CR1-C29-NP	Non-P	666,572	4,988,867	575.9	41.5	2,457
CR1-C40-NP	Non-P	657,865	4,991,818	583.8	41.5	2,690
CR1-C7-NP	Non-P	660,893	4,984,861	593.2	41.3	3,022
CR1-C38-NP	Non-P	660,639	4,991,557	597.0	41.0	3,474
CR1-C110-NP	Non-P	654,385	4,996,686	593.9	40.2	2,910
CR1-C27-NP	Non-P	656,876	4,988,683	583.0	40.1	2,549
CR1-C112-NP	Non-P	660,002	4,984,908	604.6	39.1	5,627
CR1-C67-NP	Non-P	659,789	4,985,057	606.0	39.0	5,791
CR1-C3-NP	Non-P	657,888	4,984,697	604.2	38.9	3,294
CR1-C5-NP	Non-P	659,958	4,984,794	605.2	38.9	5,659
CR1-C66-NP	Non-P	659,718	4,985,032	606.0	38.9	5,800
CR1-C4-NP	Non-P	659,744	4,984,749	605.9	38.5	5,981
CR1-C111-NP	Non-P	653,857	4,995,573	591.0	38.4	3,678
CR1-C2-NP	Non-P	658,791	4,984,483	601.6	37.4	6,273
CR1-C65-NP	Non-P	665,805	4,995,305	579.0	37.4	3,884
CR1-C33-NP	Non-P	656,839	4,990,404	569.8	37.3	6,719
CR1-C109-NP	Non-P	653,780	4,996,828	588.0	37.2	4,797
CR1-C32-NP	Non-P	655,843	4,989,581	568.6	37.0	3,714

*** Pending** **** Under Option but Likely to Expire / Not Re-sign**

Table C-4: Crowned Ridge Sound Level Tabular Results Sorted by Sound Level
Realistic case sound results 25 ft from occupied structures perimeter
Results using GE 2.3-116-90 m HH, GE 2.3-116-80 m HH WTG's
UTM NAD83 Zone 14
Codington County
continued

Receptor ID	Participation Status	Easting (m)	Northing (m)	Elevation AMSL (m)	Real Case Sound (dB(A))	Distance to Nearest Turbine (ft)
CR1-C54-NP	Non-P	663,421	4,995,376	583.4	36.5	5,351
CR1-C53-NP	Non-P	663,376	4,996,043	578.6	35.4	7,201
CR1-C45-NP	Non-P	653,390	4,993,503	573.0	35.1	5,673
CR1-C1-NP	Non-P	656,743	4,983,525	595.9	35.0	5,541
CR1-C11-P *	Participant	664,111	4,985,679	609.0	48.0	1,614
CR1-C30-P	Participant	661,699	4,988,957	615.0	47.9	1,614
CR1-C10-P	Participant	663,510	4,985,195	609.0	47.0	1,762
CR1-C13-P *	Participant	663,792	4,985,785	612.0	47.0	1,739
CR1-C50-P	Participant	656,806	4,994,388	621.0	46.8	1,591
CR1-C37-P **	Participant	663,563	4,991,342	605.1	46.5	1,631
CR1-C19-P	Participant	659,243	4,987,276	611.5	46.4	1,722
CR1-C36-P	Participant	663,181	4,990,600	615.0	46.3	1,532
CR2-C150-P	Participant	657,178	4,985,788	612.0	46.2	1,640
CR1-C15-P	Participant	663,291	4,986,026	615.0	46.1	1,952
CR1-C68-P	Participant	662,652	4,987,606	609.0	45.4	2,146
CR1-C69-P	Participant	662,685	4,987,619	609.0	45.4	2,185
CR1-C17-P	Participant	658,031	4,986,373	609.1	45.2	1,886
CR1-C57-P	Participant	656,628	4,995,266	615.0	45.0	1,568
CR1-C64-P	Participant	659,436	4,992,174	581.0	45.0	1,614
CR1-C18-P *	Participant	663,651	4,987,157	610.5	44.9	2,146
CR1-C48-P	Participant	664,247	4,993,646	588.0	44.8	1,847
CR1-C56-P	Participant	655,953	4,995,244	606.0	44.8	1,972
CR1-C42-P	Participant	659,458	4,992,229	580.0	44.7	1,801
CR1-C20-P	Participant	663,054	4,987,455	606.0	44.6	2,336
CR1-C12-P	Participant	662,222	4,985,736	603.0	44.4	2,201
CR1-C51-P	Participant	657,455	4,995,160	621.0	44.2	1,768
CR1-C35-P	Participant	662,025	4,990,475	609.0	44.0	2,123
CR1-C12-1-P	Participant	662,199	4,986,047	606.0	43.6	2,818
CR1-C59-P	Participant	661,548	5,000,754	584.1	42.9	1,644
CR1-C21-P	Participant	660,756	4,984,086	594.8	42.1	2,388
CR1-C22-P	Participant	660,755	4,984,082	594.8	42.1	2,375
CR1-C23-P	Participant	660,619	4,984,078	596.0	41.6	2,523
CR1-C26-P	Participant	657,767	4,988,493	597.0	40.6	3,484
CR1-C8-P	Participant	660,532	4,984,445	599.7	40.1	3,740
CR1-C47-P	Participant	662,825	4,993,508	613.8	39.5	3,750
CR1-C55-P *	Participant	660,914	4,995,169	607.9	39.5	3,360
CR1-C49-P	Participant	662,250	4,993,731	609.0	38.4	5,148
CR1-C6-P	Participant	662,989	4,995,228	599.8	36.5	6,102

*** Pending** **** Under Option but Likely to Expire / Not Re-sign**

Table C-4: Crowned Ridge Sound Level Tabular Results Sorted by Sound Level
Realistic case sound results 25 ft from occupied structures perimeter
Results using GE 2.3-116-90 m HH, GE 2.3-116-80 m HH WTG's
UTM NAD83 Zone 14
Grant County
continued

Receptor ID	Participation Status	Easting (m)	Northing (m)	Elevation AMSL (m)	Real Case Sound (dB(A))	Distance to Nearest Turbine (ft)
CR1-G68-NP	Non-P	669,159	4,993,632	564.7	43.0	2,113
CR1-G43-NP	Non-P	661,141	5,001,721	584.2	42.9	1,909
CR1-G125-NP	Non-P	668,289	5,000,643	543.0	42.8	1,716
CR1-G23-NP	Non-P	670,471	4,992,104	560.1	42.5	2,185
CR1-G16-NP	Non-P	668,419	4,989,861	576.0	41.8	2,070
CR1-G114-NP	Non-P	666,214	5,006,667	520.8	40.8	2,205
CR1-G34-NP	Non-P	671,320	4,995,798	531.0	40.8	2,238
CR1-G115-NP	Non-P	664,933	5,006,731	544.6	40.5	2,188
CR1-G113-NP	Non-P	666,228	5,005,549	537.0	40.3	2,746
CR1-G109-NP	Non-P	667,064	5,000,425	566.4	40.1	2,152
CR1-G26-NP	Non-P	672,589	4,993,869	531.0	39.9	3,140
CR1-G130-NP	Non-P	668,147	5,000,233	549.0	39.3	3,005
CR1-G44-NP	Non-P	661,781	5,001,732	583.7	39.2	3,123
CR1-G14-NP	Non-P	668,156	4,989,332	574.1	38.8	3,940
CR1-G42-NP	Non-P	670,566	4,997,097	518.9	38.1	3,819
CR1-G12-NP	Non-P	668,229	4,989,039	575.0	38.0	4,623
CR1-G13-NP	Non-P	672,216	4,989,142	558.0	37.2	3,576
CR1-G37-NP	Non-P	668,998	4,996,452	549.0	36.6	5,246
CR1-G36-NP	Non-P	673,559	4,996,344	498.1	35.5	6,211
CR1-G105-NP	Non-P	668,696	4,998,325	549.0	35.3	6,345
CR1-G117-NP	Non-P	663,801	5,005,084	581.3	35.3	4,501
CR1-G110-NP	Non-P	671,218	5,005,064	456.4	34.8	5,889
CR1-G22-NP	Non-P	674,670	4,991,955	527.6	34.8	5,781
CR1-G27-NP	Non-P	676,630	4,994,642	480.8	34.0	4,944
CR1-G77-NP	Non-P	676,031	4,992,629	503.1	33.2	5,728
CR1-G65-P	Participant	671,496	4,994,973	537.0	45.3	1,539
CR1-G18-P	Participant	668,678	4,990,722	585.0	45.1	1,585
CR1-G32-P	Participant	669,477	4,995,401	546.0	45.1	1,545
CR1-G21-P	Participant	666,766	4,991,807	577.1	44.9	1,555
CR1-G66-P	Participant	670,802	4,994,681	539.8	44.0	1,801
CR1-G25-P	Participant	671,391	4,992,858	549.0	43.8	1,804
CR1-G19-P	Participant	671,018	4,990,744	570.0	43.4	2,077
CR1-G28-P	Participant	673,113	4,994,772	514.1	43.2	1,614
CR1-G67-P	Participant	669,597	4,993,440	555.8	43.2	2,106
CR1-G128-P	Participant	670,242	5,001,314	513.0	42.9	2,612
CR1-G131-P	Participant	668,466	5,005,145	505.1	42.9	2,133
CR1-G124-P	Participant	669,843	5,000,605	525.0	42.7	1,791
CR1-G135-P	Participant	668,616	5,005,161	504.2	42.6	2,142

*** Pending** **** Under Option but Likely to Expire / Not Re-sign**

Table C-4: Crowned Ridge Sound Level Tabular Results Sorted by Sound Level
Realistic case sound results 25 ft from occupied structures perimeter
Results using GE 2.3-116-90 m HH, GE 2.3-116-80 m HH WTG's
UTM NAD83 Zone 14
Grant County
continued

Receptor ID	Participation Status	Easting (m)	Northing (m)	Elevation AMSL (m)	Real Case Sound (dB(A))	Distance to Nearest Turbine (ft)
CR1-G136-P	Participant	667,706	5,004,861	522.0	42.2	2,277
CR1-G138-P	Participant	664,809	5,006,456	549.0	41.8	1,824
CR1-G137-P	Participant	666,501	5,005,136	529.5	41.6	1,939
CR1-G149-P	Participant	669,284	5,003,283	503.2	41.0	2,815
CR1-G81-P	Participant	671,478	4,997,523	508.7	40.7	2,421
CR1-G132-P	Participant	669,098	5,004,948	501.0	40.6	2,703
CR1-G24-P	Participant	673,058	4,992,440	539.4	40.6	2,231
CR1-G15-P	Participant	668,396	4,989,607	576.0	40.1	2,746
CR1-G33-P	Participant	668,911	4,995,550	548.7	39.9	2,779
CR1-G139-P	Participant	668,199	5,008,062	475.9	39.8	2,612
CR1-G108-P	Participant	669,516	5,001,186	522.2	39.7	3,586
CR1-G59-P	Participant	675,755	4,994,888	488.3	39.6	2,605
CR1-G126-P	Participant	672,157	5,000,446	484.3	39.4	3,176
CR1-G127-P	Participant	669,534	4,999,939	533.9	38.8	3,369
CR1-G133-P	Participant	669,881	5,005,460	478.8	38.3	3,556
CR1-G41-P	Participant	671,563	4,997,050	497.7	37.9	3,983
CR1-G60-P	Participant	675,830	4,995,687	477.0	36.4	3,343
CR1-G129-P	Participant	673,111	4,997,703	477.8	36.3	4,153
CR1-G140-P	Participant	664,546	5,007,269	551.1	35.2	4,360
CR1-G38-P *	Participant	673,972	4,996,493	494.5	35.0	5,646

*** Pending** **** Under Option but Likely to Expire / Not Re-sign**

Table C-3: Crowned Ridge Sound Level Tabular Results Sorted by Sound Level
16 turbines removes as suggested by Mr. Hessler
Realistic case sound results at occupied structures
Results using GE 2.3-116-90 m HH, GE 2.3-116-80 m HH WTG's
UTM NAD83 Zone 14
Codington County

Receptor ID	Participation Status	Easting (m)	Northing (m)	Elevation AMSL (m)	Hessler Case Sound (dB(A))	Real Case Sound (dB(A))	Reduction (DB(A))	Distance to Nearest Turbine (ft)
CR1-C46-NP	Non-P	655,802	4,993,540	609.7	45.8	46.0	0.2	1,680
CR1-C58-NP	Non-P	657,781	4,996,906	615.0	44.8	45.1	0.3	1,647
CR1-C9-NP	Non-P	665,352	4,985,004	609.0	44.4	44.5	0.1	1,621
CR1-C107-NP	Non-P	656,811	4,999,855	598.8	43.9	44.0	0.1	1,401
CR1-C62-NP	Non-P	658,375	4,995,138	615.0	43.9	44.0	0.1	1,676
CR1-C16-NP	Non-P	661,960	4,986,288	606.0	43.2	43.3	0.1	2,736
CR1-C44-NP	Non-P	665,076	4,993,095	578.2	42.5	44.0	1.5	2,155
CR1-C41-NP	Non-P	665,053	4,992,084	576.1	42.4	45.0	2.6	2,359
CR1-C61-NP	Non-P	656,690	4,997,831	612.0	42.4	44.7	2.3	1,686
CR1-C105-NP	Non-P	658,372	5,001,257	601.5	42.1	42.2	0.1	2,549
CR1-C63-NP	Non-P	658,566	4,995,254	612.6	42.0	42.2	0.2	2,408
CR1-C72-NP	Non-P	665,158	4,988,170	595.2	41.5	42.1	0.6	3,776
CR1-C70-NP	Non-P	665,135	4,988,293	595.7	41.3	42.1	0.8	3,540
CR1-C71-NP	Non-P	665,137	4,988,378	594.6	41.2	42.1	0.9	3,448
CR1-C7-NP	Non-P	660,893	4,984,861	593.2	41.2	41.3	0.1	3,022
CR1-C60-NP	Non-P	656,855	4,998,565	613.5	41.1	42.4	1.3	2,592
CR1-C14-NP	Non-P	657,982	4,985,894	609.0	41.0	43.4	2.4	1,880
CR1-C40-NP	Non-P	657,865	4,991,818	583.8	40.5	41.5	1.0	2,690
CR1-C52-NP	Non-P	654,924	4,995,231	603.0	40.5	44.7	4.2	1,883
CR1-C28-NP	Non-P	665,429	4,988,598	590.8	40.4	42.1	1.7	2,831
CR1-C27-NP	Non-P	656,876	4,988,683	583.0	39.7	40.0	0.3	2,549
CR1-C31-NP	Non-P	665,939	4,988,950	585.4	39.7	43.4	3.7	2,126
CR1-C39-NP	Non-P	660,144	4,991,670	588.0	39.4	42.3	2.9	2,605
CR1-C38-NP	Non-P	660,639	4,991,557	597.0	39.3	41.0	1.7	3,474
CR1-C110-NP	Non-P	654,385	4,996,686	593.9	39.0	40.2	1.2	2,910
CR1-C112-NP	Non-P	660,002	4,984,908	604.6	38.9	39.1	0.2	5,627
CR1-C34-NP	Non-P	658,661	4,990,389	589.1	38.9	44.5	5.6	1,726
CR1-C67-NP	Non-P	659,789	4,985,057	606.0	38.8	39.0	0.2	5,791
CR1-C29-NP	Non-P	666,572	4,988,867	575.9	38.7	41.4	2.7	2,457
CR1-C5-NP	Non-P	659,958	4,984,794	605.2	38.7	38.9	0.2	5,659
CR1-C66-NP	Non-P	659,718	4,985,032	606.0	38.7	38.9	0.2	5,800
CR1-C3-NP	Non-P	657,888	4,984,697	604.2	38.3	38.8	0.5	3,294
CR1-C4-NP	Non-P	659,744	4,984,749	605.9	38.3	38.5	0.2	5,981
CR1-C2-NP	Non-P	658,791	4,984,483	601.6	37.0	37.4	0.4	6,273
CR1-C65-NP	Non-P	665,805	4,995,305	579.0	36.9	37.4	0.5	3,884
CR1-C32-NP	Non-P	655,843	4,989,581	568.6	36.6	37.1	0.5	3,714
CR1-C33-NP	Non-P	656,839	4,990,404	569.8	36.5	37.4	0.9	6,719
CR1-C111-NP	Non-P	653,857	4,995,573	591.0	36.4	38.4	2.0	3,678
CR1-C109-NP	Non-P	653,780	4,996,828	588.0	36.3	37.2	0.9	4,797

*** Pending** **** Under Option but Likely to Expire / Not Re-sign**

Table C-3: Crowned Ridge Sound Level Tabular Results Sorted by Sound Level
16 turbines removes as suggested by Mr. Hessler
Realistic case sound results at occupied structures
Results using GE 2.3-116-90 m HH, GE 2.3-116-80 m HH WTG's
UTM NAD83 Zone 14
Codington County
continued

Receptor ID	Participation Status	Easting (m)	Northing (m)	Elevation AMSL (m)	Hessler Case Sound (dB(A))	Real Case Sound (dB(A))	Reduction (DB(A))	Distance to Nearest Turbine (ft)
CR1-C54-NP	Non-P	663,421	4,995,376	583.4	36.0	36.5	0.5	5,351
CR1-C53-NP	Non-P	663,376	4,996,043	578.6	34.9	35.4	0.5	7,201
CR1-C1-NP	Non-P	656,743	4,983,525	595.9	34.6	34.9	0.3	5,541
CR1-C45-NP	Non-P	653,390	4,993,503	573.0	34.6	35.4	0.8	5,673
CR1-C11-P *	Participant	664,111	4,985,679	609.0	47.9	47.9	0.0	1,614
CR1-C30-P	Participant	661,699	4,988,957	615.0	47.8	47.9	0.1	1,614
CR1-C10-P	Participant	663,510	4,985,195	609.0	47.0	47.0	0.0	1,762
CR1-C13-P *	Participant	663,792	4,985,785	612.0	46.9	46.9	0.0	1,739
CR1-C50-P	Participant	656,806	4,994,388	621.0	46.7	46.8	0.1	1,591
CR1-C19-P	Participant	659,243	4,987,276	611.5	46.3	46.4	0.1	1,722
CR1-C37-P **	Participant	663,563	4,991,342	605.1	46.3	46.5	0.2	1,631
CR1-C15-P	Participant	663,291	4,986,026	615.0	46.1	46.1	0.0	1,952
CR1-C36-P	Participant	663,181	4,990,600	615.0	46.0	46.2	0.2	1,532
CR1-C68-P	Participant	662,652	4,987,606	609.0	45.3	45.4	0.1	2,146
CR1-C69-P	Participant	662,685	4,987,619	609.0	45.3	45.3	0.0	2,185
CR1-C18-P *	Participant	663,651	4,987,157	610.5	44.8	44.8	0.0	2,146
CR1-C57-P	Participant	656,628	4,995,266	615.0	44.6	44.9	0.3	1,568
CR1-C20-P	Participant	663,054	4,987,455	606.0	44.5	44.5	0.0	2,336
CR2-C150-P	Participant	657,178	4,985,788	612.0	44.5	46.1	1.6	1,640
CR1-C12-P	Participant	662,222	4,985,736	603.0	44.3	44.3	0.0	2,201
CR1-C48-P	Participant	664,247	4,993,646	588.0	44.3	44.7	0.4	1,847
CR1-C51-P	Participant	657,455	4,995,160	621.0	44.0	44.1	0.1	1,768
CR1-C56-P	Participant	655,953	4,995,244	606.0	44.0	44.8	0.8	1,972
CR1-C17-P	Participant	658,031	4,986,373	609.1	43.7	45.1	1.4	1,886
CR1-C35-P	Participant	662,025	4,990,475	609.0	43.7	43.9	0.2	2,123
CR1-C12-1-P	Participant	662,199	4,986,047	606.0	43.5	43.6	0.1	2,818
CR1-C59-P	Participant	661,548	5,000,754	584.1	42.7	42.7	0.0	1,644
CR1-C42-P	Participant	659,458	4,992,229	580.0	42.1	44.6	2.5	1,801
CR1-C22-P	Participant	660,755	4,984,082	594.8	42.0	42.0	0.0	2,375
CR1-C21-P	Participant	660,756	4,984,086	594.8	41.9	42.0	0.1	2,388
CR1-C64-P	Participant	659,436	4,992,174	581.0	41.6	44.9	3.3	1,614
CR1-C23-P	Participant	660,619	4,984,078	596.0	41.5	41.5	0.0	2,523
CR1-C26-P	Participant	657,767	4,988,493	597.0	40.2	40.6	0.4	3,484
CR1-C8-P	Participant	660,532	4,984,445	599.7	40.0	40.1	0.1	3,740
CR1-C55-P *	Participant	660,914	4,995,169	607.9	39.2	39.5	0.3	3,360
CR1-C47-P	Participant	662,825	4,993,508	613.8	38.9	39.5	0.6	3,750
CR1-C49-P	Participant	662,250	4,993,731	609.0	38.0	38.4	0.4	5,148
CR1-C6-P	Participant	662,989	4,995,228	599.8	36.0	36.5	0.5	6,102

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Table C-3: Crowned Ridge Sound Level Tabular Results Sorted by Sound Level
16 turbines removes as suggested by Mr. Hessler
Realistic case sound results at occupied structures
Results using GE 2.3-116-90 m HH, GE 2.3-116-80 m HH WTG's
UTM NAD83 Zone 14
Grant County
continued

Receptor ID	Participation Status	Easting (m)	Northing (m)	Elevation AMSL (m)	Hessler Case Sound (dB(A))	Real Case Sound (dB(A))	Reduction (DB(A))	Distance to Nearest Turbine (ft)
CR1-G43-NP	Non-P	661,141	5,001,721	584.2	42.8	43.0	0.2	1,909
CR1-G125-NP	Non-P	668,289	5,000,643	543.0	42.6	42.8	0.2	1,716
CR1-G68-NP	Non-P	669,159	4,993,632	564.7	40.8	43.0	2.2	2,113
CR1-G114-NP	Non-P	666,214	5,006,667	520.8	40.7	40.8	0.1	2,205
CR1-G34-NP	Non-P	671,320	4,995,798	531.0	40.5	40.8	0.3	2,238
CR1-G115-NP	Non-P	664,933	5,006,731	544.6	40.3	40.5	0.2	2,188
CR1-G23-NP	Non-P	670,471	4,992,104	560.1	40.3	42.6	2.3	2,185
CR1-G113-NP	Non-P	666,228	5,005,549	537.0	40.2	40.3	0.1	2,746
CR1-G109-NP	Non-P	667,064	5,000,425	566.4	39.9	40.1	0.2	2,152
CR1-G26-NP	Non-P	672,589	4,993,869	531.0	39.6	39.9	0.3	3,140
CR1-G130-NP	Non-P	668,147	5,000,233	549.0	39.2	39.3	0.1	3,005
CR1-G44-NP	Non-P	661,781	5,001,732	583.7	39.1	39.2	0.1	3,123
CR1-G16-NP	Non-P	668,419	4,989,861	576.0	38.2	41.8	3.6	2,070
CR1-G42-NP	Non-P	670,566	4,997,097	518.9	37.8	38.1	0.3	3,819
CR1-G14-NP	Non-P	668,156	4,989,332	574.1	37.1	38.8	1.7	3,940
CR1-G13-NP	Non-P	672,216	4,989,142	558.0	36.9	37.2	0.3	3,576
CR1-G12-NP	Non-P	668,229	4,989,039	575.0	36.6	38.0	1.4	4,623
CR1-G37-NP	Non-P	668,998	4,996,452	549.0	36.1	36.6	0.5	5,246
CR1-G36-NP	Non-P	673,559	4,996,344	498.1	35.3	35.5	0.2	6,211
CR1-G117-NP	Non-P	663,801	5,005,084	581.3	35.2	35.3	0.1	4,501
CR1-G105-NP	Non-P	668,696	4,998,325	549.0	35.0	35.3	0.3	6,345
CR1-G110-NP	Non-P	671,218	5,005,064	456.4	34.7	34.8	0.1	5,889
CR1-G22-NP	Non-P	674,670	4,991,955	527.6	34.6	34.8	0.2	5,781
CR1-G27-NP	Non-P	676,630	4,994,642	480.8	33.8	34.0	0.2	4,944
CR1-G77-NP	Non-P	676,031	4,992,629	503.1	33.0	33.2	0.2	5,728
CR1-G65-P	Participant	671,496	4,994,973	537.0	45.1	45.3	0.2	1,539
CR1-G32-P	Participant	669,477	4,995,401	546.0	44.6	45.1	0.5	1,545
CR1-G21-P	Participant	666,766	4,991,807	577.1	44.2	44.9	0.7	1,555
CR1-G66-P	Participant	670,802	4,994,681	539.8	43.6	44.0	0.4	1,801
CR1-G19-P	Participant	671,018	4,990,744	570.0	43.1	43.4	0.3	2,077
CR1-G28-P	Participant	673,113	4,994,772	514.1	42.9	43.2	0.3	1,614
CR1-G128-P	Participant	670,242	5,001,314	513.0	42.8	42.9	0.1	2,612
CR1-G131-P	Participant	668,466	5,005,145	505.1	42.8	42.9	0.1	2,133
CR1-G124-P	Participant	669,843	5,000,605	525.0	42.5	42.7	0.2	1,791
CR1-G135-P	Participant	668,616	5,005,161	504.2	42.4	42.6	0.2	2,142
CR1-G18-P	Participant	668,678	4,990,722	585.0	42.4	45.1	2.7	1,585
CR1-G136-P	Participant	667,706	5,004,861	522.0	42.1	42.2	0.1	2,277
CR1-G67-P	Participant	669,597	4,993,440	555.8	42.1	43.2	1.1	2,106

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Table C-3: Crowned Ridge Sound Level Tabular Results Sorted by Sound Level
16 turbines removes as suggested by Mr. Hessler
Realistic case sound results at occupied structures
Results using GE 2.3-116-90 m HH, GE 2.3-116-80 m HH WTG's
UTM NAD83 Zone 14
Grant County
continued

Receptor ID	Participation Status	Easting (m)	Northing (m)	Elevation AMSL (m)	Hessler Case Sound (dB(A))	Real Case Sound (dB(A))	Reduction (DB(A))	Distance to Nearest Turbine (ft)
CR1-G138-P	Participant	664,809	5,006,456	549.0	41.6	41.8	0.2	1,824
CR1-G137-P	Participant	666,501	5,005,136	529.5	41.4	41.6	0.2	1,939
CR1-G25-P	Participant	671,391	4,992,858	549.0	41.1	43.8	2.7	1,804
CR1-G149-P	Participant	669,284	5,003,283	503.2	40.9	41.0	0.1	2,815
CR1-G132-P	Participant	669,098	5,004,948	501.0	40.6	40.6	0.0	2,703
CR1-G81-P	Participant	671,478	4,997,523	508.7	40.5	40.7	0.2	2,421
CR1-G24-P	Participant	673,058	4,992,440	539.4	40.2	40.6	0.4	2,231
CR1-G108-P	Participant	669,516	5,001,186	522.2	39.7	39.7	0.0	3,586
CR1-G139-P	Participant	668,199	5,008,062	475.9	39.7	39.8	0.1	2,612
CR1-G59-P	Participant	675,755	4,994,888	488.3	39.4	39.6	0.2	2,605
CR1-G126-P	Participant	672,157	5,000,446	484.3	39.3	39.4	0.1	3,176
CR1-G33-P	Participant	668,911	4,995,550	548.7	39.2	39.9	0.7	2,779
CR1-G127-P	Participant	669,534	4,999,939	533.9	38.6	38.8	0.2	3,369
CR1-G133-P	Participant	669,881	5,005,460	478.8	38.3	38.3	0.0	3,556
CR1-G41-P	Participant	671,563	4,997,050	497.7	37.7	37.9	0.2	3,983
CR1-G15-P	Participant	668,396	4,989,607	576.0	37.5	40.1	2.6	2,746
CR1-G129-P	Participant	673,111	4,997,703	477.8	36.2	36.3	0.1	4,153
CR1-G60-P	Participant	675,830	4,995,687	477.0	36.2	36.4	0.2	3,343
CR1-G140-P	Participant	664,546	5,007,269	551.1	35.1	35.2	0.1	4,360
CR1-G38-P *	Participant	673,972	4,996,493	494.5	34.8	35.0	0.2	5,646

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Table C-1: Crowned Ridge Sound Level Tabular Results Sorted by Receptor ID
Realistic case sound results at land parcel boundaries and occupied structures
Results using GE 2.3-116-90 m HH, GE 2.3-116-80 m HH WTG's
UTM NAD83 Zone 14
Codington County

Receptor ID	Participation Status	Type	Easting (m)	Northing (m)	Elevation AMSL (m)	Real Case Sound (dB(A))	Distance to Nearest Turbine (ft)
CR1-C1-NP	Non-P	Boundary	657,276	4,983,921	590.3	36.5	4,258
CR1-C2-NP	Non-P	Boundary	658,435	4,984,609	601.8	37.7	5,036
CR1-C3-NP	Non-P	Boundary	657,812	4,984,785	603.4	39.4	2,936
CR1-C4-NP	Non-P	Boundary	659,890	4,985,620	605.2	40.5	3,914
CR1-C6-P	Participant	Boundary	663,383	4,994,502	591.0	38.5	3,878
CR1-C7-NP	Non-P	Boundary	661,266	4,985,387	591.0	46.6	1,253
CR1-C8-P	Participant	Boundary	661,277	4,984,852	597.0	43.1	2,139
CR1-C9-NP	Non-P	Boundary	665,462	4,985,115	609.0	45.0	1,079
CR1-C10-P	Participant	Boundary	662,869	4,985,477	601.7	52.2	610
CR1-C11-P *	Participant	Boundary	664,473	4,985,211	608.8	51.5	738
CR1-C12-P	Participant	Boundary	662,067	4,985,677	605.1	45.3	1,670
CR1-C13-P *	Participant	Boundary	664,431	4,986,195	615.0	54.0	574
CR1-C14-NP	Non-P	Boundary	657,803	4,986,003	609.0	46.1	1,191
CR1-C15-P	Participant	Boundary	663,047	4,985,700	612.9	51.1	722
CR1-C16-NP	Non-P	Boundary	661,642	4,985,677	597.0	48.8	948
CR1-C17-P	Participant	Boundary	658,819	4,986,842	611.4	49.7	1,837
CR1-C18-P *	Participant	Boundary	664,114	4,986,526	609.4	52.4	591
CR1-C19-P	Participant	Boundary	660,393	4,987,529	608.4	50.1	784
CR1-C20-P	Participant	Boundary	662,024	4,987,612	604.2	51.0	640
CR1-C26-P	Participant	Boundary	658,015	4,987,993	606.7	43.5	1,867
CR1-C27-NP	Non-P	Boundary	656,658	4,988,484	587.2	42.1	1,749
CR1-C28-NP	Non-P	Boundary	665,432	4,989,009	583.9	44.9	1,483
CR1-C29-NP	Non-P	Boundary	666,496	4,989,001	574.3	42.7	1,952
CR1-C30-P	Participant	Boundary	661,978	4,989,318	612.8	51.3	633
CR1-C31-NP	Non-P	Boundary	665,639	4,989,013	584.7	44.5	1,637
CR1-C32-NP	Non-P	Boundary	657,187	4,989,566	573.2	38.1	4,970
CR1-C33-NP	Non-P	Boundary	657,126	4,990,843	567.0	38.0	5,856
CR1-C34-NP	Non-P	Boundary	658,763	4,990,247	589.4	45.8	1,293
CR1-C35-P	Participant	Boundary	661,955	4,990,153	606.1	47.2	1,112
CR1-C36-P	Participant	Boundary	663,564	4,990,731	610.7	48.3	1,033
CR1-C37-P **	Participant	Boundary	663,879	4,990,574	594.0	51.1	699
CR1-C38-NP	Non-P	Boundary	660,955	4,990,468	591.2	47.3	1,027
CR1-C39-NP	Non-P	Boundary	659,741	4,991,242	583.3	48.5	856
CR1-C40-NP	Non-P	Boundary	658,706	4,991,231	579.8	44.9	1,555
CR1-C41-NP	Non-P	Boundary	664,801	4,991,929	578.8	46.1	1,585
CR1-C42-P	Participant	Boundary	659,828	4,992,807	580.1	51.1	604
CR1-C44-NP	Non-P	Boundary	665,447	4,992,972	578.1	44.4	1,824
CR1-C45-NP	Non-P	Boundary	653,821	4,993,552	573.0	36.7	4,291
CR1-C46-NP	Non-P	Boundary	655,910	4,993,469	609.0	45.1	561

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Table C-1: Crowned Ridge Sound Level Tabular Results Sorted by Receptor ID
Realistic case sound results at land parcel boundaries and occupied structures
Results using GE 2.3-116-90 m HH, GE 2.3-116-80 m HH WTG's
UTM NAD83 Zone 14
Codington County
continued

Receptor ID	Participation Status	Type	Easting (m)	Northing (m)	Elevation AMSL (m)	Real Case Sound (dB(A))	Distance to Nearest Turbine (ft)
CR1-C47-P	Participant	Boundary	663,454	4,992,888	612.0	46.8	1,076
CR1-C48-P	Participant	Boundary	664,262	4,992,514	586.6	53.6	410
CR1-C49-P	Participant	Boundary	662,224	4,993,664	609.0	38.5	5,105
CR1-C50-P	Participant	Boundary	656,239	4,994,042	618.0	49.6	984
CR1-C51-P	Participant	Boundary	657,753	4,994,889	620.0	51.5	564
CR1-C52-NP	Non-P	Boundary	654,986	4,995,398	603.0	45.8	1,335
CR1-C53-NP	Non-P	Boundary	664,171	4,995,340	580.5	37.4	4,009
CR1-C54-NP	Non-P	Boundary	663,495	4,995,329	582.9	36.6	5,075
CR1-C55-P *	Participant	Boundary	660,139	4,994,937	607.0	49.4	722
CR1-C56-P	Participant	Boundary	655,385	4,995,606	603.0	45.6	627
CR1-C57-P	Participant	Boundary	656,526	4,995,198	616.1	45.8	1,319
CR1-C58-NP	Non-P	Boundary	657,839	4,997,040	615.0	45.4	732
CR1-C59-P	Participant	Boundary	661,380	5,000,092	591.5	50.2	623
CR1-C60-NP	Non-P	Boundary	656,539	4,998,453	609.3	42.6	2,218
CR1-C61-NP	Non-P	Boundary	656,926	4,997,851	612.0	47.8	912
CR1-C62-NP	Non-P	Boundary	658,155	4,994,994	614.5	48.7	820
CR1-C63-NP	Non-P	Boundary	658,543	4,995,211	606.8	42.4	2,277
CR1-C64-P	Participant	Boundary	659,129	4,991,995	576.6	50.0	679
CR1-C65-NP	Non-P	Boundary	665,516	4,995,045	578.0	39.2	2,825
CR1-C70-NP	Non-P	Boundary	664,953	4,987,981	596.1	42.7	3,225
CR1-C71-NP	Non-P	Boundary	664,658	4,987,355	600.0	48.6	1,050
CR1-C105-NP	Non-P	Boundary	658,351	5,000,265	609.0	49.8	604
CR1-C107-NP	Non-P	Boundary	655,923	4,998,435	595.6	48.5	673
CR1-C109-NP	Non-P	Boundary	654,533	4,997,357	592.6	40.9	1,909
CR1-C110-NP	Non-P	Boundary	654,553	4,996,633	588.7	41.3	2,365
CR1-C111-NP	Non-P	Boundary	654,576	4,995,809	599.1	45.6	1,240
CR1-C112-NP	Non-P	Boundary	660,152	4,984,994	604.0	39.4	5,075
CR2-C150-P	Participant	Boundary	657,308	4,986,173	600.0	51.3	591
CR1-C1-NP	Non-P	Structure	656,743	4,983,525	596.0	34.9	5,541
CR1-C2-NP	Non-P	Structure	658,791	4,984,483	602.0	37.4	6,273
CR1-C3-NP	Non-P	Structure	657,888	4,984,697	604.2	38.8	3,294
CR1-C4-NP	Non-P	Structure	659,744	4,984,749	606.0	38.5	5,981
CR1-C5-NP	Non-P	Structure	659,958	4,984,794	604.8	38.9	5,659
CR1-C6-P	Participant	Structure	662,989	4,995,228	599.8	36.5	6,102
CR1-C7-NP	Non-P	Structure	660,893	4,984,861	593.2	41.3	3,022
CR1-C8-P	Participant	Structure	660,532	4,984,445	599.4	40.1	3,740
CR1-C9-NP	Non-P	Structure	665,352	4,985,004	609.0	44.5	1,621
CR1-C10-P	Participant	Structure	663,510	4,985,195	609.0	47.0	1,762

*** Pending** **** Under Option but Likely to Expire / Not Re-sign**

Table C-1: Crowned Ridge Sound Level Tabular Results Sorted by Receptor ID
Realistic case sound results at land parcel boundaries and occupied structures
Results using GE 2.3-116-90 m HH, GE 2.3-116-80 m HH WTG's
UTM NAD83 Zone 14
Codington County
continued

Receptor ID	Participation Status	Type	Easting (m)	Northing (m)	Elevation AMSL (m)	Real Case Sound (dB(A))	Distance to Nearest Turbine (ft)
CR1-C11-P *	Participant	Structure	664,111	4,985,679	609.0	47.9	1,614
CR1-C12-1-P	Participant	Structure	662,199	4,986,047	606.0	43.6	2,818
CR1-C12-P	Participant	Structure	662,222	4,985,736	603.0	44.3	2,201
CR1-C13-P *	Participant	Structure	663,792	4,985,785	612.0	46.9	1,739
CR1-C14-NP	Non-P	Structure	657,982	4,985,894	609.0	43.4	1,880
CR1-C15-P	Participant	Structure	663,291	4,986,026	615.0	46.1	1,952
CR1-C16-NP	Non-P	Structure	661,960	4,986,288	606.0	43.3	2,736
CR1-C17-P	Participant	Structure	658,031	4,986,373	609.1	45.1	1,886
CR1-C18-P *	Participant	Structure	663,651	4,987,157	610.4	44.8	2,146
CR1-C19-P	Participant	Structure	659,243	4,987,276	611.6	46.4	1,722
CR1-C20-P	Participant	Structure	663,054	4,987,455	606.0	44.5	2,336
CR1-C21-P	Participant	Structure	660,756	4,984,086	594.0	42.0	2,388
CR1-C22-P	Participant	Structure	660,755	4,984,082	594.0	42.0	2,375
CR1-C23-P	Participant	Structure	660,619	4,984,078	595.8	41.5	2,523
CR1-C26-P	Participant	Structure	657,767	4,988,493	597.0	40.6	3,484
CR1-C27-NP	Non-P	Structure	656,876	4,988,683	583.0	40.0	2,549
CR1-C28-NP	Non-P	Structure	665,429	4,988,598	590.9	42.1	2,831
CR1-C29-NP	Non-P	Structure	666,572	4,988,867	575.9	41.4	2,457
CR1-C30-P	Participant	Structure	661,699	4,988,957	615.0	47.9	1,614
CR1-C31-NP	Non-P	Structure	665,939	4,988,950	585.4	43.4	2,126
CR1-C32-NP	Non-P	Structure	655,843	4,989,581	568.8	37.0	3,714
CR1-C33-NP	Non-P	Structure	656,839	4,990,404	569.8	37.3	6,719
CR1-C34-NP	Non-P	Structure	658,661	4,990,389	588.2	44.5	1,726
CR1-C35-P	Participant	Structure	662,025	4,990,475	609.0	43.9	2,123
CR1-C36-P	Participant	Structure	663,181	4,990,600	615.0	46.2	1,532
CR1-C37-P **	Participant	Structure	663,563	4,991,342	605.1	46.5	1,631
CR1-C38-NP	Non-P	Structure	660,639	4,991,557	597.0	41.0	3,474
CR1-C39-NP	Non-P	Structure	660,144	4,991,670	588.0	42.2	2,605
CR1-C40-NP	Non-P	Structure	657,865	4,991,818	583.7	41.5	2,690
CR1-C41-NP	Non-P	Structure	665,053	4,992,084	576.1	45.0	2,359
CR1-C42-P	Participant	Structure	659,458	4,992,229	580.0	44.6	1,801
CR1-C44-NP	Non-P	Structure	665,076	4,993,095	578.2	44.0	2,155
CR1-C45-NP	Non-P	Structure	653,390	4,993,503	573.2	35.1	5,673
CR1-C46-NP	Non-P	Structure	655,802	4,993,540	609.1	44.4	1,680
CR1-C47-P	Participant	Structure	662,825	4,993,508	613.9	39.5	3,750
CR1-C48-P	Participant	Structure	664,247	4,993,646	588.0	44.7	1,847
CR1-C49-P	Participant	Structure	662,250	4,993,731	609.0	38.4	5,148
CR1-C50-P	Participant	Structure	656,806	4,994,388	621.0	46.8	1,591

*** Pending** **** Under Option but Likely to Expire / Not Re-sign**

Table C-1: Crowned Ridge Sound Level Tabular Results Sorted by Receptor ID
Realistic case sound results at land parcel boundaries and occupied structures
Results using GE 2.3-116-90 m HH, GE 2.3-116-80 m HH WTG's
UTM NAD83 Zone 14
Codington County
continued

Receptor ID	Participation Status	Type	Easting (m)	Northing (m)	Elevation AMSL (m)	Real Case Sound (dB(A))	Distance to Nearest Turbine (ft)
CR1-C51-P	Participant	Structure	657,455	4,995,160	621.0	44.1	1,768
CR1-C52-NP	Non-P	Structure	654,924	4,995,231	603.0	44.6	1,883
CR1-C53-NP	Non-P	Structure	663,376	4,996,043	578.8	35.3	7,201
CR1-C54-NP	Non-P	Structure	663,421	4,995,376	583.4	36.5	5,351
CR1-C55-P *	Participant	Structure	660,914	4,995,169	607.5	39.4	3,360
CR1-C56-P	Participant	Structure	655,953	4,995,244	606.5	44.7	1,972
CR1-C57-P	Participant	Structure	656,628	4,995,266	615.0	44.8	1,568
CR1-C58-NP	Non-P	Structure	657,781	4,996,906	615.0	43.7	1,647
CR1-C59-P	Participant	Structure	661,548	5,000,754	584.2	42.7	1,644
CR1-C60-NP	Non-P	Structure	656,855	4,998,565	613.5	42.1	2,592
CR1-C61-NP	Non-P	Structure	656,690	4,997,831	612.0	44.2	1,686
CR1-C62-NP	Non-P	Structure	658,375	4,995,138	615.0	44.0	1,676
CR1-C63-NP	Non-P	Structure	658,566	4,995,254	612.4	42.1	2,408
CR1-C64-P	Participant	Structure	659,436	4,992,174	581.0	44.9	1,614
CR1-C65-NP	Non-P	Structure	665,805	4,995,305	579.0	37.3	3,884
CR1-C66-NP	Non-P	Structure	659,718	4,985,032	606.0	38.9	5,800
CR1-C67-NP	Non-P	Structure	659,789	4,985,057	606.0	39.0	5,791
CR1-C68-P	Participant	Structure	662,652	4,987,606	609.0	45.4	2,146
CR1-C69-P	Participant	Structure	662,685	4,987,619	609.0	45.3	2,185
CR1-C70-NP	Non-P	Structure	665,135	4,988,293	595.9	42.1	3,540
CR1-C71-NP	Non-P	Structure	665,137	4,988,378	595.6	42.1	3,448
CR1-C72-NP	Non-P	Structure	665,158	4,988,170	594.6	42.1	3,776
CR1-C105-NP	Non-P	Structure	658,372	5,001,257	600.3	42.2	2,549
CR1-C107-NP	Non-P	Structure	656,811	4,999,855	598.8	43.9	1,401
CR1-C109-NP	Non-P	Structure	653,780	4,996,828	588.0	37.1	4,797
CR1-C110-NP	Non-P	Structure	654,385	4,996,686	593.9	40.2	2,910
CR1-C111-NP	Non-P	Structure	653,857	4,995,573	591.0	38.3	3,678
CR1-C112-NP	Non-P	Structure	660,002	4,984,908	604.6	39.0	5,627
CR2-C150-P	Participant	Structure	657,178	4,985,788	612.0	46.1	1,640

*** Pending** **** Under Option but Likely to Expire / Not Re-sign**

Table C-1: Crowned Ridge Sound Level Tabular Results Sorted by Receptor ID
Realistic case sound results at occupied structures
Results using GE 2.3-116-90 m HH, GE 2.3-116-80 m HH WTG's
UTM NAD83 Zone 14
Grant County
continued

Receptor ID	Participation Status	Type	Easting (m)	Northing (m)	Elevation AMSL (m)	Real Case Sound (dB(A))	Distance to Nearest Turbine (ft)
CR1-G12-NP	Non-P	Structure	668,229	4,989,039	575.0	38.0	4,623
CR1-G13-NP	Non-P	Structure	672,216	4,989,142	558.0	37.2	3,576
CR1-G14-NP	Non-P	Structure	668,156	4,989,332	574.1	38.8	3,940
CR1-G15-P	Participant	Structure	668,396	4,989,607	576.0	40.1	2,746
CR1-G16-NP	Non-P	Structure	668,419	4,989,861	576.0	41.8	2,070
CR1-G18-P	Participant	Structure	668,678	4,990,722	585.0	45.1	1,585
CR1-G19-P	Participant	Structure	671,018	4,990,744	570.0	43.4	2,077
CR1-G21-P	Participant	Structure	666,766	4,991,807	577.1	44.9	1,555
CR1-G22-NP	Non-P	Structure	674,670	4,991,955	527.6	34.8	5,781
CR1-G23-NP	Non-P	Structure	670,471	4,992,104	560.0	42.5	2,185
CR1-G24-P	Participant	Structure	673,058	4,992,440	539.4	40.6	2,231
CR1-G25-P	Participant	Structure	671,391	4,992,858	549.0	43.8	1,804
CR1-G26-NP	Non-P	Structure	672,589	4,993,869	531.0	39.9	3,140
CR1-G27-NP	Non-P	Structure	676,630	4,994,642	480.8	34.0	4,944
CR1-G28-P	Participant	Structure	673,113	4,994,772	513.9	43.2	1,614
CR1-G32-P	Participant	Structure	669,477	4,995,401	546.0	45.1	1,545
CR1-G33-P	Participant	Structure	668,911	4,995,550	548.7	39.9	2,779
CR1-G34-NP	Non-P	Structure	671,320	4,995,798	531.0	40.8	2,238
CR1-G36-NP	Non-P	Structure	673,559	4,996,344	498.0	35.5	6,211
CR1-G37-NP	Non-P	Structure	668,998	4,996,452	549.0	36.6	5,246
CR1-G38-P *	Participant	Structure	673,972	4,996,493	494.5	35.0	5,646
CR1-G41-P	Participant	Structure	671,563	4,997,050	497.6	37.9	3,983
CR1-G42-NP	Non-P	Structure	670,566	4,997,097	518.9	38.1	3,819
CR1-G43-NP	Non-P	Structure	661,141	5,001,721	583.6	42.9	1,909
CR1-G44-NP	Non-P	Structure	661,781	5,001,732	583.7	39.2	3,123
CR1-G59-P	Participant	Structure	675,755	4,994,888	487.7	39.6	2,605
CR1-G60-P	Participant	Structure	675,830	4,995,687	477.0	36.4	3,343
CR1-G65-P	Participant	Structure	671,496	4,994,973	537.0	45.3	1,539
CR1-G66-P	Participant	Structure	670,802	4,994,681	539.7	44.0	1,801
CR1-G67-P	Participant	Structure	669,597	4,993,440	556.1	43.2	2,106
CR1-G68-NP	Non-P	Structure	669,159	4,993,632	565.6	43.0	2,113
CR1-G77-NP	Non-P	Structure	676,031	4,992,629	502.7	33.2	5,728
CR1-G81-P	Participant	Structure	671,478	4,997,523	508.8	40.7	2,421
CR1-G105-NP	Non-P	Structure	668,696	4,998,325	549.0	35.3	6,345
CR1-G108-P	Participant	Structure	669,516	5,001,186	522.2	39.7	3,586
CR1-G109-NP	Non-P	Structure	667,064	5,000,425	566.2	40.1	2,152
CR1-G110-NP	Non-P	Structure	671,218	5,005,064	456.2	34.8	5,889
CR1-G113-NP	Non-P	Structure	666,228	5,005,549	537.0	40.3	2,746

*** Pending** **** Under Option but Likely to Expire / Not Re-sign**

Table C-1: Crowned Ridge Sound Level Tabular Results Sorted by Receptor ID
Realistic case sound results at occupied structures
Results using GE 2.3-116-90 m HH, GE 2.3-116-80 m HH WTG's
UTM NAD83 Zone 14
Grant County
continued

Receptor ID	Participation Status	Type	Easting (m)	Northing (m)	Elevation AMSL (m)	Real Case Sound (dB(A))	Distance to Nearest Turbine (ft)
CR1-G114-NP	Non-P	Structure	666,214	5,006,667	521.1	40.8	2,205
CR1-G115-NP	Non-P	Structure	664,933	5,006,731	544.6	40.5	2,188
CR1-G117-NP	Non-P	Structure	663,801	5,005,084	581.3	35.3	4,501
CR1-G124-P	Participant	Structure	669,843	5,000,605	525.0	42.7	1,791
CR1-G125-NP	Non-P	Structure	668,289	5,000,643	543.0	42.8	1,716
CR1-G126-P	Participant	Structure	672,157	5,000,446	484.3	39.4	3,176
CR1-G127-P	Participant	Structure	669,534	4,999,939	533.8	38.8	3,369
CR1-G128-P	Participant	Structure	670,242	5,001,314	513.0	42.9	2,612
CR1-G129-P	Participant	Structure	673,111	4,997,703	478.1	36.3	4,153
CR1-G130-NP	Non-P	Structure	668,147	5,000,233	549.0	39.3	3,005
CR1-G131-P	Participant	Structure	668,466	5,005,145	505.2	42.9	2,133
CR1-G132-P	Participant	Structure	669,098	5,004,948	501.0	40.6	2,703
CR1-G133-P	Participant	Structure	669,881	5,005,460	478.8	38.3	3,556
CR1-G135-P	Participant	Structure	668,616	5,005,161	504.0	42.6	2,142
CR1-G136-P	Participant	Structure	667,706	5,004,861	522.0	42.2	2,277
CR1-G137-P	Participant	Structure	666,501	5,005,136	529.3	41.6	1,939
CR1-G138-P	Participant	Structure	664,809	5,006,456	549.0	41.8	1,824
CR1-G139-P	Participant	Structure	668,199	5,008,062	476.2	39.8	2,612
CR1-G140-P	Participant	Structure	664,546	5,007,269	551.4	35.2	4,360
CR1-G149-P	Participant	Structure	669,284	5,003,283	503.2	41.0	2,815

Table C-2: Crowned Ridge Sound Level Tabular Results Sorted by Sound Level
Realistic case sound results at land parcel boundaries and occupied structures
Results using GE 2.3-116-90 m HH, GE 2.3-116-80 m HH WTG's
UTM NAD83 Zone 14
Codington County

Receptor ID	Participation Status	Type	Easting (m)	Northing (m)	Elevation AMSL (m)	Real Case Sound (dB(A))	Distance to Nearest Turbine (ft)
CR1-C105-NP	Non-P	Boundary	658,351	5,000,265	609.0	49.8	604
CR1-C16-NP	Non-P	Boundary	661,642	4,985,677	597.0	48.8	948
CR1-C62-NP	Non-P	Boundary	658,155	4,994,994	614.5	48.7	820
CR1-C71-NP	Non-P	Boundary	664,658	4,987,355	600.0	48.6	1,050
CR1-C107-NP	Non-P	Boundary	655,923	4,998,435	595.6	48.5	673
CR1-C39-NP	Non-P	Boundary	659,741	4,991,242	583.3	48.5	856
CR1-C61-NP	Non-P	Boundary	656,926	4,997,851	612.0	47.8	912
CR1-C38-NP	Non-P	Boundary	660,955	4,990,468	591.2	47.3	1,027
CR1-C7-NP	Non-P	Boundary	661,266	4,985,387	591.0	46.6	1,253
CR1-C14-NP	Non-P	Boundary	657,803	4,986,003	609.0	46.1	1,191
CR1-C41-NP	Non-P	Boundary	664,801	4,991,929	578.8	46.1	1,585
CR1-C34-NP	Non-P	Boundary	658,763	4,990,247	589.4	45.8	1,293
CR1-C52-NP	Non-P	Boundary	654,986	4,995,398	603.0	45.8	1,335
CR1-C111-NP	Non-P	Boundary	654,576	4,995,809	599.1	45.6	1,240
CR1-C58-NP	Non-P	Boundary	657,839	4,997,040	615.0	45.4	732
CR1-C46-NP	Non-P	Boundary	655,910	4,993,469	609.0	45.1	561
CR1-C9-NP	Non-P	Boundary	665,462	4,985,115	609.0	45.0	1,079
CR1-C28-NP	Non-P	Boundary	665,432	4,989,009	583.9	44.9	1,483
CR1-C40-NP	Non-P	Boundary	658,706	4,991,231	579.8	44.9	1,555
CR1-C31-NP	Non-P	Boundary	665,639	4,989,013	584.7	44.5	1,637
CR1-C44-NP	Non-P	Boundary	665,447	4,992,972	578.1	44.4	1,824
CR1-C29-NP	Non-P	Boundary	666,496	4,989,001	574.3	42.7	1,952
CR1-C70-NP	Non-P	Boundary	664,953	4,987,981	596.1	42.7	3,225
CR1-C60-NP	Non-P	Boundary	656,539	4,998,453	609.3	42.6	2,218
CR1-C63-NP	Non-P	Boundary	658,543	4,995,211	606.8	42.4	2,277
CR1-C27-NP	Non-P	Boundary	656,658	4,988,484	587.2	42.1	1,749
CR1-C110-NP	Non-P	Boundary	654,553	4,996,633	588.7	41.3	2,365
CR1-C109-NP	Non-P	Boundary	654,533	4,997,357	592.6	40.9	1,909
CR1-C4-NP	Non-P	Boundary	659,890	4,985,620	605.2	40.5	3,914
CR1-C112-NP	Non-P	Boundary	660,152	4,984,994	604.0	39.4	5,075
CR1-C3-NP	Non-P	Boundary	657,812	4,984,785	603.4	39.4	2,936
CR1-C65-NP	Non-P	Boundary	665,516	4,995,045	578.0	39.2	2,825
CR1-C32-NP	Non-P	Boundary	657,187	4,989,566	573.2	38.1	3,714
CR1-C33-NP	Non-P	Boundary	657,126	4,990,843	567.0	38.0	5,856
CR1-C2-NP	Non-P	Boundary	658,435	4,984,609	601.8	37.7	5,036
CR1-C53-NP	Non-P	Boundary	664,171	4,995,340	580.5	37.4	4,009
CR1-C45-NP	Non-P	Boundary	653,821	4,993,552	573.0	36.7	4,291
CR1-C54-NP	Non-P	Boundary	663,495	4,995,329	582.9	36.6	5,075
CR1-C1-NP	Non-P	Boundary	657,276	4,983,921	590.3	36.5	4,258

*** Pending** **** Under Option but Likely to Expire / Not Re-sign**

Table C-2: Crowned Ridge Sound Level Tabular Results Sorted by Sound Level
Realistic case sound results at land parcel boundaries and occupied structures
Results using GE 2.3-116-90 m HH, GE 2.3-116-80 m HH WTG's
UTM NAD83 Zone 14
Codington County
continued

Receptor ID	Participation Status	Type	Easting (m)	Northing (m)	Elevation AMSL (m)	Real Case Sound (dB(A))	Distance to Nearest Turbine (ft)
CR1-C13-P *	Participant	Boundary	664,431	4,986,195	615.0	54.0	1,739
CR1-C48-P	Participant	Boundary	664,262	4,992,514	586.6	53.6	410
CR1-C18-P *	Participant	Boundary	664,114	4,986,526	609.4	52.4	2,146
CR1-C10-P	Participant	Boundary	662,869	4,985,477	601.7	52.2	610
CR1-C11-P *	Participant	Boundary	664,473	4,985,211	608.8	51.5	1,614
CR1-C51-P	Participant	Boundary	657,753	4,994,889	620.0	51.5	564
CR1-C30-P	Participant	Boundary	661,978	4,989,318	612.8	51.3	1,614
CR2-C150-P	Participant	Boundary	657,308	4,986,173	600.0	51.3	1,640
CR1-C15-P	Participant	Boundary	663,047	4,985,700	612.9	51.1	1,952
CR1-C37-P **	Participant	Boundary	663,879	4,990,574	594.0	51.1	1,631
CR1-C42-P	Participant	Boundary	659,828	4,992,807	580.1	51.1	1,801
CR1-C20-P	Participant	Boundary	662,024	4,987,612	604.2	51.0	2,336
CR1-C59-P	Participant	Boundary	661,380	5,000,092	591.5	50.2	623
CR1-C19-P	Participant	Boundary	660,393	4,987,529	608.4	50.1	1,722
CR1-C64-P	Participant	Boundary	659,129	4,991,995	576.6	50.0	1,614
CR1-C17-P	Participant	Boundary	658,819	4,986,842	611.4	49.7	1,886
CR1-C50-P	Participant	Boundary	656,239	4,994,042	618.0	49.6	984
CR1-C55-P *	Participant	Boundary	660,139	4,994,937	607.0	49.4	3,360
CR1-C36-P	Participant	Boundary	663,564	4,990,731	610.7	48.3	1,532
CR1-C35-P	Participant	Boundary	661,955	4,990,153	606.1	47.2	2,123
CR1-C47-P	Participant	Boundary	663,454	4,992,888	612.0	46.8	3,750
CR1-C57-P	Participant	Boundary	656,526	4,995,198	616.1	45.8	1,568
CR1-C56-P	Participant	Boundary	655,385	4,995,606	603.0	45.6	1,972
CR1-C12-P	Participant	Boundary	662,067	4,985,677	605.1	45.3	1,670
CR1-C26-P	Participant	Boundary	658,015	4,987,993	606.7	43.5	3,484
CR1-C8-P	Participant	Boundary	661,277	4,984,852	597.0	43.1	3,740
CR1-C49-P	Participant	Boundary	662,224	4,993,664	609.0	38.5	5,148
CR1-C6-P	Participant	Boundary	663,383	4,994,502	591.0	38.5	3,878
CR1-C9-NP	Non-P	Structure	665,352	4,985,004	609.0	47.7	1,621
CR1-C41-NP	Non-P	Structure	665,053	4,992,084	576.1	45.0	2,359
CR1-C52-NP	Non-P	Structure	654,924	4,995,231	603.0	44.6	1,883
CR1-C34-NP	Non-P	Structure	658,661	4,990,389	588.2	44.5	1,726
CR1-C46-NP	Non-P	Structure	655,802	4,993,540	609.1	44.4	1,680
CR1-C61-NP	Non-P	Structure	656,690	4,997,831	612.0	44.2	1,686
CR1-C44-NP	Non-P	Structure	665,076	4,993,095	578.2	44.0	2,155
CR1-C62-NP	Non-P	Structure	658,375	4,995,138	615.0	44.0	1,676
CR1-C107-NP	Non-P	Structure	656,811	4,999,855	598.8	43.9	1,401
CR1-C58-NP	Non-P	Structure	657,781	4,996,906	615.0	43.7	1,647

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UTM NAD83 Zone 14
Codington County
continued

Receptor ID	Participation Status	Type	Easting (m)	Northing (m)	Elevation AMSL (m)	Real Case Sound (dB(A))	Distance to Nearest Turbine (ft)
CR1-C14-NP	Non-P	Structure	657,982	4,985,894	609.0	43.4	1,880
CR1-C31-NP	Non-P	Structure	665,939	4,988,950	585.4	43.4	2,126
CR1-C16-NP	Non-P	Structure	661,960	4,986,288	606.0	43.3	2,736
CR1-C105-NP	Non-P	Structure	658,372	5,001,257	600.3	42.2	2,549
CR1-C39-NP	Non-P	Structure	660,144	4,991,670	588.0	42.2	2,605
CR1-C28-NP	Non-P	Structure	665,429	4,988,598	590.9	42.1	2,831
CR1-C60-NP	Non-P	Structure	656,855	4,998,565	613.5	42.1	2,592
CR1-C63-NP	Non-P	Structure	658,566	4,995,254	612.4	42.1	2,408
CR1-C70-NP	Non-P	Structure	665,135	4,988,293	595.9	42.1	3,540
CR1-C71-NP	Non-P	Structure	665,137	4,988,378	595.6	42.1	3,448
CR1-C72-NP	Non-P	Structure	665,158	4,988,170	594.6	42.1	3,776
CR1-C40-NP	Non-P	Structure	657,865	4,991,818	583.7	41.5	2,690
CR1-C29-NP	Non-P	Structure	666,572	4,988,867	575.9	41.4	2,457
CR1-C7-NP	Non-P	Structure	660,893	4,984,861	593.2	41.3	3,022
CR1-C38-NP	Non-P	Structure	660,639	4,991,557	597.0	41.0	3,474
CR1-C110-NP	Non-P	Structure	654,385	4,996,686	593.9	40.2	2,910
CR1-C27-NP	Non-P	Structure	656,876	4,988,683	583.0	40.0	2,549
CR1-C112-NP	Non-P	Structure	660,002	4,984,908	604.6	39.0	5,627
CR1-C67-NP	Non-P	Structure	659,789	4,985,057	606.0	39.0	5,791
CR1-C5-NP	Non-P	Structure	659,958	4,984,794	604.8	38.9	5,659
CR1-C66-NP	Non-P	Structure	659,718	4,985,032	606.0	38.9	5,800
CR1-C3-NP	Non-P	Structure	657,888	4,984,697	604.2	38.8	3,294
CR1-C4-NP	Non-P	Structure	659,744	4,984,749	606.0	38.5	5,981
CR1-C111-NP	Non-P	Structure	653,857	4,995,573	591.0	38.3	3,678
CR1-C2-NP	Non-P	Structure	658,791	4,984,483	602.0	37.4	6,273
CR1-C33-NP	Non-P	Structure	656,839	4,990,404	569.8	37.3	6,719
CR1-C65-NP	Non-P	Structure	665,805	4,995,305	579.0	37.3	3,884
CR1-C109-NP	Non-P	Structure	653,780	4,996,828	588.0	37.1	4,797
CR1-C32-NP	Non-P	Structure	655,843	4,989,581	568.8	37.0	3,714
CR1-C54-NP	Non-P	Structure	663,421	4,995,376	583.4	36.5	5,351
CR1-C53-NP	Non-P	Structure	663,376	4,996,043	578.8	35.3	7,201
CR1-C45-NP	Non-P	Structure	653,390	4,993,503	573.2	35.1	5,673
CR1-C1-NP	Non-P	Structure	656,743	4,983,525	596.0	34.9	5,541
CR1-C11-P *	Participant	Structure	664,111	4,985,679	609.0	47.9	1,614
CR1-C30-P	Participant	Structure	661,699	4,988,957	615.0	47.9	1,614
CR1-C10-P	Participant	Structure	663,510	4,985,195	609.0	47.0	1,762
CR1-C13-P *	Participant	Structure	663,792	4,985,785	612.0	46.9	1,739
CR1-C50-P	Participant	Structure	656,806	4,994,388	621.0	46.8	1,591

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Realistic case sound results at land parcel boundaries and occupied structures
Results using GE 2.3-116-90 m HH, GE 2.3-116-80 m HH WTG's
UTM NAD83 Zone 14
Codington County
continued

Receptor ID	Participation Status	Type	Easting (m)	Northing (m)	Elevation AMSL (m)	Real Case Sound (dB(A))	Distance to Nearest Turbine (ft)
CR1-C37-P **	Participant	Structure	663,563	4,991,342	605.1	46.5	1,631
CR1-C19-P	Participant	Structure	659,243	4,987,276	611.6	46.4	1,722
CR1-C36-P	Participant	Structure	663,181	4,990,600	615.0	46.2	1,532
CR1-C15-P	Participant	Structure	663,291	4,986,026	615.0	46.1	1,952
CR2-C150-P	Participant	Structure	657,178	4,985,788	612.0	46.1	1,640
CR1-C68-P	Participant	Structure	662,652	4,987,606	609.0	45.4	2,146
CR1-C69-P	Participant	Structure	662,685	4,987,619	609.0	45.3	2,185
CR1-C17-P	Participant	Structure	658,031	4,986,373	609.1	45.1	1,886
CR1-C64-P	Participant	Structure	659,436	4,992,174	581.0	44.9	1,614
CR1-C18-P *	Participant	Structure	663,651	4,987,157	610.4	44.8	2,146
CR1-C57-P	Participant	Structure	656,628	4,995,266	615.0	44.8	1,568
CR1-C48-P	Participant	Structure	664,247	4,993,646	588.0	44.7	1,847
CR1-C56-P	Participant	Structure	655,953	4,995,244	606.5	44.7	1,972
CR1-C42-P	Participant	Structure	659,458	4,992,229	580.0	44.6	1,801
CR1-C20-P	Participant	Structure	663,054	4,987,455	606.0	44.5	2,336
CR1-C12-P	Participant	Structure	662,222	4,985,736	603.0	44.3	2,201
CR1-C51-P	Participant	Structure	657,455	4,995,160	621.0	44.1	1,768
CR1-C35-P	Participant	Structure	662,025	4,990,475	609.0	43.9	2,123
CR1-C12-1-P	Participant	Structure	662,199	4,986,047	606.0	43.6	2,818
CR1-C59-P	Participant	Structure	661,548	5,000,754	584.2	42.7	1,644
CR1-C21-P	Participant	Structure	660,756	4,984,086	594.0	42.0	2,388
CR1-C22-P	Participant	Structure	660,755	4,984,082	594.0	42.0	2,375
CR1-C23-P	Participant	Structure	660,619	4,984,078	595.8	41.5	2,523
CR1-C26-P	Participant	Structure	657,767	4,988,493	597.0	40.6	3,484
CR1-C8-P	Participant	Structure	660,532	4,984,445	599.4	40.1	3,740
CR1-C47-P	Participant	Structure	662,825	4,993,508	613.9	39.5	3,750
CR1-C55-P *	Participant	Structure	660,914	4,995,169	607.5	39.4	3,360
CR1-C49-P	Participant	Structure	662,250	4,993,731	609.0	38.4	5,148
CR1-C6-P	Participant	Structure	662,989	4,995,228	599.8	36.5	6,102

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Realistic case sound results at occupied structures
Results using GE 2.3-116-90 m HH, GE 2.3-116-80 m HH WTG's
UTM NAD83 Zone 14
Grant County
continued

Receptor ID	Participation Status	Type	Easting (m)	Northing (m)	Elevation AMSL (m)	Real Case Sound (dB(A))	Distance to Nearest Turbine (ft)
CR1-G68-NP	Non-P	Structure	669,159	4,993,632	565.6	43.0	2,113
CR1-G43-NP	Non-P	Structure	661,141	5,001,721	583.6	42.9	1,909
CR1-G125-NP	Non-P	Structure	668,289	5,000,643	543.0	42.8	1,716
CR1-G23-NP	Non-P	Structure	670,471	4,992,104	560.0	42.5	2,185
CR1-G16-NP	Non-P	Structure	668,419	4,989,861	576.0	41.8	2,070
CR1-G114-NP	Non-P	Structure	666,214	5,006,667	521.1	40.8	2,205
CR1-G34-NP	Non-P	Structure	671,320	4,995,798	531.0	40.8	2,238
CR1-G115-NP	Non-P	Structure	664,933	5,006,731	544.6	40.5	2,188
CR1-G113-NP	Non-P	Structure	666,228	5,005,549	537.0	40.3	2,746
CR1-G109-NP	Non-P	Structure	667,064	5,000,425	566.2	40.1	2,152
CR1-G26-NP	Non-P	Structure	672,589	4,993,869	531.0	39.9	3,140
CR1-G130-NP	Non-P	Structure	668,147	5,000,233	549.0	39.3	3,005
CR1-G44-NP	Non-P	Structure	661,781	5,001,732	583.7	39.2	3,123
CR1-G14-NP	Non-P	Structure	668,156	4,989,332	574.1	38.8	3,940
CR1-G42-NP	Non-P	Structure	670,566	4,997,097	518.9	38.1	3,819
CR1-G12-NP	Non-P	Structure	668,229	4,989,039	575.0	38.0	4,623
CR1-G13-NP	Non-P	Structure	672,216	4,989,142	558.0	37.2	3,576
CR1-G37-NP	Non-P	Structure	668,998	4,996,452	549.0	36.6	5,246
CR1-G36-NP	Non-P	Structure	673,559	4,996,344	498.0	35.5	6,211
CR1-G105-NP	Non-P	Structure	668,696	4,998,325	549.0	35.3	6,345
CR1-G117-NP	Non-P	Structure	663,801	5,005,084	581.3	35.3	4,501
CR1-G110-NP	Non-P	Structure	671,218	5,005,064	456.2	34.8	5,889
CR1-G22-NP	Non-P	Structure	674,670	4,991,955	527.6	34.8	5,781
CR1-G27-NP	Non-P	Structure	676,630	4,994,642	480.8	34.0	4,944
CR1-G77-NP	Non-P	Structure	676,031	4,992,629	502.7	33.2	5,728
CR1-G65-P	Participant	Structure	671,496	4,994,973	537.0	45.3	1,539
CR1-G18-P	Participant	Structure	668,678	4,990,722	585.0	45.1	1,585
CR1-G32-P	Participant	Structure	669,477	4,995,401	546.0	45.1	1,545
CR1-G21-P	Participant	Structure	666,766	4,991,807	577.1	44.9	1,555
CR1-G66-P	Participant	Structure	670,802	4,994,681	539.7	44.0	1,801
CR1-G25-P	Participant	Structure	671,391	4,992,858	549.0	43.8	1,804
CR1-G19-P	Participant	Structure	671,018	4,990,744	570.0	43.4	2,077
CR1-G28-P	Participant	Structure	673,113	4,994,772	513.9	43.2	1,614
CR1-G67-P	Participant	Structure	669,597	4,993,440	556.1	43.2	2,106
CR1-G128-P	Participant	Structure	670,242	5,001,314	513.0	42.9	2,612
CR1-G131-P	Participant	Structure	668,466	5,005,145	505.2	42.9	2,133
CR1-G124-P	Participant	Structure	669,843	5,000,605	525.0	42.7	1,791
CR1-G135-P	Participant	Structure	668,616	5,005,161	504.0	42.6	2,142

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Realistic case sound results at occupied structures
Results using GE 2.3-116-90 m HH, GE 2.3-116-80 m HH WTG's
UTM NAD83 Zone 14
Grant County
continued

Receptor ID	Participation Status	Type	Easting (m)	Northing (m)	Elevation AMSL (m)	Real Case Sound (dB(A))	Distance to Nearest Turbine (ft)
CR1-G136-P	Participant	Structure	667,706	5,004,861	522.0	42.2	2,277
CR1-G138-P	Participant	Structure	664,809	5,006,456	549.0	41.8	1,824
CR1-G137-P	Participant	Structure	666,501	5,005,136	529.3	41.6	1,939
CR1-G149-P	Participant	Structure	669,284	5,003,283	503.2	41.0	2,815
CR1-G81-P	Participant	Structure	671,478	4,997,523	508.8	40.7	2,421
CR1-G132-P	Participant	Structure	669,098	5,004,948	501.0	40.6	2,703
CR1-G24-P	Participant	Structure	673,058	4,992,440	539.4	40.6	2,231
CR1-G15-P	Participant	Structure	668,396	4,989,607	576.0	40.1	2,746
CR1-G33-P	Participant	Structure	668,911	4,995,550	548.7	39.9	2,779
CR1-G139-P	Participant	Structure	668,199	5,008,062	476.2	39.8	2,612
CR1-G108-P	Participant	Structure	669,516	5,001,186	522.2	39.7	3,586
CR1-G59-P	Participant	Structure	675,755	4,994,888	487.7	39.6	2,605
CR1-G126-P	Participant	Structure	672,157	5,000,446	484.3	39.4	3,176
CR1-G127-P	Participant	Structure	669,534	4,999,939	533.8	38.8	3,369
CR1-G133-P	Participant	Structure	669,881	5,005,460	478.8	38.3	3,556
CR1-G41-P	Participant	Structure	671,563	4,997,050	497.6	37.9	3,983
CR1-G60-P	Participant	Structure	675,830	4,995,687	477.0	36.4	3,343
CR1-G129-P	Participant	Structure	673,111	4,997,703	478.1	36.3	4,153
CR1-G140-P	Participant	Structure	664,546	5,007,269	551.1	35.2	4,360
CR1-G38-P *	Participant	Structure	673,972	4,996,493	494.5	35.0	5,646

BEFORE THE PUBLIC UTILITIES COMMISSION
OF THE STATE OF SOUTH DAKOTA

IN THE MATTER OF THE APPLICATION OF
CROWNED RIDGE WIND, LLC FOR A FACILITIES PERMIT TO
CONSTRUCT A 300 MEGAWATT WIND FACILITY

Docket No. EL19-003

SUPPLEMENTAL TESTIMONY

OF TYLER WILHELM AND SAM MASSEY

May 24, 2019

INTRODUCTION

Q. PLEASE STATE YOUR NAMES AND BUSINESS ADDRESS.

A. Tyler Wilhelm and Sam Massey. Our business address is 700 Universe Blvd., Juno Beach, Florida, 33408.

Q. BY WHOM ARE YOU EMPLOYED AND IN WHAT CAPACITY?

A. We are both employed by NextEra Energy Resources, LLC. Mr. Wilhelm is a Project Manager of Renewable Development, while Mr. Massey is Director of Renewable Development.

Q. WHAT ARE YOUR RESPONSIBILITIES?

A. Together, we are responsible for the development, permitting, community outreach, regulatory compliance, and meeting the commercial operations date for the up to 300 megawatt Crowned Ridge Wind, LLC ("CRW") generation project ("Project").

Q. ARE YOU THE SAME TYLER WILHELM AND SAM MASSEY WHO SUBMITTED DIRECT TESTIMONY IN THIS PROCEEDING ON JANUARY 30, 2019 AND SUPPLEMENTAL TESTIMONY ON APRIL 10, 2019?

A. Yes.

Q. HAS THIS TESTIMONY BEEN PREPARED BY YOU OR UNDER YOUR DIRECT SUPERVISION?

A. Yes.

TESTIMONY

Q. PLEASE DESCRIBE THE PURPOSE OF THE TESTIMONY.

A. The purpose of our testimony is to address the direct testimony of Staff witness Darren Kearney, Staff witness David Hessler, Intervenor John Thompson, and Intervenors' proposed conditions as set forth in Staff witness Darren Kearney's Direct Testimony, Exhibit DK-8.

Shadow/Flicker Waiver

Q. STAFF WITNESS KEARNEY'S TESTIMONY AT PAGE 10, LINES 22-33 STATES THAT IF CRW CANNOT OBTAIN A WAIVER FOR A NON-PARTICIPATING RECEPTOR (CR1-C61-NP), WHO IS EXPECTED TO EXPERIENCE 49 HOURS AND 6 MINUTES OF SHADOW FLICKER PER YEAR, CRW SHOULD ELIMINATE THE USE OF THE WIND TURBINE CAUSING THE SHADOW/FLICKER OR AUTOMATICALLY CONTROL THE TURBINE SO THAT THE RECEPTOR DOES NOT EXPERIENCE OVER 30 HOURS OF SHADOW/FLICKER PER YEAR. WITNESS KEARNEY ALSO REQUESTS THAT CRW PROVIDE IN REBUTTAL TESTIMONY THE FINAL PLAN FOR LIMITING SHADOW/FLICKER AT RECEPTOR (CR1-C61-NP). WHAT IS YOUR FINAL PLAN FOR LIMITING SHADOW/FLICKER AT THE RECEPTOR IN QUESTION?

A. For this receptor, if a waiver is not obtained by the issuance of the Commission's final order in this proceeding, CRW's final plan will be to curtail turbine CR-16 by approximately 20 hours on an annual basis to avoid shadow flicker in excess of 30 hours/year on receptor CR1-C61-NP.

Q. STAFF WITNESS KEARNEY'S TESTIMONY AT PAGE 11, LINES 9-12 REQUESTS THAT CRW SUBMIT A MITIGATION STRATEGY FOR PARTICIPATING RECEPTOR (CR1-C106-P). WHAT IS THE MITIGATION STRATEGY?

A. The landowner has confirmed that this receptor is an unoccupied structure. The structure has been vacant for over 40 years and the landowner plans to remove the structure once allowed by the local fire department. See Exhibit TW-SM-R-1. Given the receptor is an unoccupied structure that will be removed, no mitigation is necessary.

Status of County Permits

Q. STAFF WITNESS KEARNEY'S TESTIMONY AT PAGES 13-15 PROVIDES AN OVERVIEW OF THE COUNTY PERMITTING OF CRW AND REQUEST A STATUS UPDATE. HAS CRW OBTAINED ALL PERMITS NEEDED FROM GRANT COUNTY TO CONSTRUCT THE CROWNED RIDGE WIND FACILITY?

A. Yes. The required Grant County Permits have been issued and remain in effect. CRW was issued a Conditional Use Permit ("CUP") on December 17, 2018, for a wind energy system in Grant County, South Dakota. Certain individuals have appealed the issuance of the CUP by filing a Petition for Writ of Certiorari dated January 17, 2019. The Writ has been issued and the Return to the Writ was served April 2, 2019. The matter remains pending in Circuit Court.

Cattle Ridge Wind Farm, LLC was issued a Conditional Use Permit for the remaining footprint of the Crowned Ridge Wind project within Grant County on April 8, 2019. Findings of Fact were entered April 18, 2019, and to date we have not been informed of an appeal.

Q. HAS CROWNED RIDGE WIND OBTAINED ALL PERMITS NEEDED FROM CODINGTON COUNTY TO CONSTRUCT THE CROWNED RIDGE WIND FACILITY?

A. Yes. The required Codington County Permits have been issued and remain in effect. CRW was issued a CUP for the wind energy project within Codington County on July 16, 2018. Certain individuals appealed the issuance of the CUP by Petition for Writ of Certiorari. Hearing on the Writ has been held and a decision denying the appeal was entered and filed by the Circuit Court on March 22, 2019. Findings of Fact and Conclusions of Law were signed by the Court April 30, 2019, and no appeal therefrom has been served to date.

Decommissioning Condition

Q. STAFF WITNESS KEARNEY'S TESTIMONY AT PAGE 24, LINE 26 THROUGH PAGE 25, LINE 11 ASSERTS THAT IT IS MORE PRACTICABLE FOR THE COUNTIES OF GRANT AND CODINGTON TO ACCEPT THE DECOMMISSIONING ESCROW ACCOUNT ESTABLISHED BY THE

COMMISSION, BECAUSE OF THE DIFFERENCES IN THE TWO COUNTIES APPROACHES. DO YOU AGREE?

A. Yes, CRW agrees with this approach and will engage with Grant and Codington Counties about establishing a uniform escrow agreement that includes requirements consistent with the Commission's goals. However, the project does not have the ability to require either county to accept escrow requirements outside of or beyond their existing requirements, so establishing a uniform escrow agreement will ultimately be contingent on approval from both counties. CRW has recently engaged Grant County to provide the decommissioning financial security required prior to the start of construction. In the event a uniform escrow agreement is accepted, then CRW will request that the uniform escrow agreement be taken into consideration and ultimately as this financial security is likely to be in place prior to uniform escrow agreement, if adopted.

Sound Study

Q. STAFF WITNESS HESSLER'S TESTIMONY AT PAGE 5 LINES 17 TO PAGE 6 LINE 5 CLAIMS THAT CRW SHOULD MOVE 16 PRIMARY TURBINE LOCATIONS TO ALTERNATIVE LOCATIONS TO REDUCE THE DBA FOR NON-PARTICIPANTS FROM A RANGE OF 43-45 DBA TO 41 OR 42 DBA. IN DOING SO, HE INFERS THAT THESE RELOCATIONS CAN BE COMPLETED WITHOUT AFFECTING THE TOTAL POWER PRODUCT OR ECONOMICS OF THE PROJECT. DO YOU AGREE WITH HIS INFERENCE?

A. No. A significant part of the development process involved discussing primary turbine locations with landowners to engineer access roads and collection in a manner that is compatible with existing farming operations to the extent practicable. To adopt Mr. Hessler's recommendation would essentially eliminate the development work with these landowners for no material benefit.

Also, as shown in the Rebuttal Testimony of Jay Haley, the CRW wind project, as designed, does not exceed 45 dBA at the residence of a non-participant nor 50 dBA at the residence of a participant. Using this data, the Rebuttal Testimony of CRW witnesses Chris Ollson and Robert McCunney shows that there are no material health, welfare, or reduction of complaints or annoyance for a sound level below 45 dBA, which demonstrates that there is no material benefit to the non-participants if Mr. Hessler's recommendation is adopted.

Further, there are economic impacts to CRW if Mr. Hessler's recommendation is adopted. For example, the economic impact of using the turbines identified by Mr. Hessler is substantial since these alternate locations would require incremental collection costs in the range of \$2.5 - \$3.5 million to connect these northern most turbines to the centralized project substation. Additionally, the use of 16 alternative turbines for this purpose would effectively exhaust our alternative turbine locations, which could limit the amount of turbines constructed should unexpected conditions be found at the alternative turbine locations or at other primary turbine locations not impacted by Hessler's recommendation.

<u>Non-Participant</u>

Q. INTERVENOR WITNESS THOMPSON TESTIFIED THAT THE CRW MAP 3A SHOWING WHO HAS SIGNED EASEMENTS IS NOT CORRECT, BECAUSE IT SHOWS HIM AS SIGNING AN EASEMENT AGREEMENT AND HE HAS NOT SIGNED AN EASEMENT AGREEMENT. PLEASE EXPLAIN WHY MR. THOMPSON WAS INCLUDED ON THE MAP WHEN HE HAD NOT SIGNED AN EASEMENT AGREEMENT.

A. When the Cattle Ridge Wind Farm, LLC ("Cattle Ridge Wind") was acquired, Cattle Ridge Wind represented to CRW that the Thompson properties were participating in the project. Although James Thompson stated in an email message that the CRW planning map should not show the Thompson proprieties as participating and hosting collector lines, Mr. Wilhelm received a voice mail message from Cheryl Thompson, James Thompson's mother, expressing an interest in participating in the project. Mr. Wilhelm and John Thompson also discussed participation in the project. In response to these inquiries, Russel Lloyd, a land agent for CRW, sent draft easement option documents to the Thompsons. On April 4, 2019, as a follow-up, Mr. Lloyd sent an email to James, John, and Cheryl Thompson seeking to have a call to discuss the easement material. John Thompson emailed back "I don't think we are interested and are busy. It was at that time that Mr. Wilhelm understood the Thompson's were not interested in participating. He then started working with the CRW team to re-locate the planned collector lines off of the Thompson's properties. Mr. Wilhelm also worked with the CRW team to conduct an overall update of the CRW Maps, including Map 3, for land status changes and minor adjustments to project infrastructure to accommodate participating landowners. The task of moving the collector lines off the Thompson's properties was completed on May 14, 2019 and the task of updating the CRW Maps was completed on May 23, 2019. On May 23, 2019, the CRW Maps were filed in the docket, which showed the Thompson properties as not participating, and, also, showed that there will be no collector lines located on the Thompson's properties. Map 3 is also attached to this testimony as Exhibit TW-SM-R-2.

Q. WHERE THERE OTHER UPDATES TO CRW MAPS?

A. Yes, the following updates were made to Exhibit TW-SM-R-2 as well as to other CRW Maps filed on May 23, 2019:

1) Revisions to property land statuses. These changes take into account properties where easement option agreements have expired and are subject to renewal (shown as pending on Exhibit TW-SM-R-2), an easement option agreement that will expire prior to the construction of the project that is likely not to be renewed.

2) Minor refinements to locations of project infrastructure. Notable changes to project infrastructure include (a) the shift of collection from the Thompson property, the removal of collection; (b) removal of a temporary construction easement from the Stricherz property located in Section 22, addition to adjacent property; (c) proposed shifts to access roads for turbines CR-122 through CR-126 at the requests of landowners; (d) minor revisions to collection routing were made on properties throughout the Project, which include collection routing identified at

met tower SM01, turbine CR-105, between turbines CR-112 and CR-114, CR-115, CR-116, CR-163, CR- ALT7 and between CR-ALT20 and CR-ALT22.

Intervenors' Proposed Conditions

Q. THE INTERVENORS' PROPOSED CONDITION 1 (KEARNEY EXHIBIT DK-8) WOULD REQUIRE A "2 MILE SETBACK FROM ALL NON-PARTICIPATING LANDOWNERS." DO YOU AGREE WITH THIS PROPOSED CONDITION?

A. No. A 2-mile setback to all non-participating landowners would eliminate all 130 turbines in the project. Also, as shown in the rebuttal testimony of CRW witnesses Ollson, McCunney, Haley, and Lampeter, such a setback is not supported from a technical, health, or welfare standpoint. Therefore, CRW does not agree it is appropriate for adoption.

Q. THE INTERVENORS' PROPOSED CONDITION 2 (KEARNEY EXHIBIT DK-8) WOULD REQUIRE A "2 MILE SETBACK FROM THE WAVERLY SCHOOL." DO YOU AGREE WITH THIS PROPOSED CONDITION?

A. No. As currently designed, the closest CRW project turbine to the Waverly School is turbine CR1-94, which is 6,207 feet away. Implementation of a 2-mile setback to the Waverly School would eliminate 13 turbine locations and would impose an unnecessary commercial burden on the Applicant. In addition, as shown in the rebuttal testimony of CRW witnesses Ollson, McCunney, Haley, and Lampeter, such a setback is not supported from a technical, health, or welfare standpoint. Therefore, CRW does not agree it is appropriate for adoption.

Q. THE INTERVENORS' PROPOSED CONDITION 9 (KEARNEY EXHIBIT DK-8) WOULD REQUIRE AIRCRAFT DETECTION LIGHTING SYSTEMS BE USED IMMEDIATELY UPON OPERATION." DO YOU AGREE WITH THIS PROPOSED CONDITION?

A. No. The Federal Aviation Administration ("FAA") has sole jurisdiction and authority over the approval and implementation of Aircraft Detection Lighting Systems ("ADLS"). CRW cannot comply with this proposed condition since it cannot compel the FAA to approve of the use of ADLS. As stated in the supplemental responses to intervenors and staff data requests, the Applicant intends to utilize ADLS technology for the Project. The Applicant is currently working with vendors to establish design requirements and will apply with the FAA for use of ADLS, once the FAA first provides its initial determination of no hazard which is expected in July 2019.

Also, CRW's plan to implement the use of ADLS, if approved by the FAA, is consistent with the requirements in both the Grant and Codington County local ordinances, "Subject to FAA approval, applicants will install an ADLS within one (1) year of approval by FAA for the specified project. In the event FAA does not approve an ADLS system, the turbine owner will comply with all lighting and markings otherwise required by FAA." Therefore, for these reasons, the Commission should not adopt this proposed condition.

Q. THE INTERVENORS' PROPOSED CONDITION 18 (KEARNEY EXHIBIT DK-8) WOULD REQUIRE "NO FLICKER SHALL BE ALLOWED TO CROSS NON-PARTICIPATING LANDOWNER'S PROPERTY LINE." DO YOU AGREE WITH THIS PROPOSED CONDITION?

A. No. This proposed condition is unnecessary because the project will comply with all shadow flicker requirements. As shown in the rebuttal testimony of CRW witnesses Ollson, McCunney, Haley, and Lampeter, such a condition is not supported from a technical, health, or welfare standpoint. Therefore, CRW does not agree it is appropriate for adoption. Additionally, this proposed condition is unduly burdensome because, if implemented, it would eliminate 80 turbines from the project.

Q. THE INTERVENORS' PROPOSED CONDITION 21 (KEARNEY EXHIBIT DK-8) WOULD REQUIRE "THE PUC SHALL FOR THE LIFE OF THE PROJECT, CRADLE TO GRAVE, ENFORCE THE 40 DB(A) L10 BY REQUIRING THE REMOVAL OF TURBINES AND FINES IN EXCESS OF $10,000 PER INCIDENT, FOR EQUIPMENT NOISE VIOLATIONS. THE FINE REVENUE SHALL BE REMANDED TO THE AFFECTED PROPERTY OWNER WHERE THE VIOLATION OCCURRED." DO YOU AGREE WITH THIS PROPOSED CONDITION?

A. No. First, we reject the premise that the limit of 40 dba and the use of the L10 measurement are appropriate and reasonable for the reasons set forth in the rebuttal testimony of CRW witnesses Ollson, McCunney, Haley, and Lampeter. Second, even for the sake of argument, if a post-construction sound monitoring evaluation indicated that a

Commission-imposed dba limit was exceeded we do not agree that the turbine should be removed and a fine assessed. Any issues raised by community members regarding potential sound impact from operation of CRW should be addressed through the complaint resolution process described in ARSD Chapter 20: 10:01.

Q. THE INTERVENORS' PROPOSED CONDITION 22 (KEARNEY EXHIBIT DK-8) WOULD REQUIRE:

> **THE APPLICANT SHALL DEVELOP A REPORT CONCERNING HEALTH, SAFETY AND WELFARE OF LIVING, WORKING, RECREATING, AND COMMUTING IN THE TURBINE PROJECT. THIS REPORT SHALL COVER BUT NOT LIMITED TO INFRASOUND, LOW FREQUENCY NOISE, COMMUNITY WITHIN THE PROJECT DURING CONSTRUCTION, DURING ICING CONDITIONS, ICE THROW, FIRE DANGERS INCLUDING PRAIRIE FIRES CAUSED BY TURBINES, SAFETY SETBACKS, A MAP OF TURBINE LOCATIONS AND ID ADDRESS FOR EMERGENCY RESPONDERS, AND THE PUC PHONE NUMBER TO REGISTER COMPLAINTS. THIS REPORT SHALL BE FOR THE LIFE OF THE PROJECT BE PUBLISHED ANNUALLY EACH FALL IN PUBLIC OPINION NEWSPAPER IN WATERTOWN, SD, SOUTH SHORE GAZETTE IN SOUTH SHORE, SD AND THE GRANT COUNTY REVIEW IN MILBANK, SD.**

DO YOU AGREE WITH THIS PROPOSED CONDITION?

A. No. The rebuttal testimony of CRW witnesses Thompson, Ollson, McCunney, Haley, Sappington, and Lampeter show that the underlying subject matter regarding health, safety, and welfare in this condition do not warrant the reporting proposed in this Condition. Additionally, this proposed condition is redundant and duplicative of existing reporting channels since the applicant is already required to coordinate with emergency responders in setting up an emergency action plan in the event of fire or other hazardous condition, as previously described in section 18.3.3 of the Application.

Q. THE INTERVENORS' PROPOSED CONDITION 25 (KEARNEY EXHIBIT DK-8) WOULD REQUIRE "THE APPLICANT [TO] REMOVE ALL TURBINES THAT DO NOT MEET THE CONDITIONS OF THE LOCAL AND STATE PERMITS, RULES AND LAWS." DO YOU AGREE WITH THIS PROPOSED CONDITION?

A. No. This proposed condition is redundant as CRW is required to comply with all applicable local, state, and federal laws. In the event that there is a question whether a turbine is in compliance with these laws, CRW would want to present proof of compliance or possible mitigate measures to bring the turbine into compliance, and, only as a last resort remove the turbine if the agency considering the issue of possible non-compliance ordered the company to remove the turbine after an opportunity to present proof of compliance and/or the mitigation measures.

Q. THE INTERVENORS' PROPOSED CONDITION 26 (KEARNEY EXHIBIT DK-8) WOULD REQUIRE "IF THE PUC REQUIRES A LIAISON, THE LIAISON SHALL LIVE IN THE CROWNED RIDGE LLC BOUNDARY." DO YOU AGREE WITH THIS PROPOSED CONDITION?

A. No. The roles and responsibilities of the liaison will be articulated by the Commission in its conditions. CRW will propose a candidate liaison to the Commission and the Commission will approve or disapprove of that candidate based on an evaluation of the candidate's suitability for the role.

Q. THE INTERVENORS' PROPOSED CONDITION 27 (KEARNEY EXHIBIT DK-8) WOULD REQUIRES "IN THE FIRST WEEK OF MAY, BY LETTER, THE PUC SHALL SURVEY THE PARTICIPATING AND NON PARTICIPATING LANDOWNERS WITHIN 2 MILES OF THE PROJECT BOUNDARY FOOTPRINT WITH 10 QUESTIONS WRITTEN BY THE INTERVENORS." DO YOU AGREE WITH THIS PROPOSED CONDITION?

A. No. Based on the language of this proposed condition, it is unclear what the purpose of the survey would be and what service it would perform in the public interest.

Q. THE INTERVENORS' PROPOSED CONDITION 28 (KEARNEY EXHIBIT DK-8) WOULD REQUIRE THAT "THE PUC SHALL REQUIRE THE APPLICANT TO REMOVE AND NOTIFY THE PARTICIPATING LANDOWNERS THAT THE CONFIDENTIALITY [EASEMENT] AGREEMENT IS NULLIFIED." THIS NOTICE SHALL BE SENT BY APRIL 30TH." DO YOU AGREE WITH THIS PROPOSED CONDITION?

A. No. The participating landowners have entered into a voluntary and private business agreement with the Applicant on terms mutually agreeable to both parties. The terms and conditions and pricing are confidential and sensitive commercial information, which if disclosed would harm the competitive position of the project and other affiliates of CRW who use the same terms and conditions.

Q. THE INTERVENORS' PROPOSED CONDITION 31 (KEARNEY EXHIBIT DK-8) WOULD REQUIRE:

THE PUC, FOR THE LIFE OF THE PROJECT, SHALL ANNUALLY SEND OUT A SURVEY TO ALL PARTICIPATING AND NONPARTICIPATING LANDOWNERS WITHIN THE PROJECT BOUNDARY FOOTPRINT AND WITHIN 2 MILES OF THE PROJECT BOUNDARY FOOTPRINT. THE SURVEY SHALL QUERY BUT NOT LIMITED TO, PERCEPTIONS OF PROPERTY VALUE, QUALITY OF LIFE, HEALTH CONCERNS RELATED TO TURBINES, CONCERNS ABOUT THE TURBINES.

DO YOU AGREE WITH THIS PROPOSED CONDITION?

A. No. The rebuttal testimony of CRW witnesses Baker, Ollson, and McCunney shows that the underlying subject matter does not warrant an annual survey. Furthermore, this proposed condition is redundant as there will be a complaint process in place (as required by ARSD Chapter 20: 10:01) that provides members of the community an opportunity, at any time, to raise concerns and seek resolution, and, therefore, the proposed condition is not needed.

Q. THE INTERVENORS' PROPOSED CONDITION 32 (KEARNEY EXHIBIT DK-8) WOULD REQUIRE THE PUC NOT TO ALLOW TURBINE SHIFTS. DO YOU AGREE WITH THE PROPOSED CONDITION?

A. The Commission in past cases (Prevailing Wind, condition no. 23, and Dakota Range I and II, condition no. 22) has allowed turbine shifts of up to 250 feet or less from the turbine locations identified in the application without prior Commission approval, subject to a number of conditions. CRW agrees with the Commission's approach on turbine moves and is agreeable to complying with the same conditions imposed in the Prevailing Wind and Dakota Range cases.

The Commission-approved condition in those cases also requires that a turbine that is moved within 250 feet must continue to comply with all applicable setbacks, sounds and shadow/flicker requirements; therefore, the moving of the turbine will not result in non-compliance with these setbacks and requirements. Prior to the move, the Commission-approved condition would require that CRW will file in the docket an affidavit demonstrating compliance with the conditions. Any turbine move that does not comply with the limitations would require Commission approval. Thus, we believe the Commission has appropriately conditioned turbine moves, and CRW is willing to comply with such a condition. Therefore, the proposed condition prohibiting turbine moves should not be adopted.

Q. THE INTERVENORS' PROPOSED CONDITION 34 (KEARNEY EXHIBIT DK-8) WOULD REQUIRE "THE APPLICANT SHALL PROVIDE A CRADLE TO GRAVE CARBON FOOTPRINT REPORT FOR THIS PROJECT." DO YOU AGREE WITH THE PROPOSED CONDITION?

A. No. CRW's wind facility is a zero carbon emission energy resource. There is no basis that CRW file a report essentially stating the same.

Q. THE INTERVENORS' PROPOSED CONDITION 36 (KEARNEY EXHIBIT DK-8) WOULD REQUIRE CRW TO "COMMIT TO AN END DATE TO THE PROJECT." DO YOU AGREE WITH THIS PROPOSED CONDITION?

A. The estimated life of the Project is 25 years, which is the same term as the power purchase agreement ("PPA") with Northern States Power Company. At the end of the PPA, CRW will consider selling the energy from the wind facility to other buyers. CRW may also extend the life of the project through retrofitting or repowering. To the extent, retrofitting and repowering requires Commission approval at that time, CRW will seek that approval prior to conducting the retrofitting and repowering. Therefore, at this time, there is no specific date to provide when the project will end, but CRW is amendable to notifying the Commission after 25 years if it will not retrofit or repower the project, if the Commission desires.

Q. THE INTERVENORS' PROPOSED CONDITION 38 (KEARNEY EXHIBIT DK-8) WOULD REQUIRE:

AN ANNUAL REPORT PUBLISHED IN THE FOLLOWING PUBLIC PUBLICATIONS, FOR THE LIFE OF THE PROJECT: PUBLIC OPINION NEWSPAPER IN WATERTOWN, SD, SOUTH SHORE GAZETTE IN SOUTH SHORE, SD AND THE GRANT COUNTY REVIEW IN MILBANK, SD WHICH INCLUDES A REPORT OF THE FOLLOWING INFORMATION:

- **TAX REVENUE VERSUS PREDICTIONS FOR EACH ENTITY: COUNTY, TOWNSHIP AND SCHOOL DISTRICT.**
- **ACTUAL POWER PRODUCTION VERSUS PREDICTIONS.**
- **ELECTRIC PRICES EXPERIENCED BY CITIZENS VERSUS ELECTRIC PRICES AT THE START OF THE PROJECT.**
- **THE AMOUNT OF NET NEGATIVE ENERGY USED FROM THE GRID AND THE PRICE COST PER KILOWATT AND TOTAL COST PER TURBINE THE APPLICANT PAID FOR IT.**
- **SCHOOL ENROLLMENT NUMBERS AT WAVERLY SCHOOL VERSUS AT THE START OF THE PROJECT.**
- **A SURVEY OF ALL LANDOWNERS THAT IS COMPLETED BY A THIRD PARTY SELECTED BY THE PUC, WITH THE RESULTS BEING SENT DIRECTLY FROM THE SURVEY COMPANY TO THE PUC. THE QUESTIONS ON THE SURVEY SHALL INCLUDE:**

  - **DO YOU FEEL YOUR QUALITY OF LIFE HAS BEEN IMPACTED AS A RESULT OF THE WIND PROJECT, CROWNED RIDGE I? IF YES, HAS IT BEEN IMPACTED FOR THE BETTER OR WORSE?**
  - **DO YOU BELIEVE THE COMMUNITY HAS BEEN IMPACTED AS A RESULT OF THE WIND PROJECT, CROWNED**

RIDGE I? IF YES, HAS IT BEEN IMPACTED FOR THE BETTER OR WORSE?

DO YOU AGREE WITH THESE PROPOSED CONDITIONS?

A. No. As written, it is unclear what the proposed conditions would achieve as this data is either publicly available or commercial and private in nature. Further, the following provides additional reasons why each subject matter should not be part of an annual report.

Tax

County, Township, and School District tax revenues are publicly available, and, therefore, the Intervenors can obtain such information without publishing it the newspaper.

Actual Production Versus Predictions

Many factors can lead to differences between predicted and actual energy production, such as weather resource variability and equipment outages. CRW employs a dedicated team of professionals to forecast project energy production, but there can be differences between predicted and actual production. These differences can be commercially sensitive due to the competitive nature of wind energy development, and, therefore, CRW would oppose publishing them in a newspaper.

School Enrollment

As shown in the rebuttal testimony of CRW witnesses Ollson, McCunney, Haley, and Lampeter, there is no supporting evidence from a technical, health, or welfare standpoint that the students of Waverly school will be impacted by this project. Accordingly, the reporting on school enrollment serves no purpose.

Survey by third party

As shown in the rebuttal testimony of CRW witnesses Ollson, McCunney, Haley, and Lampeter, there is no supporting evidence from a technical, health, or welfare standpoint that warrants a third party survey on quality of life and community impact.

Q. **DOES THIS CONCLUDE YOUR TESTIMONY?**

A. Yes, it does.

STATE OF DELAWARE)
) ss
COUNTY OF NEW CASTLE)

I, Sam Massey, being duly sworn on oath, depose and state that I am the witness identified in the foregoing prepared testimony and I am familiar with its contents, and that the facts set forth are true to the best of my knowledge, information and belief.

Sam Massey

Subscribed and sworn to before me this 23 day of May 2019.

SEAL

Notary Public

My Commission Expires ________ PAMELA MARIE HEVERIN
Notary Public - State of Delaware
My Commission Expires August 3, 2021

STATE OF FLORIDA)
) ss
COUNTY OF PALM BEACH)

I, Tyler Wilhelm, being duly sworn on oath, depose and state that I am the witness identified in the foregoing prepared testimony and I am familiar with its contents, and that the facts set forth are true to the best of my knowledge, information and belief.

____
Tyler Wilhelm

Subscribed and sworn to before me this 23rd day of May 2019.

SEAL

____
Notary Public

My Commission Expires ________

JULIE N. KRAUSS
Commission # GG 092884
Expires June 3, 2021
Bonded Thru Troy Fain Insurance 800-385-7019

May 22, 2019

To whom it may concern:

This is Dennis Schmeling, I have the house in NW1/4 Section 4-T119-R51. This house is un-livable, the floors are rotted out, it's full of raccoons, windows are gone. It has no value and has been vacant since 1995.
I intend to remove the structure when local fire department allows removal.

Regards,

Dennis Schmeling

605-467-9876

Exhibit A44-2

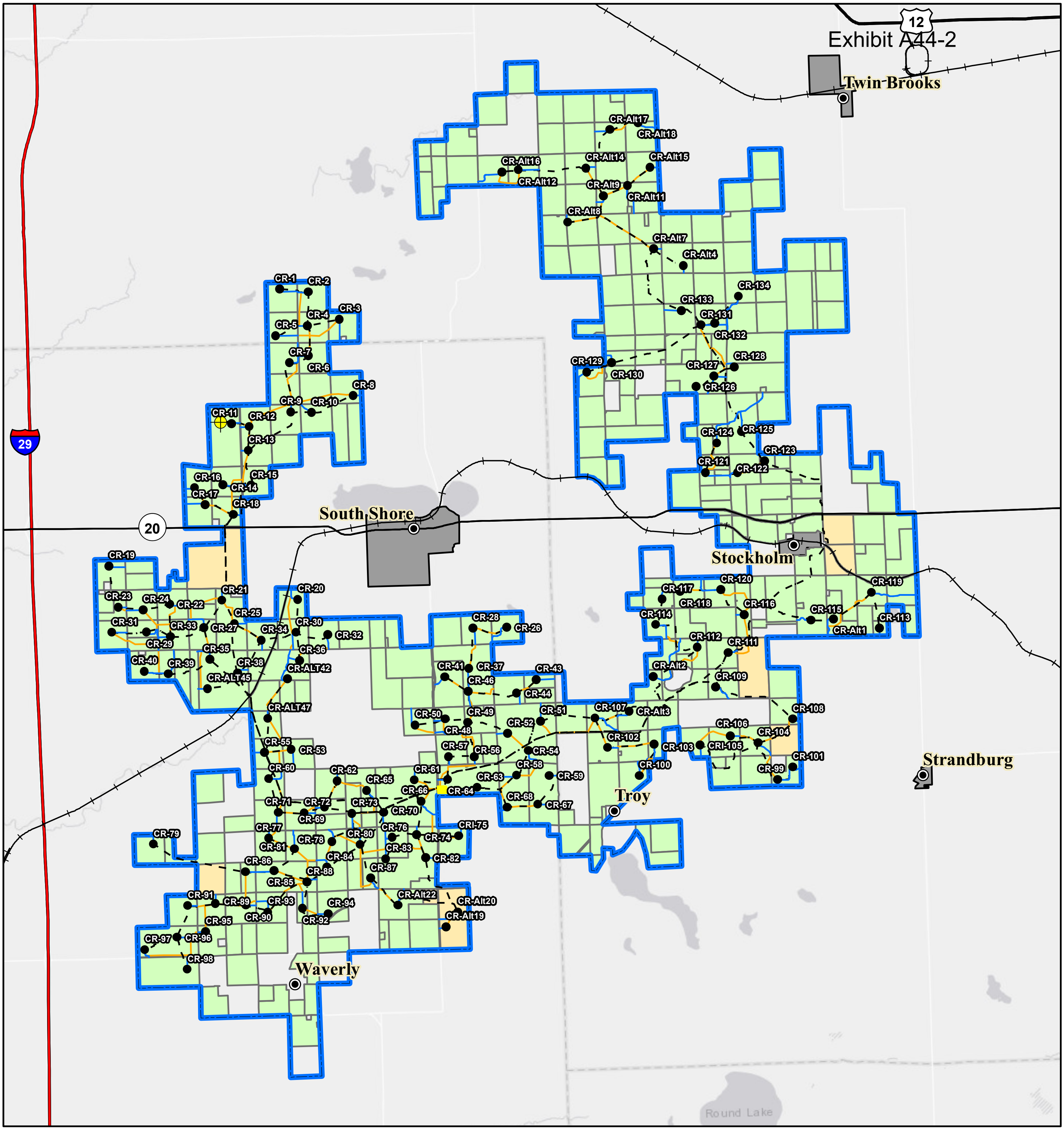
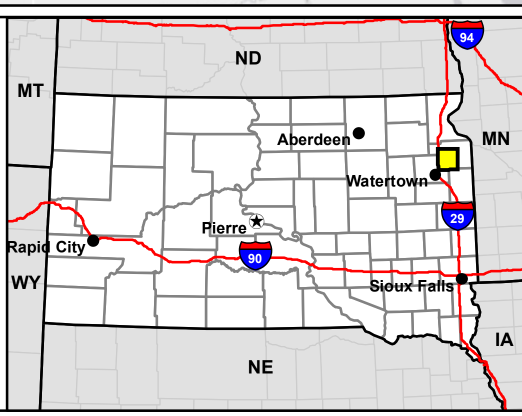


Figure 3. Project Map

Crowned Ridge Wind Farm

MET Tower	U.S. Highway
Turbine	State Highway
City	O&M Facility/ Substation
Access Road	Town Boundary
Collector Line	Project Boundary
Crane Path	**Lease Status**
Railroad	Leased, Signed
Interstate Highway	Pending Approval



Kilometers

0 2.5 5

Miles

0 2.5 5

N W E S

Base Map: World Light Gray Canvas Base
Sources: Esri, HERE, Garmin, © OpenStreetMap contributors, and the GIS user community
Codington and Grant Counties, South Dakota

017282 Page 000001

SWCA ENVIRONMENTAL CONSULTANTS

Projection: NAD 1983 UTM Zone 14N

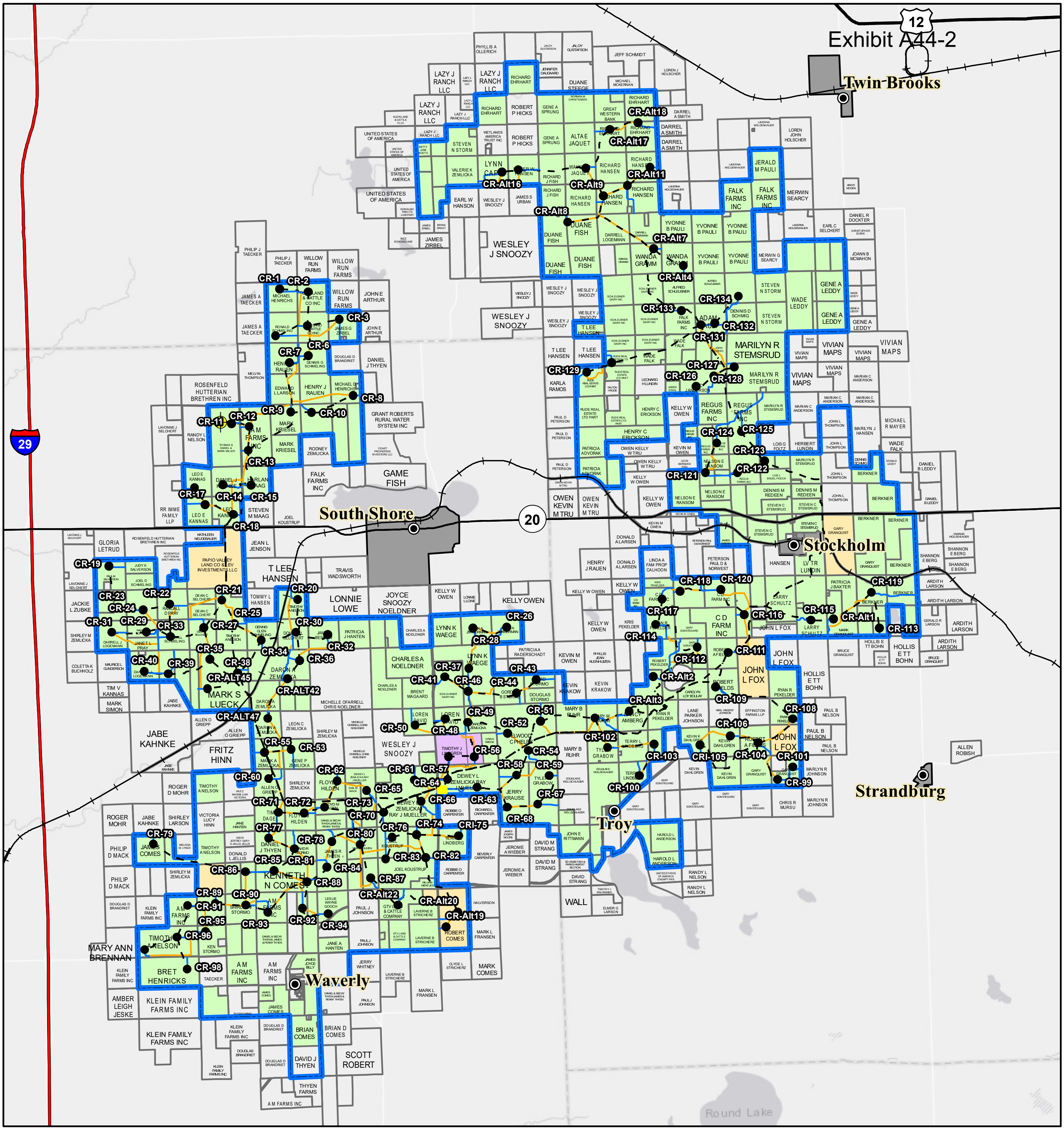


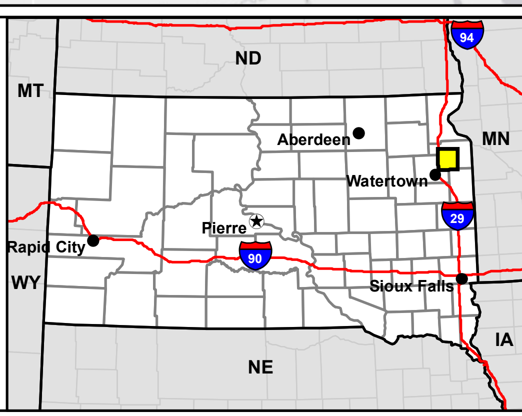
Figure 3a. Project Map

Crowned Ridge Wind Farm

- MET Tower
- Turbine
- City
- Access Road
- Collector Line
- Crane Path
- Railroad
- Interstate Highway
- U.S. Highway
- State Highway
- O&M Facility/ Substation
- Town Boundary
- Project Boundary
- Parcel Boundary

Lease Status

- Leased, Signed
- Pending Approval
- Under Option but Likely to Expire/Not Resign



Kilometers
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Miles
0 2.5 5

Base Map: World Light Gray Canvas Base
Sources: Esri, HERE, Garmin, © OpenStreetMap contributors, and the GIS user community
Codington and Grant Counties, South Dakota

017283 Page 000002

SWCA ENVIRONMENTAL CONSULTANTS

Projection: NAD 1983 UTM Zone 14N

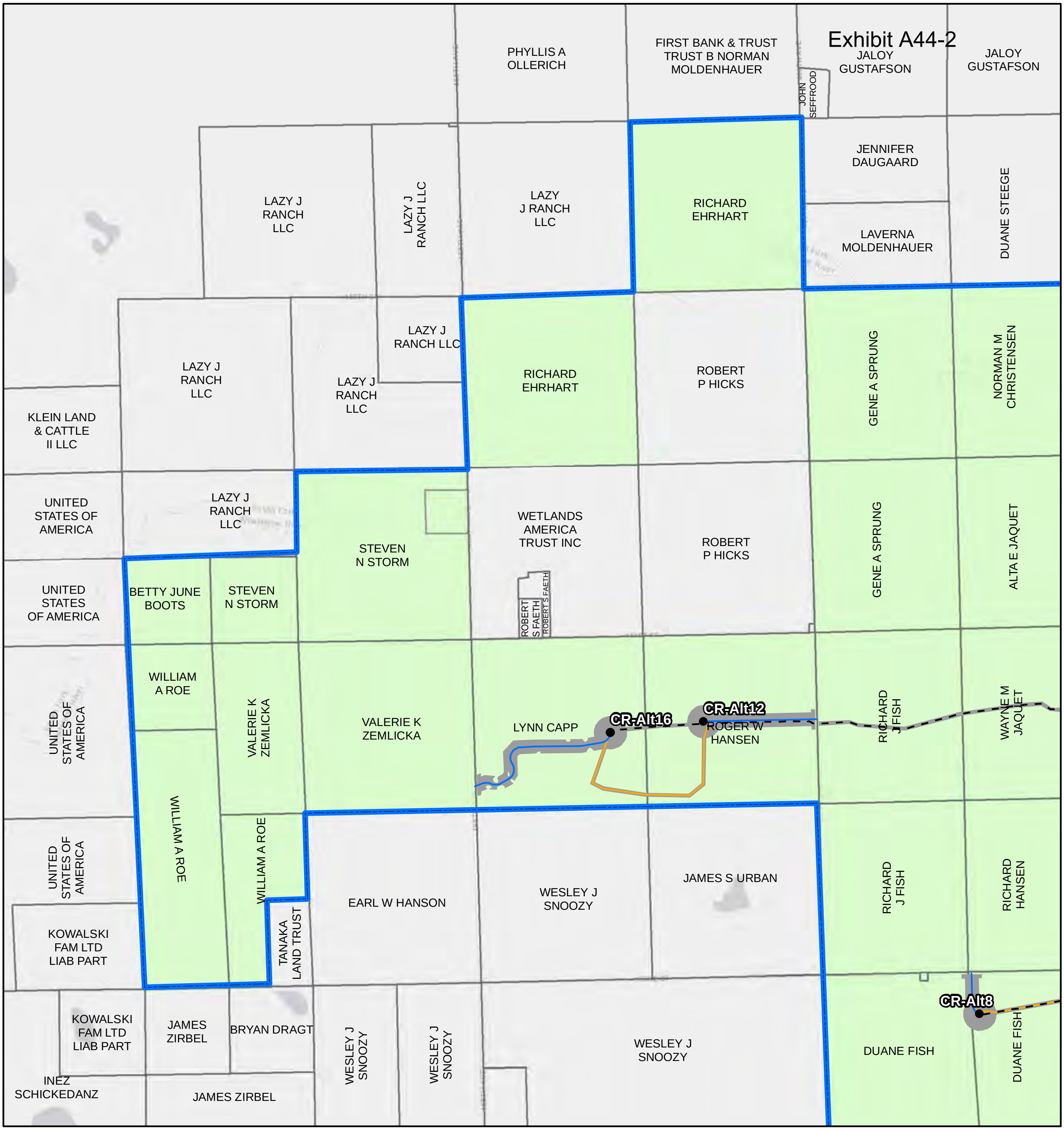


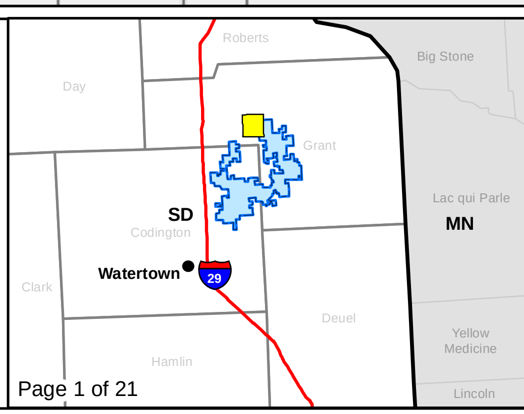
Figure 3a. Project Map

Crowned Ridge Wind Farm

- Turbine
- MET Tower
- City
- Access Road
- Collector Line
- Crane Path
- Railroad
- O&M Facility/ Substation
- Batch Plant
- Laydown Yard
- Construction Easement
- Parcel Boundary
- Project Boundary
- County Boundary

Lease Status

- Leased, Signed
- Pending
- Under Option but Likely to Expire/Not Resign



Page 1 of 21

Kilometers

0 0.5 1

Miles

0 0.25 0.5

Service Layer Credits: Esri, HERE, Garmin, © OpenStreetMap contributors, and the GIS user community

Quadrangle: Antelope Valley (1973), Twin Brooks (1973)

Township/Range: T120N, R51W, T120N, R50W

Grant County, South Dakota

017284 Page 000003

Projection: NAD 1983 UTM Zone 14N

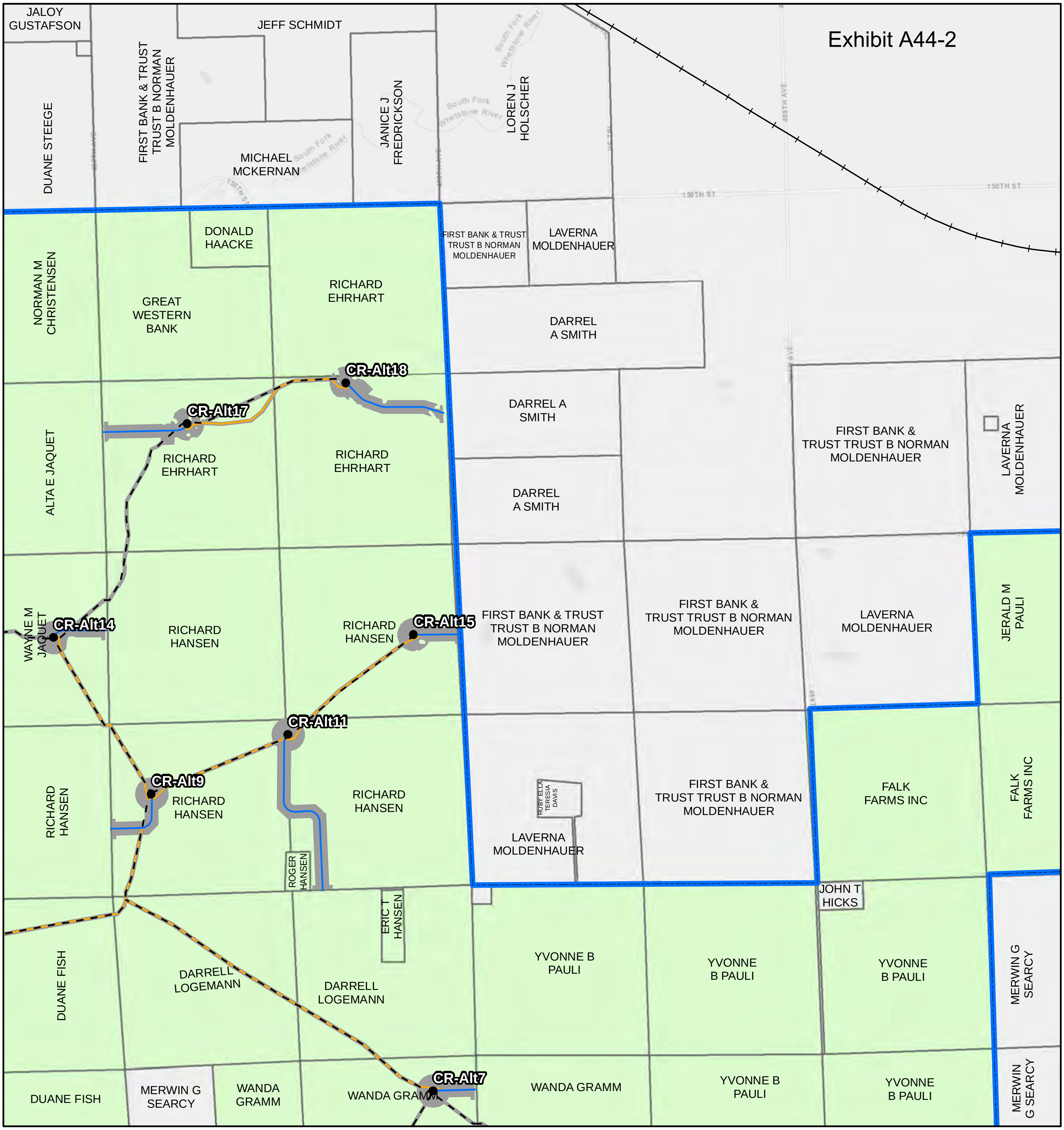


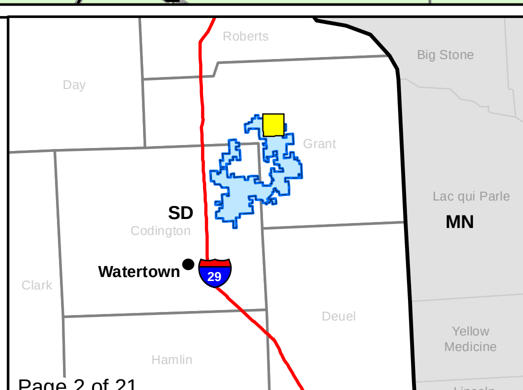
Figure 3a. Project Map

Crowned Ridge Wind Farm

- Turbine
- MET Tower
- City
- Access Road
- Collector Line
- Crane Path
- Railroad
- O&M Facility/ Substation
- Batch Plant
- Laydown Yard
- Construction Easement
- Parcel Boundary
- Project Boundary
- County Boundary

Lease Status

- Leased, Signed
- Pending
- Under Option but Likely to Expire/Not Resign



Kilometers
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Miles
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N W E S

Service Layer Credits: Esri, HERE, Garmin, © OpenStreetMap contributors, and the GIS user community
Quadrangle: Twin Brooks (1973)

Township/Range: T120N, R50W

Grant County, South Dakota

017285

SWCA ENVIRONMENTAL CONSULTANTS

Projection: NAD 1983 UTM Zone 14N

Exhibit A44-2

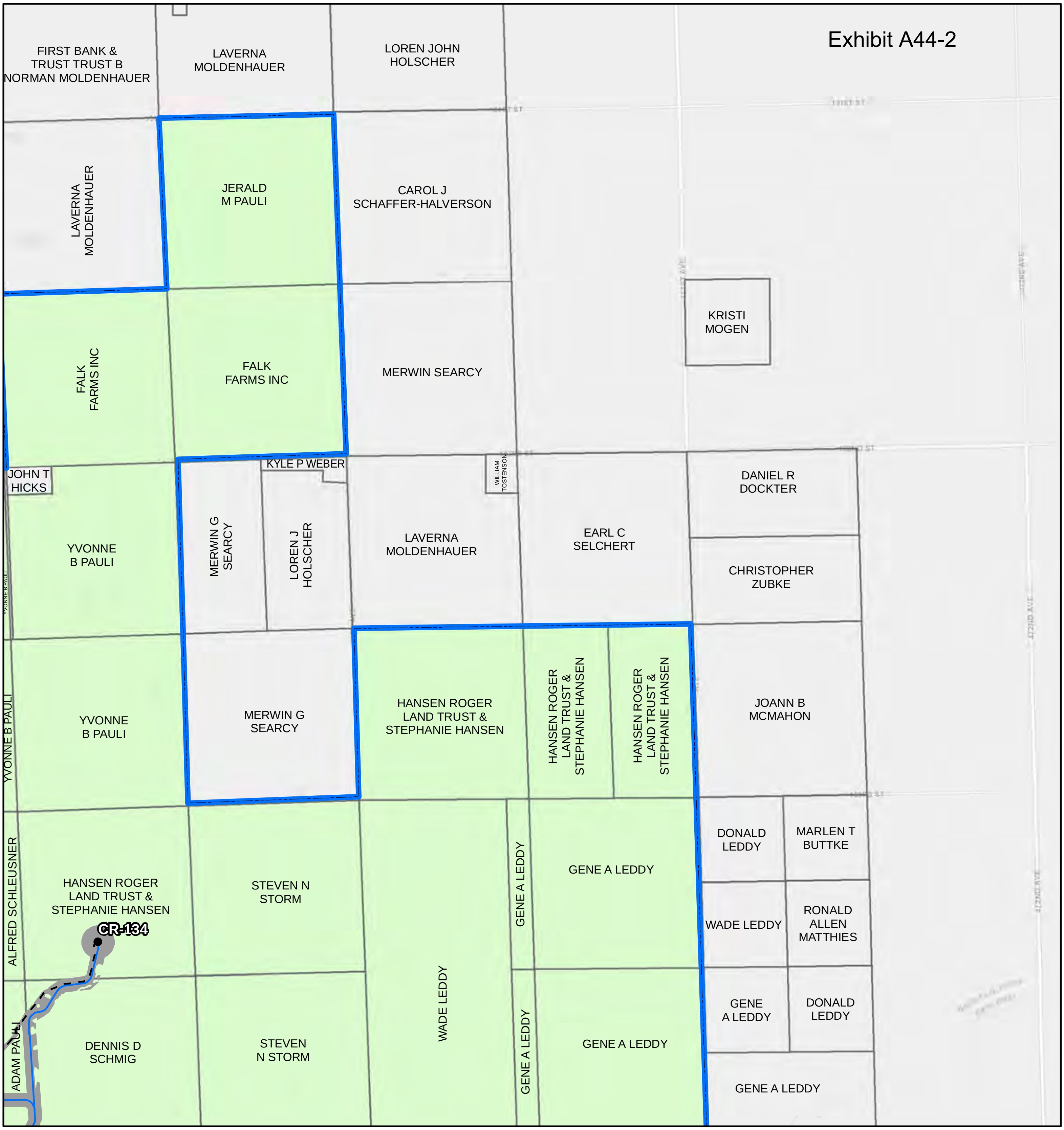


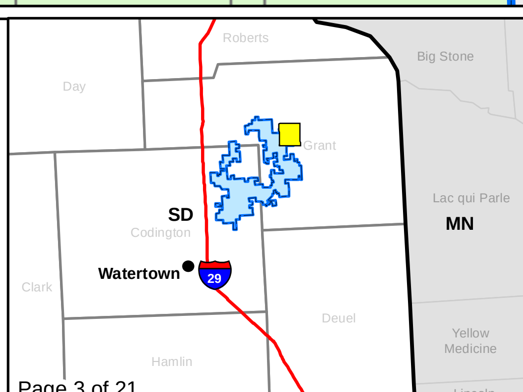
Figure 3a. Project Map

Crowned Ridge Wind Farm

- Turbine
- MET Tower
- City
- Access Road
- Collector Line
- Crane Path
- Railroad
- O&M Facility/ Substation
- Batch Plant
- Laydown Yard
- Construction Easement
- Parcel Boundary
- Project Boundary
- County Boundary

Lease Status

- Leased, Signed
- Pending
- Under Option but Likely to Expire/Not Resign



Kilometers
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Miles
0 0.25 0.5

N W E S

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Quadrangle: Twin Brooks (1973)

Township/Range: T120N, R50W

017286

Grant County, South Dakota

Projection: NAD 1983 UTM Zone 14N

SWCA ENVIRONMENTAL CONSULTANTS

Exhibit A44-2

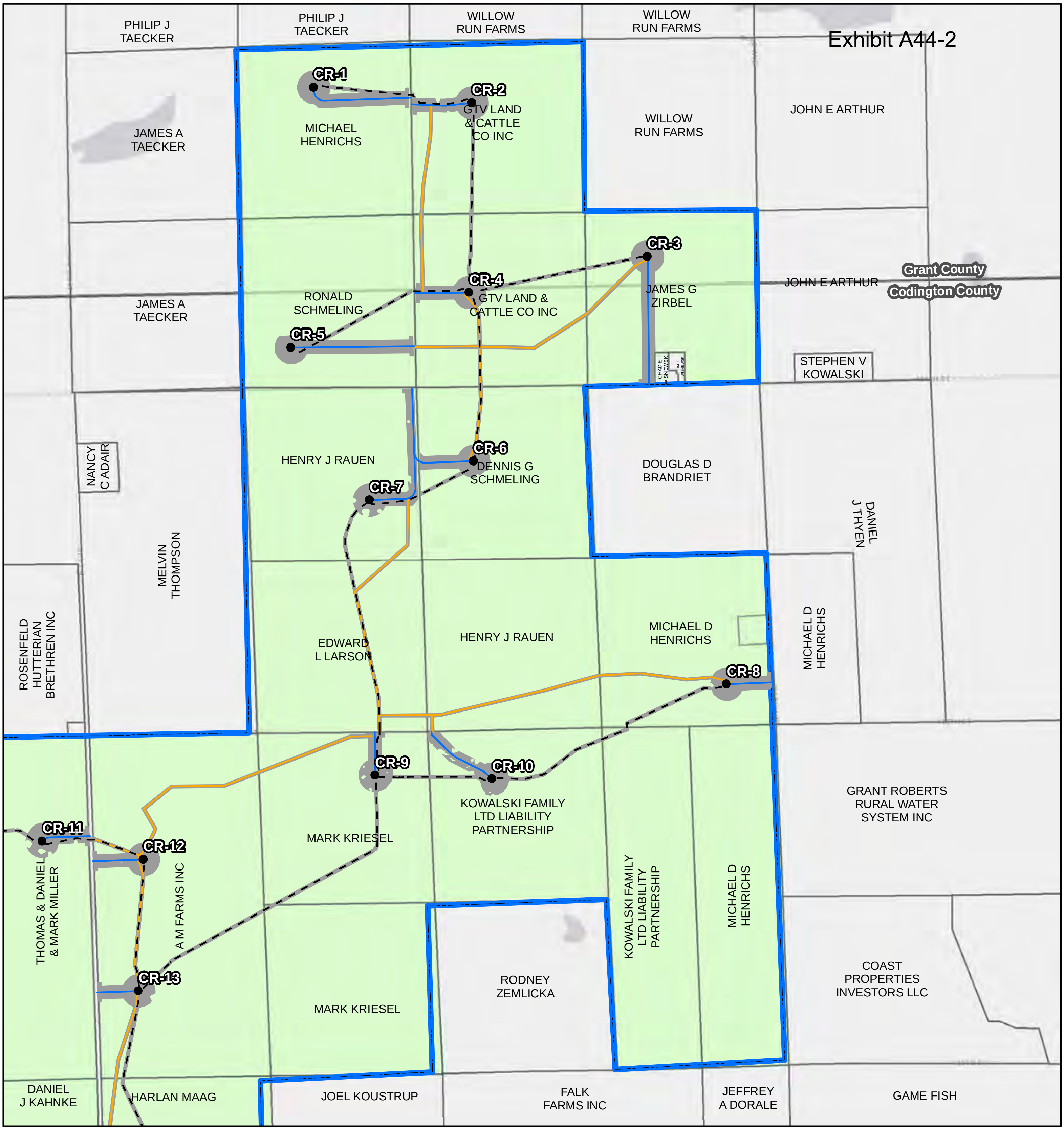


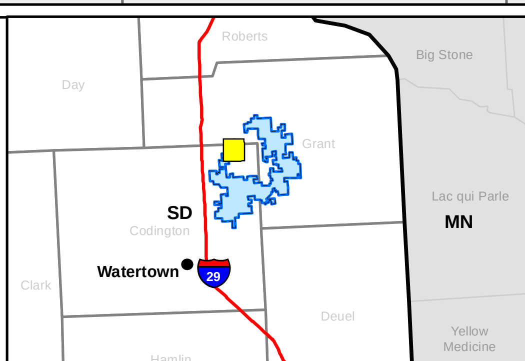
Figure 3a. Project Map

Crowned Ridge Wind Farm

- Turbine
- MET Tower
- City
- Access Road
- Collector Line
- Crane Path
- Railroad
- O&M Facility/ Substation
- Batch Plant
- Laydown Yard
- Construction Easement
- Parcel Boundary
- Project Boundary
- County Boundary

Lease Status

- Leased, Signed
- Pending
- Under Option but Likely to Expire/Not Resign



Kilometers
0 0.5 1

Miles
0 0.25 0.5

N W E S

Service Layer Credits: Esri, HERE, Garmin, © OpenStreetMap contributors, and the GIS user community
Quadrangle: Antelope Valley (1973), South Shore (1973)
Township/Range: T120N, R51W, T119N, R51W,
Codington and Grant Counties, South Dakota

017287

SWCA ENVIRONMENTAL CONSULTANTS

Projection: NAD 1983 UTM Zone 14N

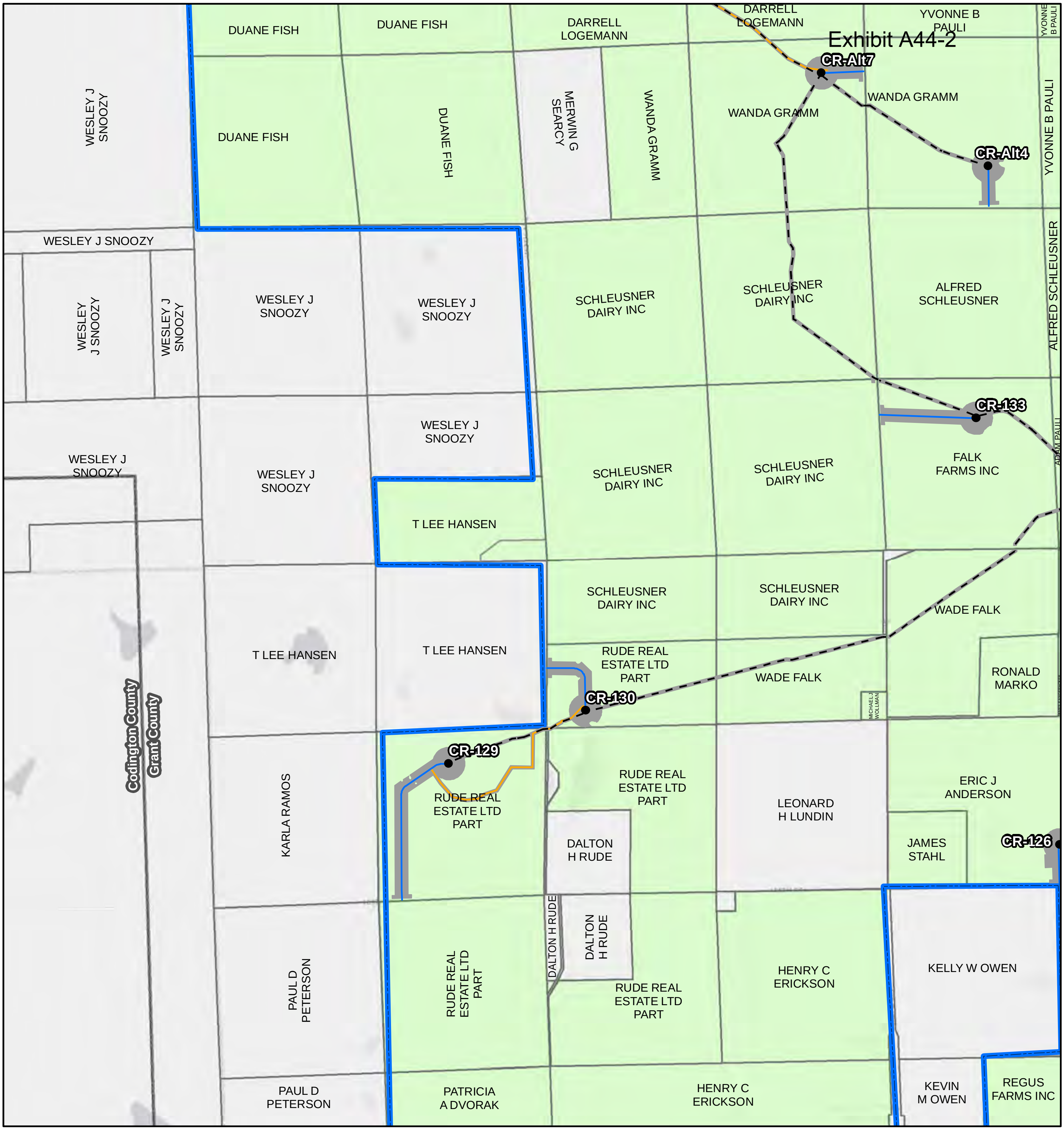


Figure 3a. Project Map

Crowned Ridge Wind Farm

- Turbine
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- City
- Access Road
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Lease Status

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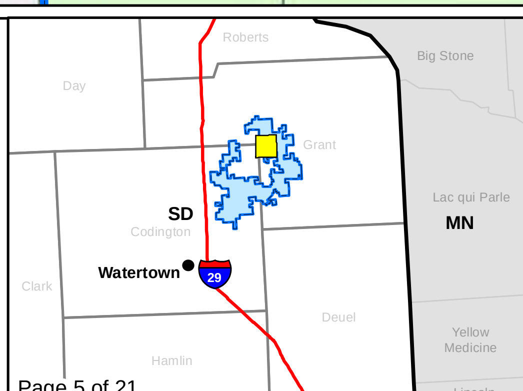


Kilometers
0 0.5 1

Miles
0 0.25 0.5

Service Layer Credits: Esri, HERE, Garmin, © OpenStreetMap contributors, and the GIS user community
Quadrangle: Antelope Valley (1973), Twin Brooks (1973)
Township/Range: T120N, R51W, T120N, R50W, T119N, R51W, T119N, R50W
Codington and Grant Counties, South Dakota

Projection: NAD 1983 UTM Zone 14N

SWCA ENVIRONMENTAL CONSULTANTS

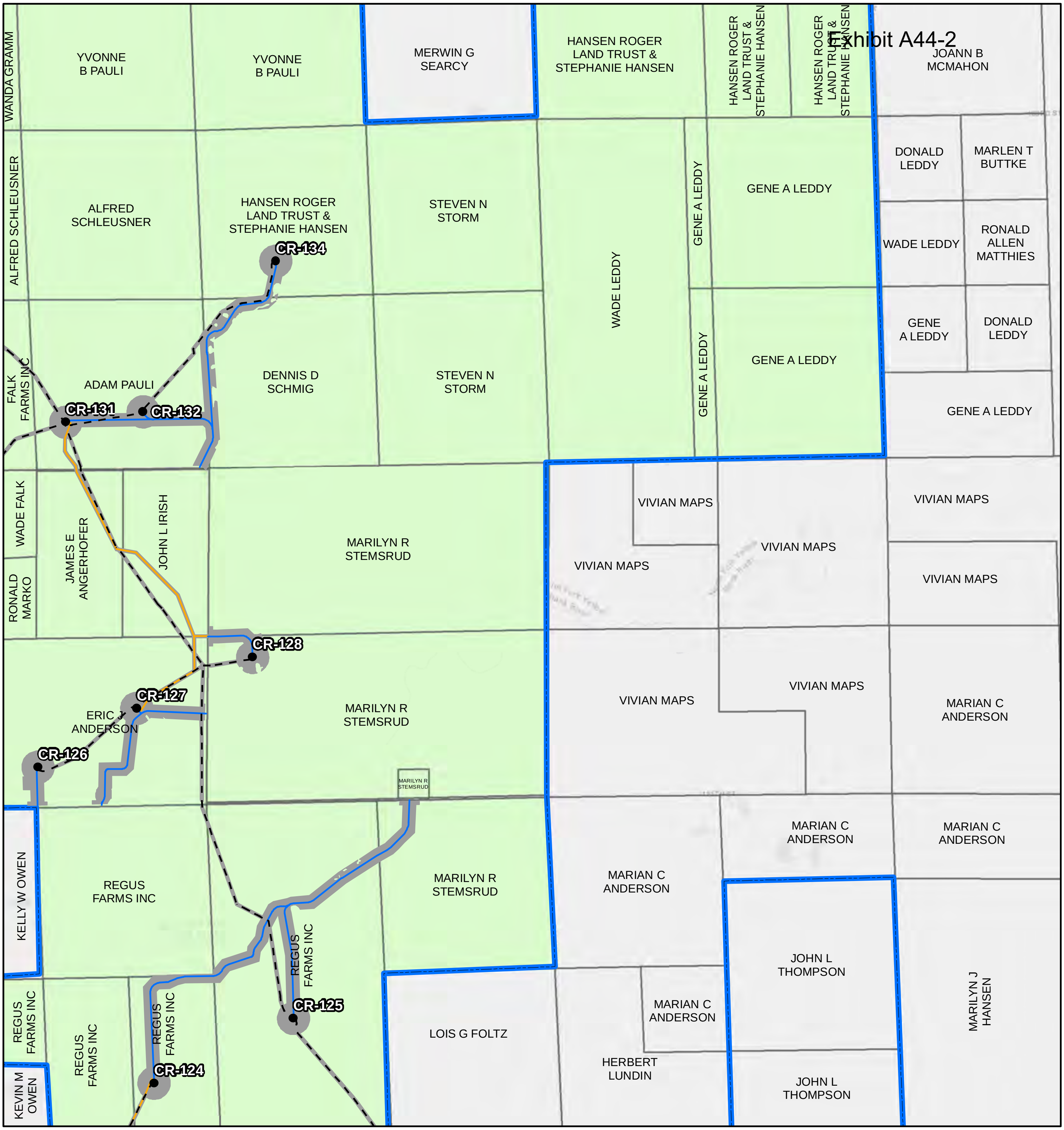


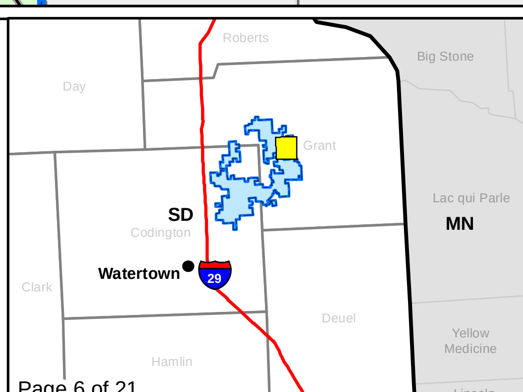
Figure 3a. Project Map

Crowned Ridge Wind Farm

- Turbine
- MET Tower
- City
- Access Road
- Collector Line
- Crane Path
- Railroad
- O&M Facility/ Substation
- Batch Plant
- Laydown Yard
- Construction Easement
- Parcel Boundary
- Project Boundary
- County Boundary

Lease Status

- Leased, Signed
- Pending
- Under Option but Likely to Expire/Not Resign



Kilometers
0 0.5 1

Miles
0 0.25 0.5

Service Layer Credits: Esri, HERE, Garmin, © OpenStreetMap contributors, and the GIS user community
Quadrangle: Twin Brooks (1973), Stockholm (1973)
Township/Range: T120N, R50W, T119N, R50W
Grant County, South Dakota
Projection: NAD 1983 UTM Zone 14N

017289

SWCA ENVIRONMENTAL CONSULTANTS

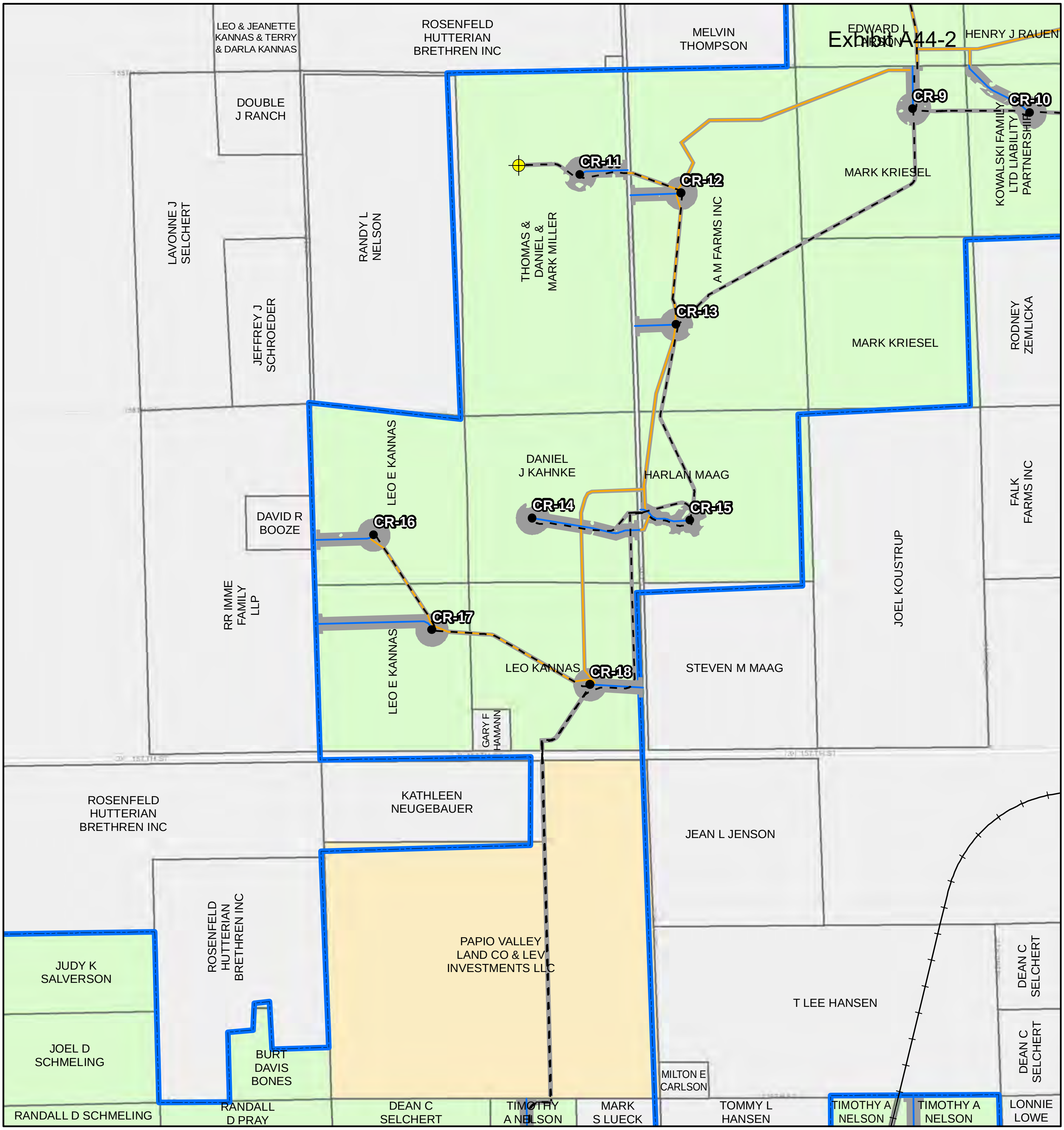


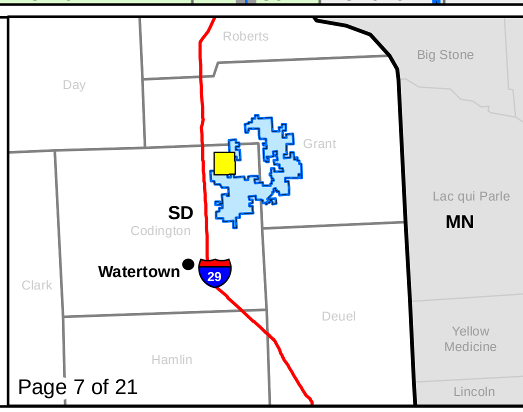
Figure 3a. Project Map

Crowned Ridge Wind Farm

- Turbine
- MET Tower
- City
- Access Road
- Collector Line
- Crane Path
- Railroad
- O&M Facility/ Substation
- Batch Plant
- Laydown Yard
- Construction Easement
- Parcel Boundary
- Project Boundary
- County Boundary

Lease Status

- Leased, Signed
- Pending
- Under Option but Likely to Expire/Not Resign



Kilometers
0 0.5 1

Miles
0 0.25 0.5

Service Layer Credits: Esri, HERE, Garmin, © OpenStreetMap contributors, and the GIS user community
Quadrangle: Still Lake NE (1970), Antelope Valley (1973), Still Lake SE (1970), South Shore (1973)
Township/Range: T119N, R52W, T119N, R51W
Codington County, South Dakota
Projection: NAD 1983 UTM Zone 14N

017290

SWCA ENVIRONMENTAL CONSULTANTS

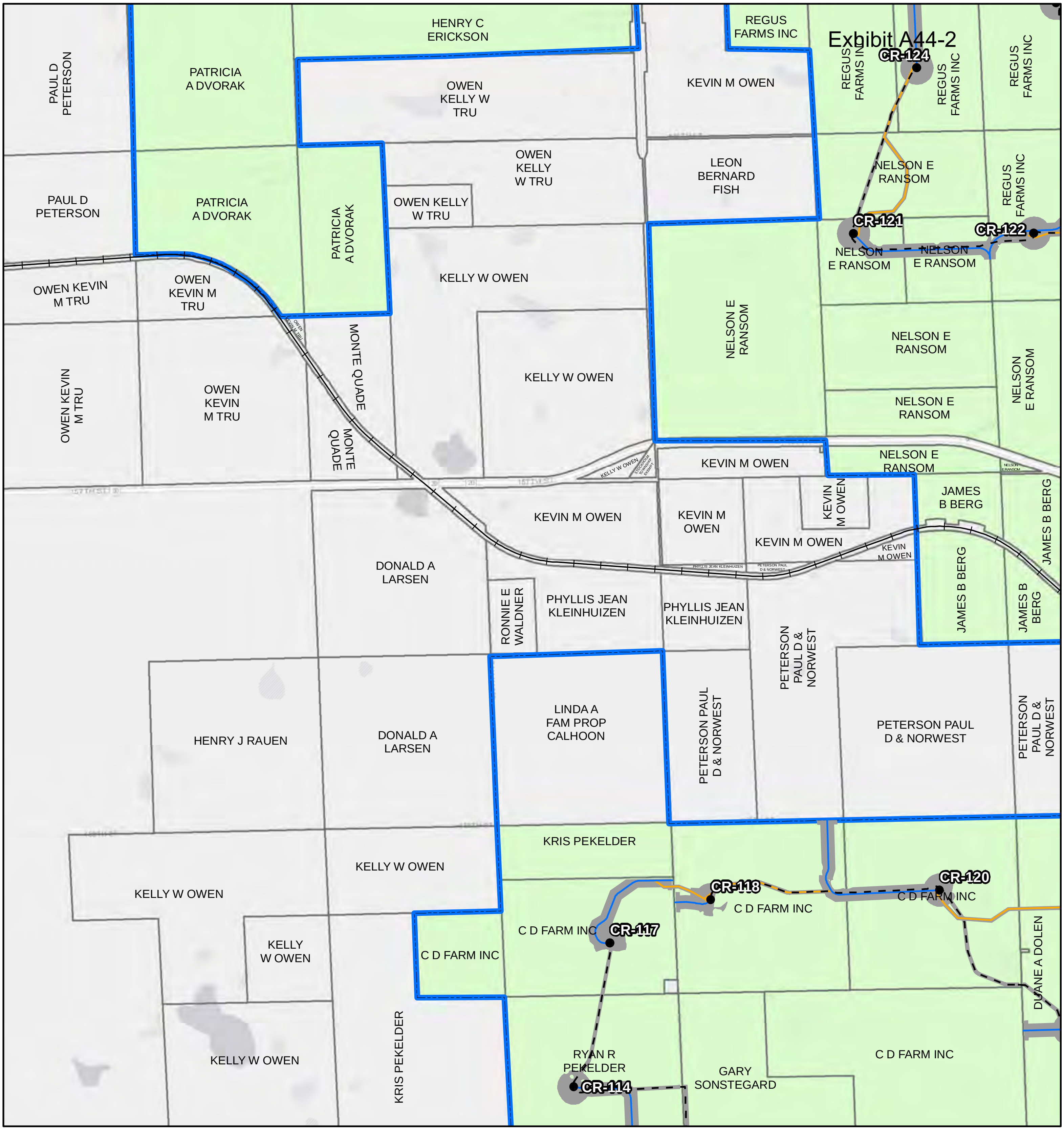


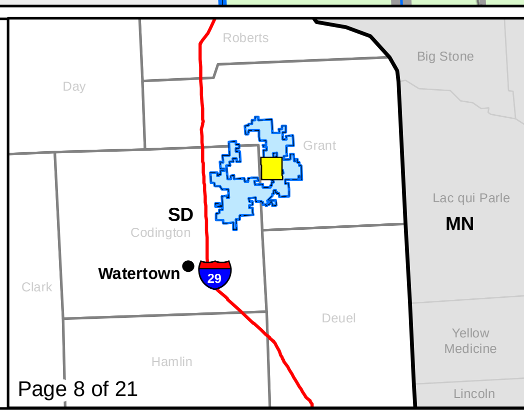
Figure 3a. Project Map

Crowned Ridge Wind Farm

- Turbine
- MET Tower
- City
- Access Road
- Collector Line
- Crane Path
- Railroad
- O&M Facility/ Substation
- Batch Plant
- Laydown Yard
- Construction Easement
- Parcel Boundary
- Project Boundary
- County Boundary

Lease Status

- Leased, Signed
- Pending
- Under Option but Likely to Expire/Not Resign



Kilometers

0 0.5 1

Miles

0 0.25 0.5

Service Layer Credits: Esri, HERE, Garmin, © OpenStreetMap contributors, and the GIS user community

Quadrangle: Stockholm (1973), Antelope Valley (1973), Twin Brooks (1973), South Shore (1973)

Township/Range: T119N, R50W

Grant County, South Dakota

Projection: NAD 1983 UTM Zone 14N

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Exhibit A44-2

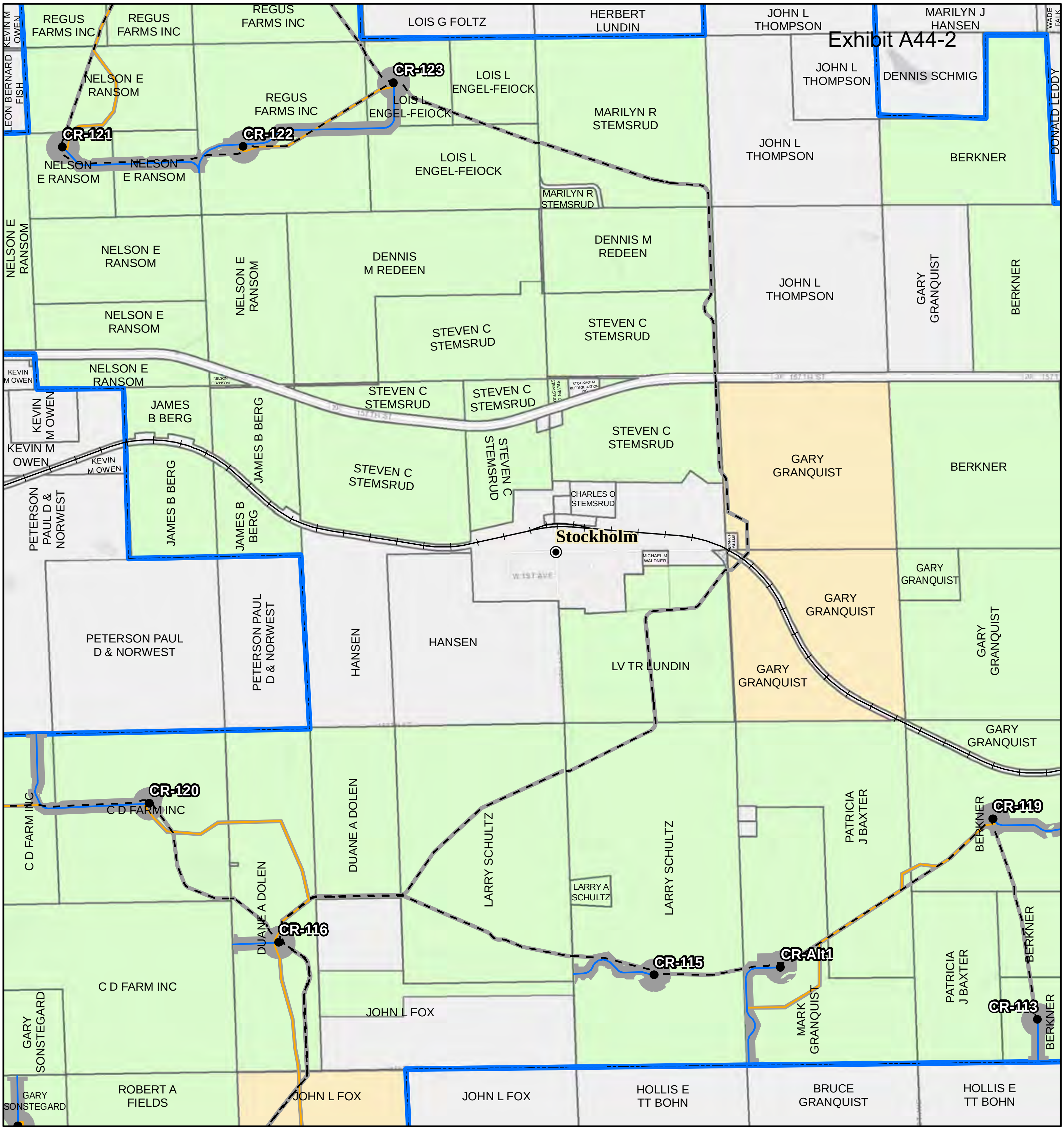
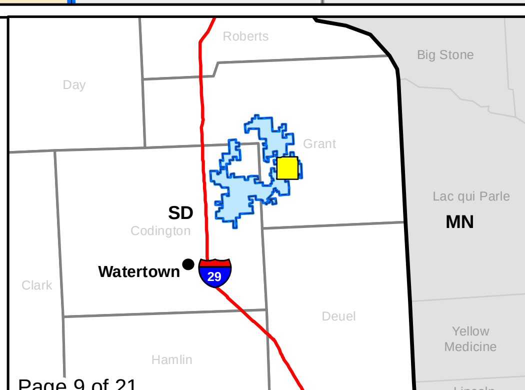


Figure 3a. Project Map

Crowned Ridge Wind Farm

Turbine		Construction Easement	
MET Tower		Parcel Boundary	
City		Project Boundary	
Access Road		County Boundary	
Collector Line		**Lease Status**	
Crane Path		Leased, Signed	
Railroad		Pending	
O&M Facility/ Substation		Under Option but Likely to Expire/Not Resign	
Batch Plant			
Laydown Yard			



Kilometers
0 0.5 1

Miles
0 0.25 0.5

Service Layer Credits: Esri, HERE, Garmin, © OpenStreetMap contributors, and the GIS user community
Quadrangle: Stockholm (1973)

Township/Range: T119N, R50W

017292

Grant County, South Dakota

Projection: NAD 1983 UTM Zone 14N

SWCA ENVIRONMENTAL CONSULTANTS

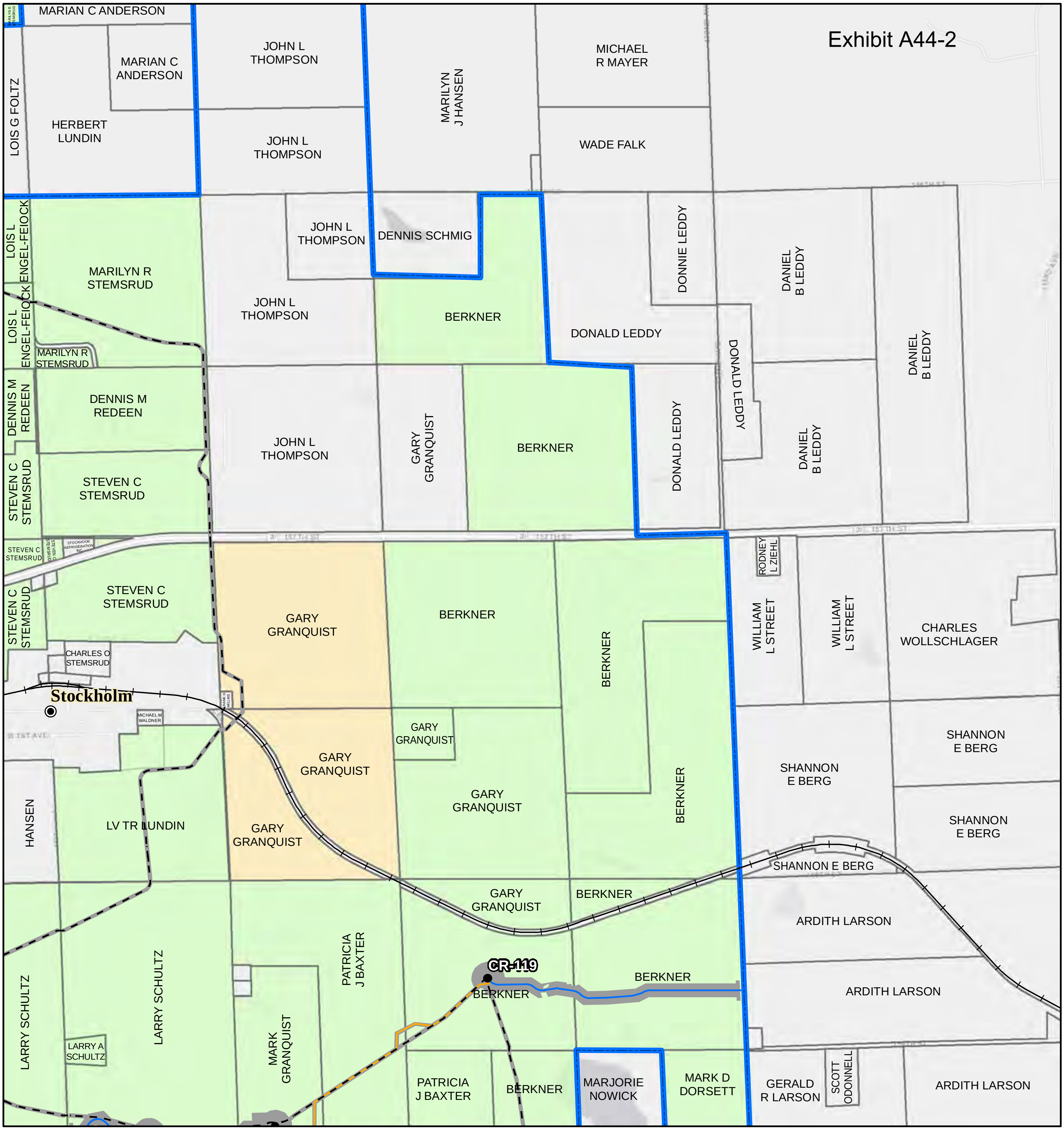


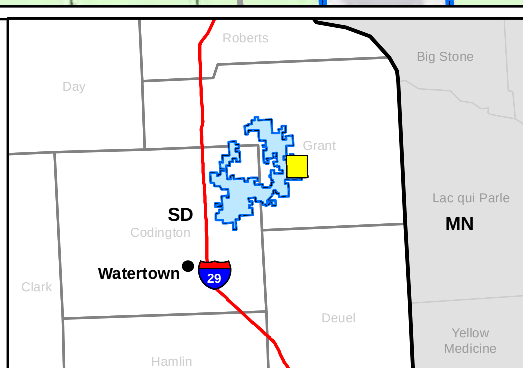
Figure 3a. Project Map

Crowned Ridge Wind Farm

- Turbine
- MET Tower
- City
- Access Road
- Collector Line
- Crane Path
- Railroad
- O&M Facility/ Substation
- Batch Plant
- Laydown Yard
- Construction Easement
- Parcel Boundary
- Project Boundary
- County Boundary

Lease Status

- Leased, Signed
- Pending
- Under Option but Likely to Expire/Not Resign



Page 10 of 21

Kilometers

0 0.5 1

Miles

0 0.25 0.5

Service Layer Credits: Esri, HERE, Garmin, © OpenStreetMap contributors, and the GIS user community

Quadrangle: Twin Brooks (1973), Stockholm (1973)

Township/Range: T119N, R50W, T119N, R49W

Grant County, South Dakota

017293

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Projection: NAD 1983 UTM Zone 14N

Exhibit A44-2

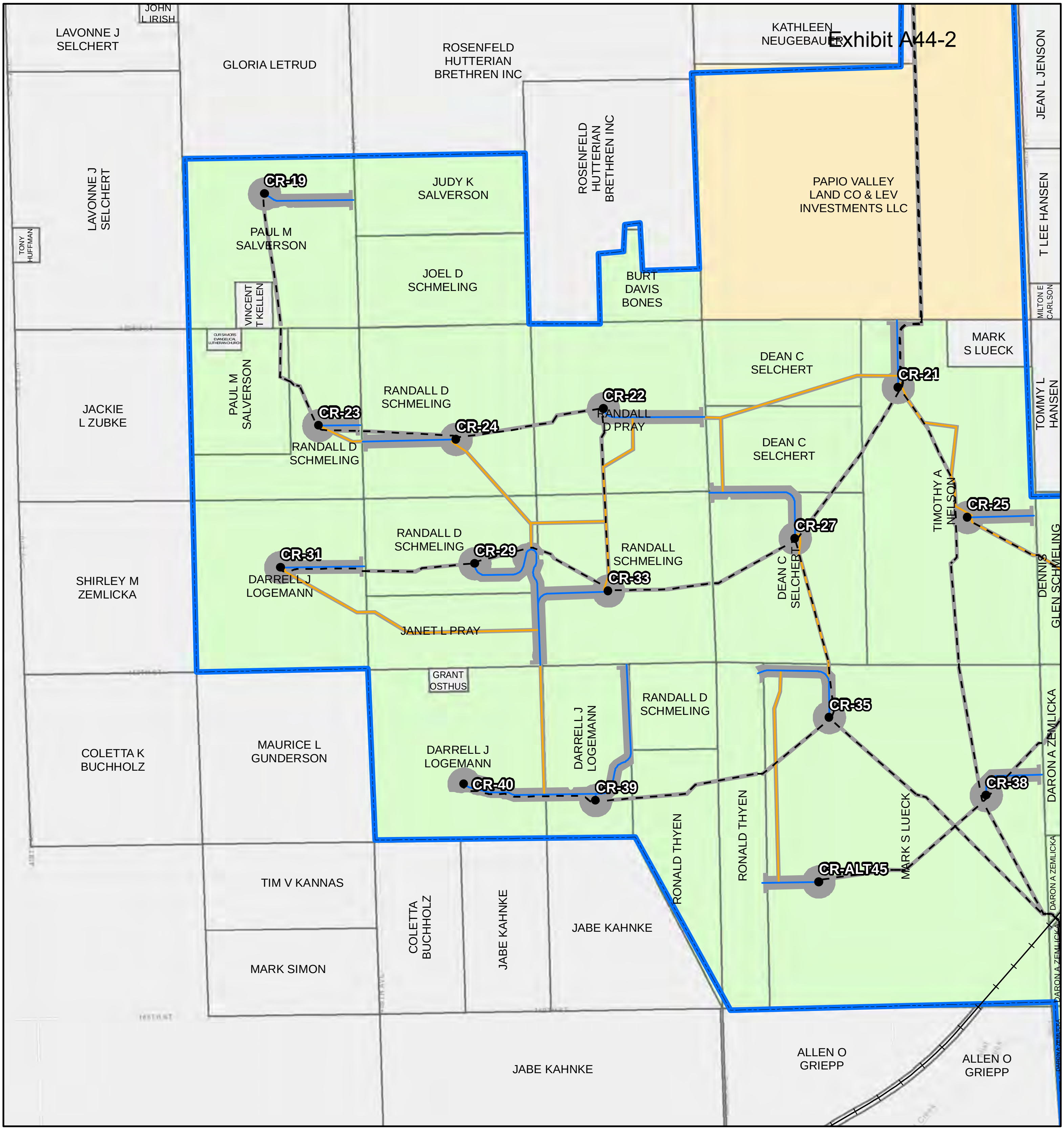


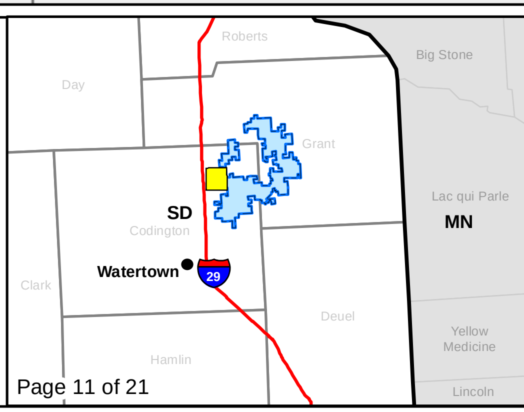
Figure 3a. Project Map

Crowned Ridge Wind Farm

- Turbine
- MET Tower
- City
- Access Road
- Collector Line
- Crane Path
- Railroad
- O&M Facility/ Substation
- Batch Plant
- Laydown Yard
- Construction Easement
- Parcel Boundary
- Project Boundary
- County Boundary

Lease Status

- Leased, Signed
- Pending
- Under Option but Likely to Expire/Not Resign



Kilometers: 0, 0.5, 1

Miles: 0, 0.25, 0.5

Service Layer Credits: Esri, HERE, Garmin, © OpenStreetMap contributors, and the GIS user community
Quadrangle: Still Lake SE (1970), South Shore (1973)
Township/Range: T119N, R52W, T119N, R51W, T118N, R52W, T118N, R51W
Codington County, South Dakota

Projection: NAD 1983 UTM Zone 14N

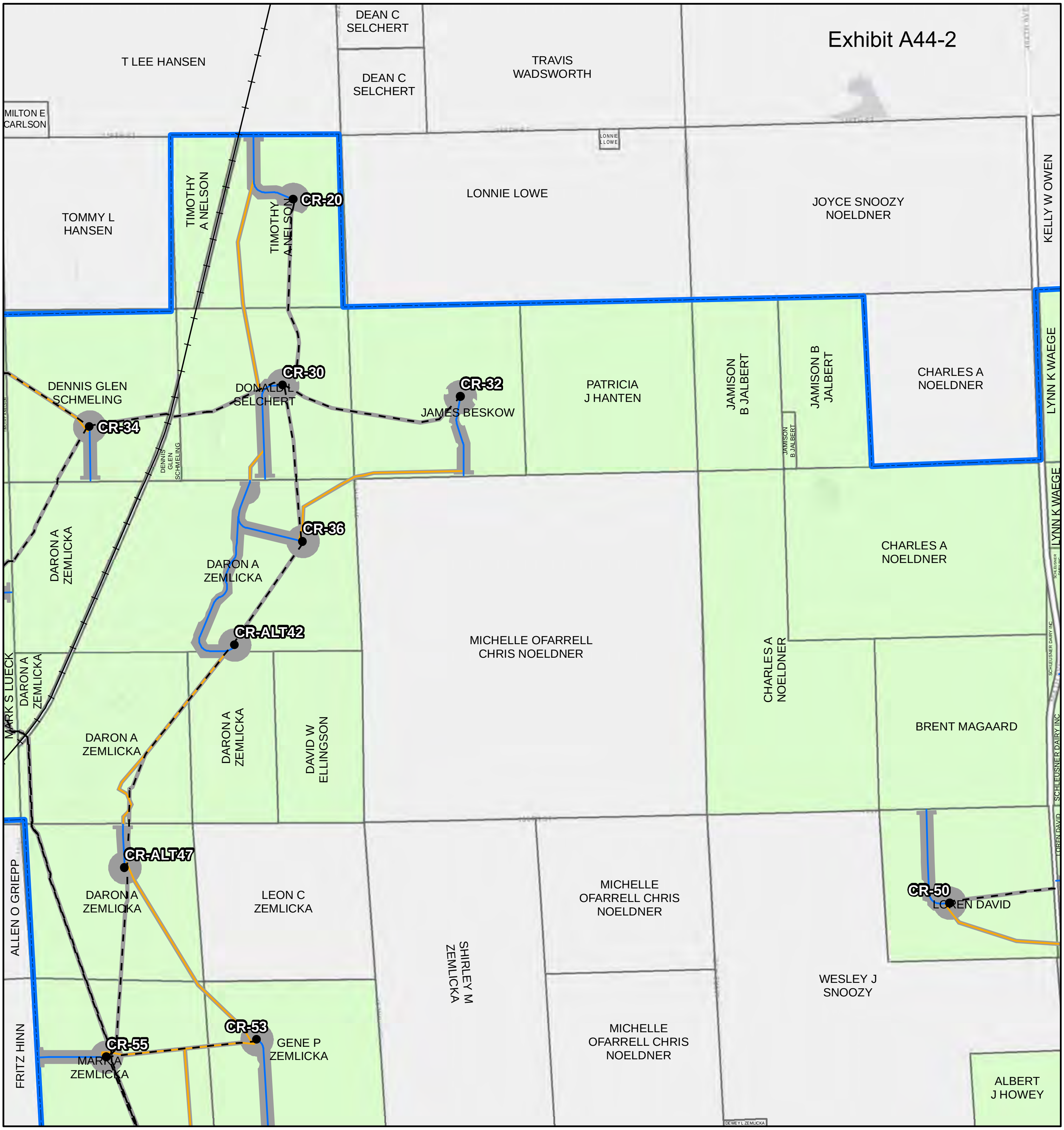


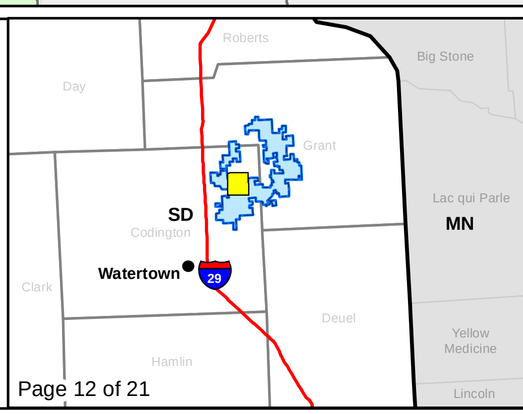
Figure 3a. Project Map

Crowned Ridge Wind Farm

- Turbine
- MET Tower
- City
- Access Road
- Collector Line
- Crane Path
- Railroad
- O&M Facility/ Substation
- Batch Plant
- Laydown Yard
- Construction Easement
- Parcel Boundary
- Project Boundary
- County Boundary

Lease Status

- Leased, Signed
- Pending
- Under Option but Likely to Expire/Not Resign



Page 12 of 21

Kilometers
0 0.5 1

Miles
0 0.25 0.5

Service Layer Credits: Esri, HERE, Garmin, © OpenStreetMap contributors, and the GIS user community
Quadrangle: South Shore (1973)

Township/Range: T119N, R51W, T118N, R51W
Codington County, South Dakota

017295

Page 000014

Projection: NAD 1983 UTM Zone 14N

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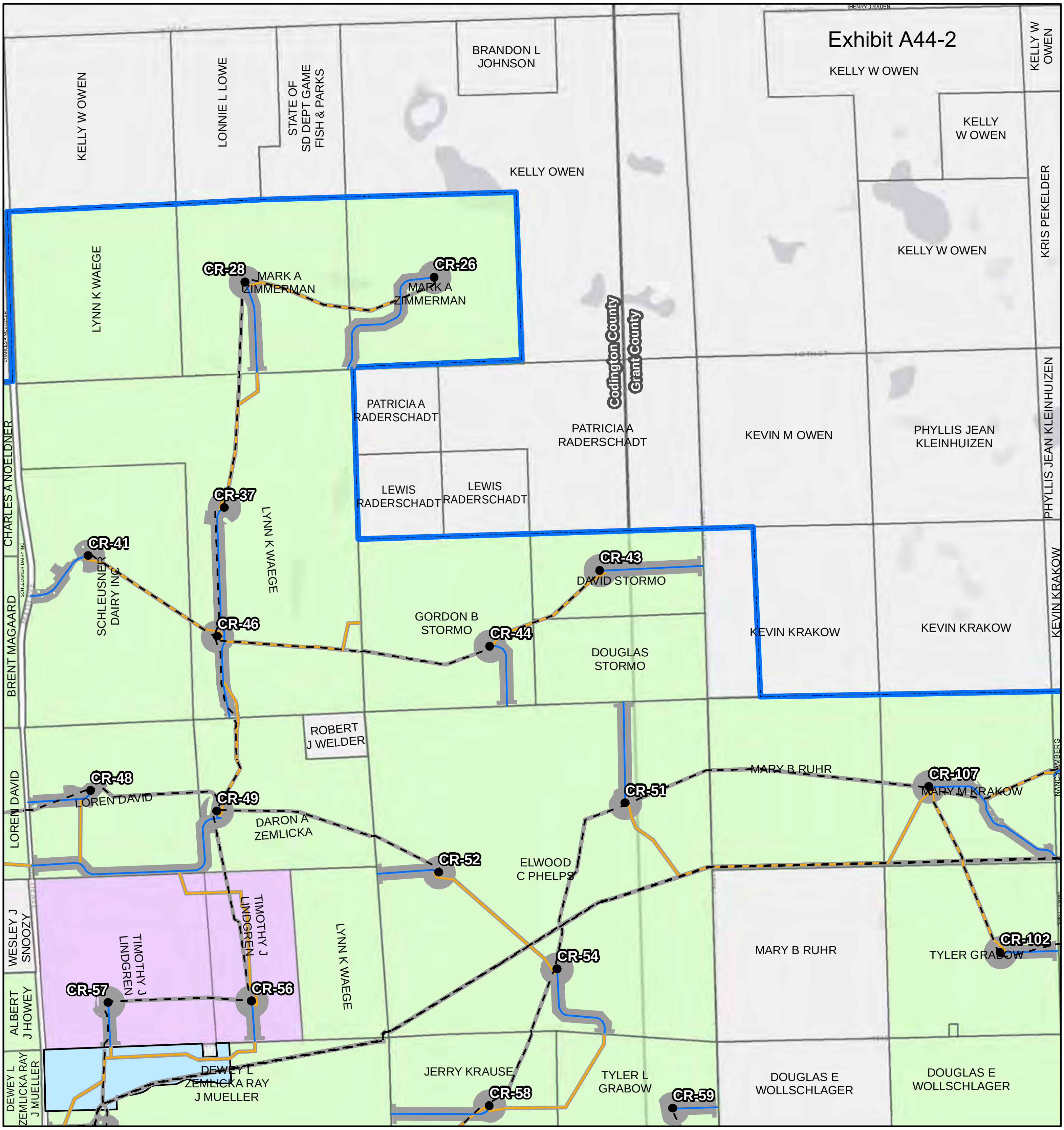


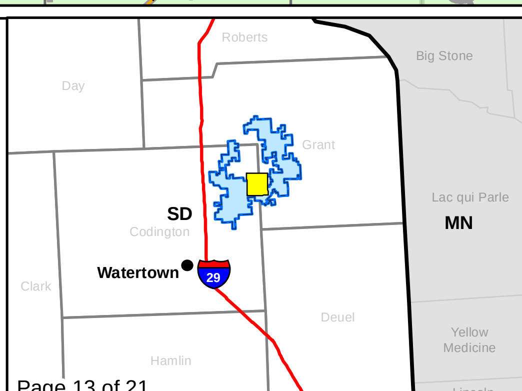
Figure 3a. Project Map

Crowned Ridge Wind Farm

- Turbine
- MET Tower
- City
- Access Road
- Collector Line
- Crane Path
- Railroad
- O&M Facility/ Substation
- Batch Plant
- Laydown Yard
- Construction Easement
- Parcel Boundary
- Project Boundary
- County Boundary

Lease Status

- Leased, Signed
- Pending
- Under Option but Likely to Expire/Not Resign



Kilometers
0 0.5 1

Miles
0 0.25 0.5

Service Layer Credits: Esri, HERE, Garmin, © OpenStreetMap contributors, and the GIS user community
Quadrangle: South Shore (1973), Stockholm (1973)
Township/Range: T119N, R51W, T119N, R50W, T118N, R51W, T118N, R50W
Codington and Grant Counties, South Dakota

Projection: NAD 1983 UTM Zone 14N

Exhibit A44-2

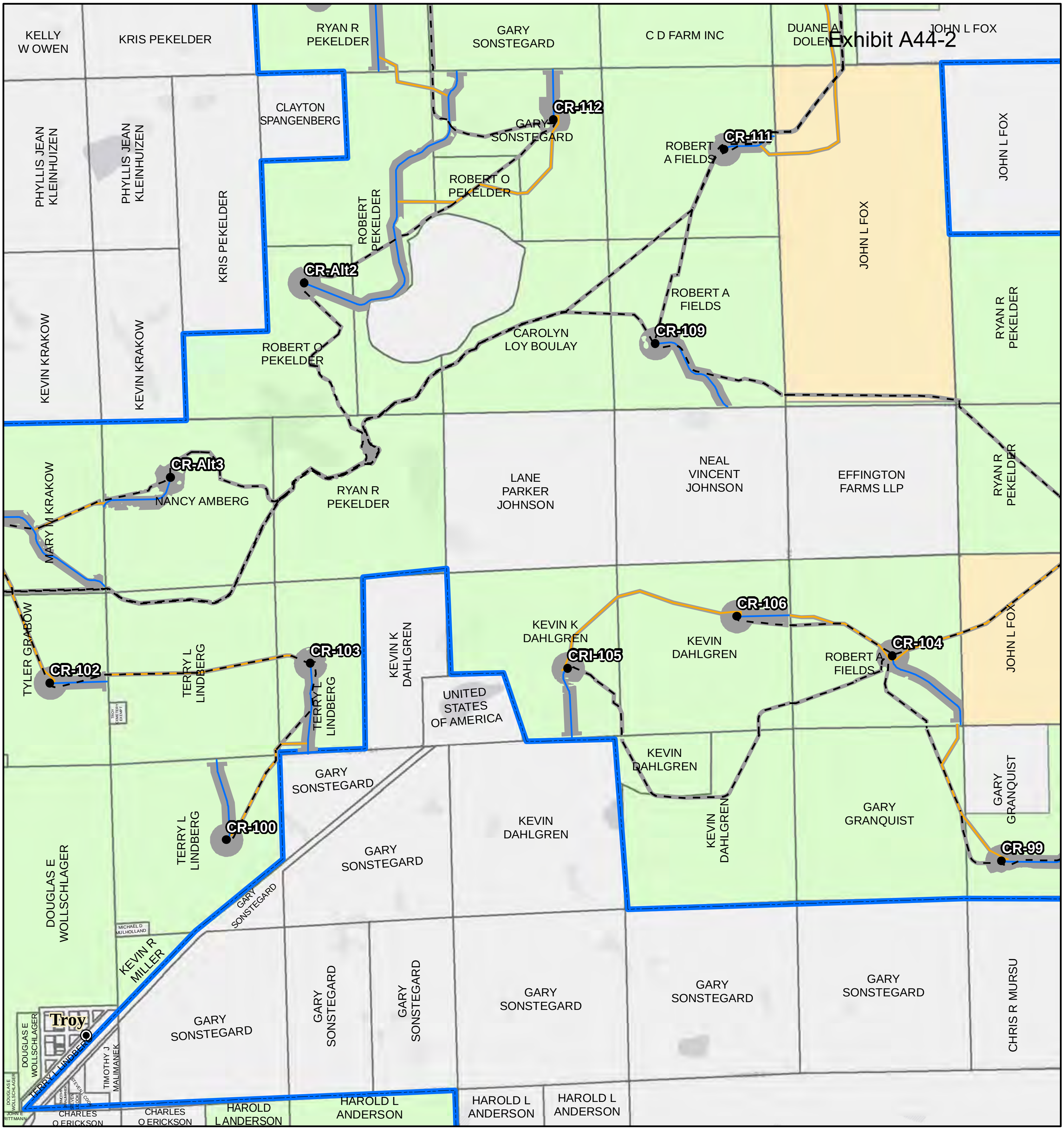
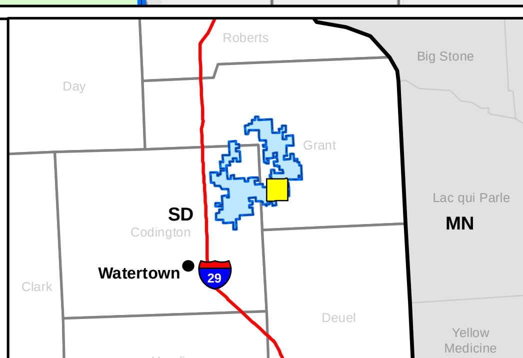


Figure 3a. Project Map

Crowned Ridge Wind Farm

Turbine	Construction Easement
MET Tower	Parcel Boundary
City	Project Boundary
Access Road	County Boundary
Collector Line	**Lease Status**
Crane Path	Leased, Signed
Railroad	Pending
O&M Facility/ Substation	Under Option but Likely to Expire/Not Resign
Batch Plant	
Laydown Yard	



Page 14 of 21

Kilometers
0 0.5 1

Miles
0 0.25 0.5

N W E S

Service Layer Credits: Esri, HERE, Garmin, © OpenStreetMap contributors, and the GIS user community

Quadrangle: Stockholm (1973)

Township/Range: T119N, R50W, T118N, R50W

Grant County, South Dakota

017297

Page 000016

Projection: NAD 1983 UTM Zone 14N

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Exhibit A44-2

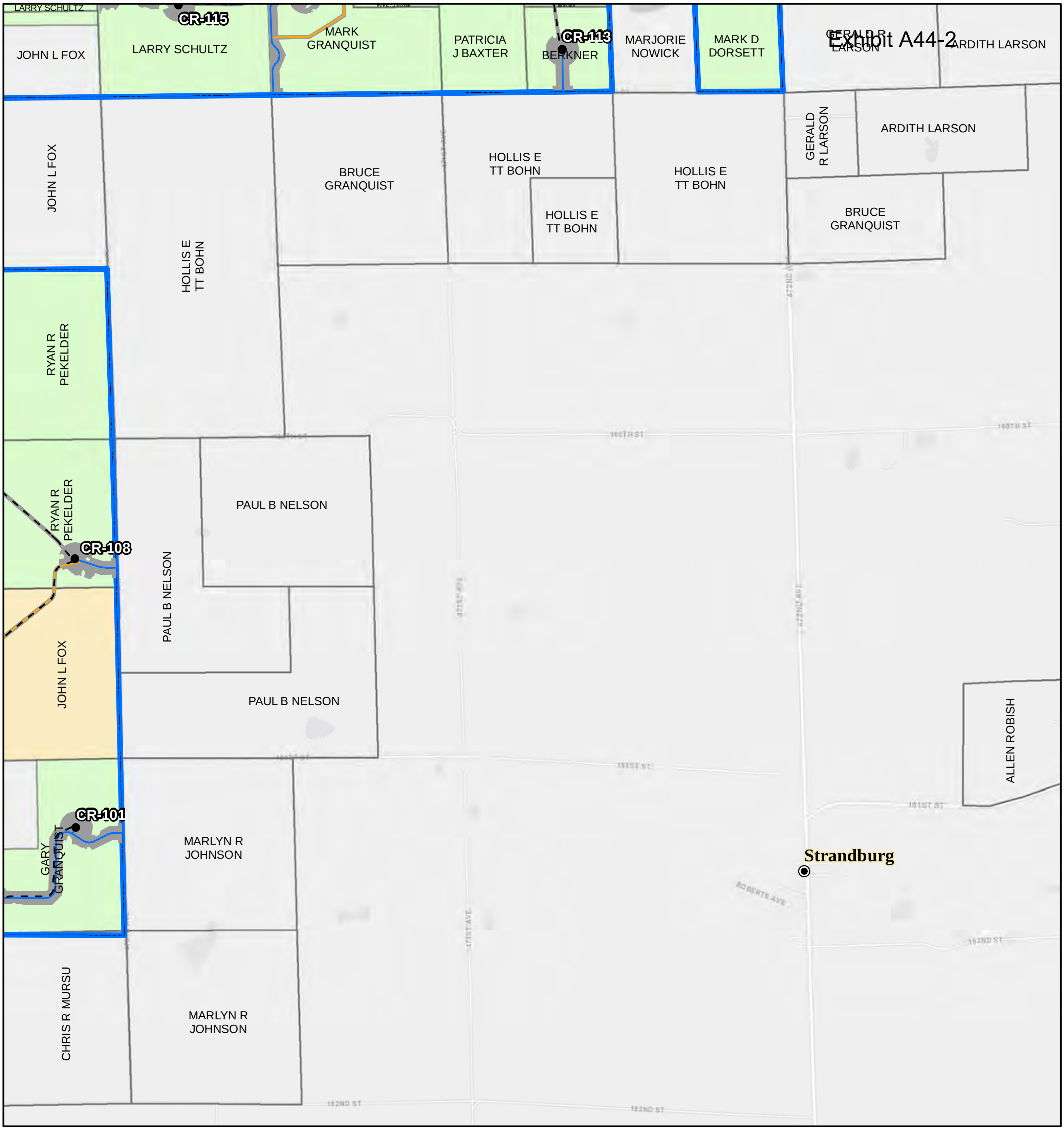


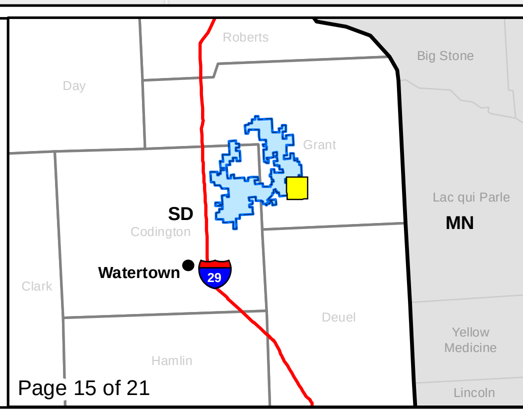
Figure 3a. Project Map

Crowned Ridge Wind Farm

- Turbine
- MET Tower
- City
- Access Road
- Collector Line
- Crane Path
- Railroad
- O&M Facility/ Substation
- Batch Plant
- Laydown Yard
- Construction Easement
- Parcel Boundary
- Project Boundary
- County Boundary

Lease Status

- Leased, Signed
- Pending
- Under Option but Likely to Expire/Not Resign



Kilometers
0 0.5 1

Miles
0 0.25 0.5

Service Layer Credits: Esri, HERE, Garmin, © OpenStreetMap contributors, and the GIS user community
Quadrangle: Stockholm (1973)

Township/Range: T119N, R50W, T118N, R50W
Grant County, South Dakota

Projection: NAD 1983 UTM Zone 14N

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017298

Exhibit A44-2

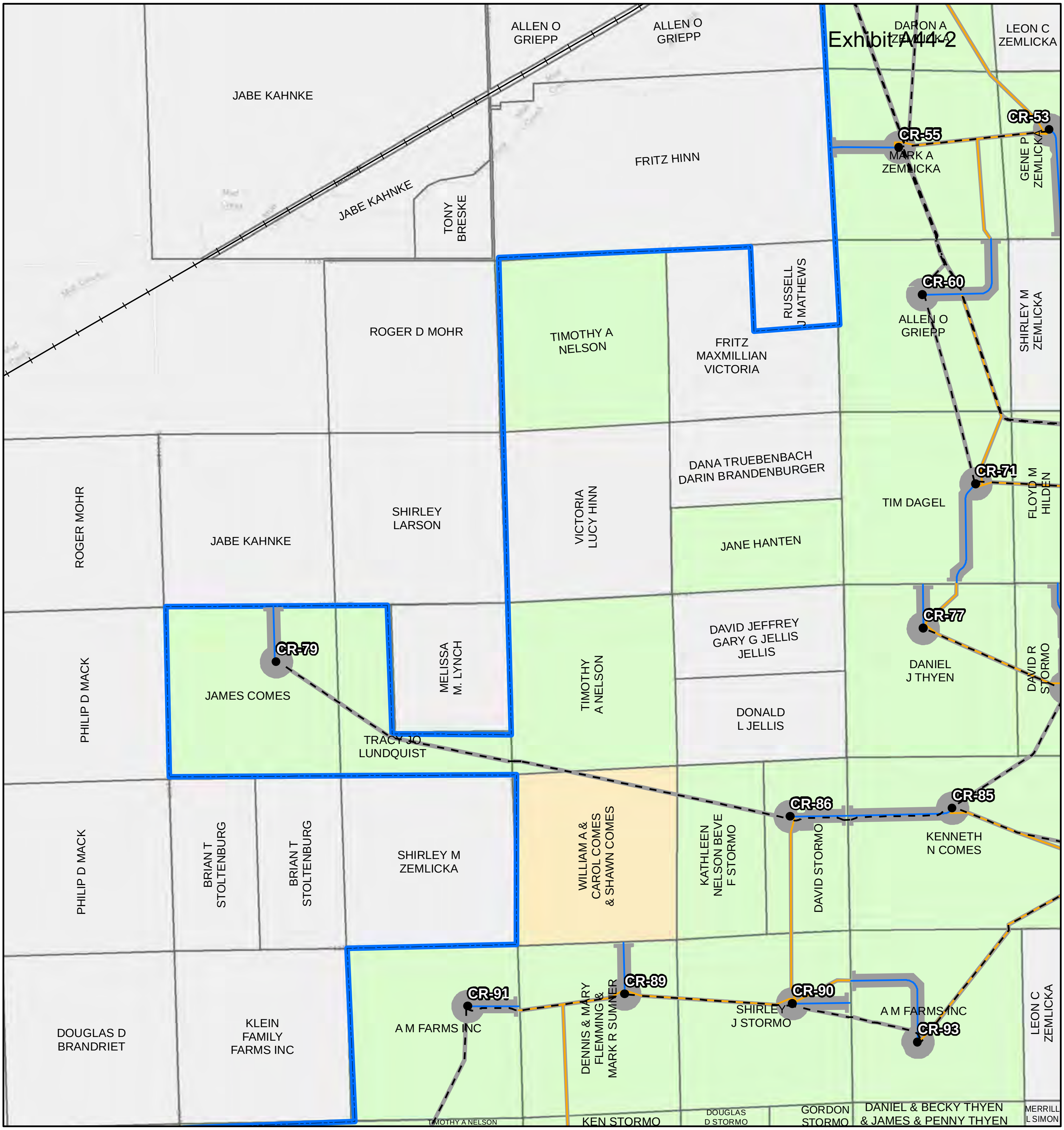


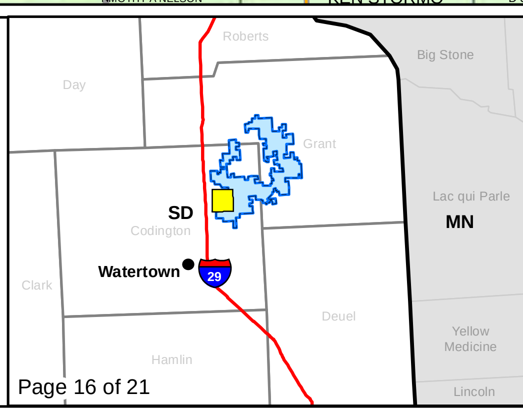
Figure 3a. Project Map

Crowned Ridge Wind Farm

- Turbine
- MET Tower
- City
- Access Road
- Collector Line
- Crane Path
- Railroad
- O&M Facility/ Substation
- Batch Plant
- Laydown Yard
- Construction Easement
- Parcel Boundary
- Project Boundary
- County Boundary

Lease Status

- Leased, Signed
- Pending
- Under Option but Likely to Expire/Not Resign



Kilometers

0 0.5 1

Miles

0 0.25 0.5

Service Layer Credits: Esri, HERE, Garmin, © OpenStreetMap contributors, and the GIS user community

Quadrangle: Still Lake SE (1970), South Shore (1973)

Township/Range: T118N, R52W, T118N, R51W

Codington County, South Dakota

017299

Projection: NAD 1983 UTM Zone 14N

SWCA ENVIRONMENTAL CONSULTANTS

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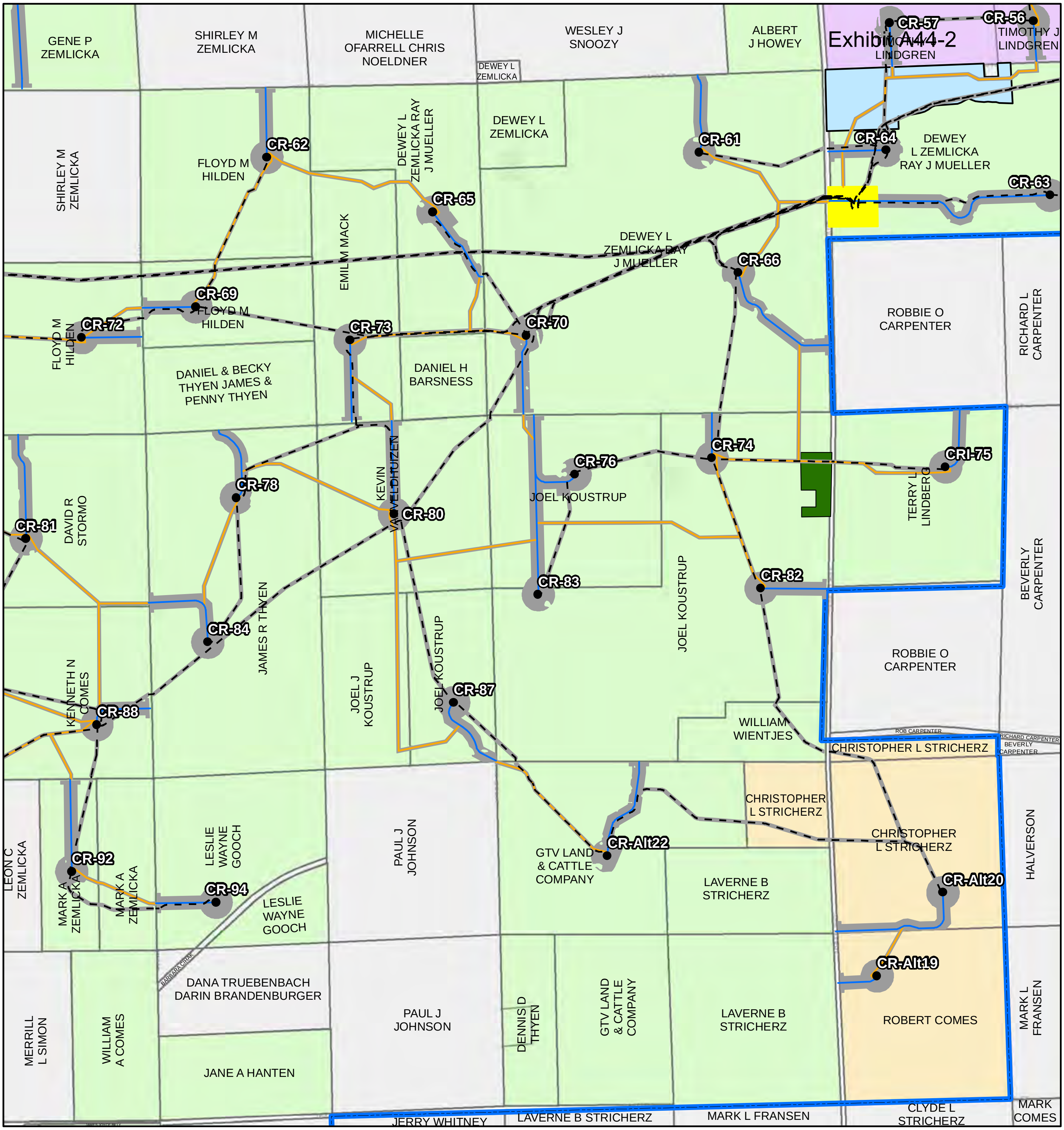


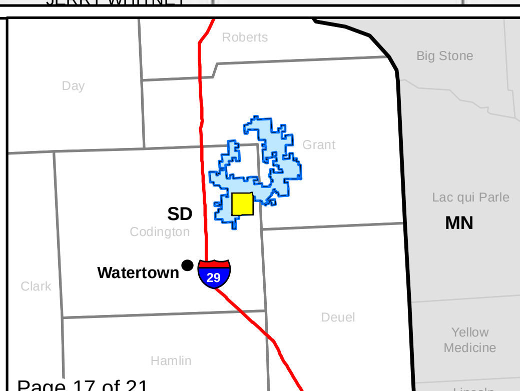
Figure 3a. Project Map

Crowned Ridge Wind Farm

- Turbine
- MET Tower
- City
- Access Road
- Collector Line
- Crane Path
- Railroad
- O&M Facility/ Substation
- Batch Plant
- Laydown Yard
- Construction Easement
- Parcel Boundary
- Project Boundary
- County Boundary

Lease Status

- Leased, Signed
- Pending
- Under Option but Likely to Expire/Not Resign



Kilometers
0 0.5 1
Miles
0 0.25 0.5

Service Layer Credits: Esri, HERE, Garmin, © OpenStreetMap contributors, and the GIS user community
Quadrangle: South Shore (1973)

Township/Range: T118N, R51W

Codington County, South Dakota

Projection: NAD 1983 UTM Zone 14N

SWCA ENVIRONMENTAL CONSULTANTS

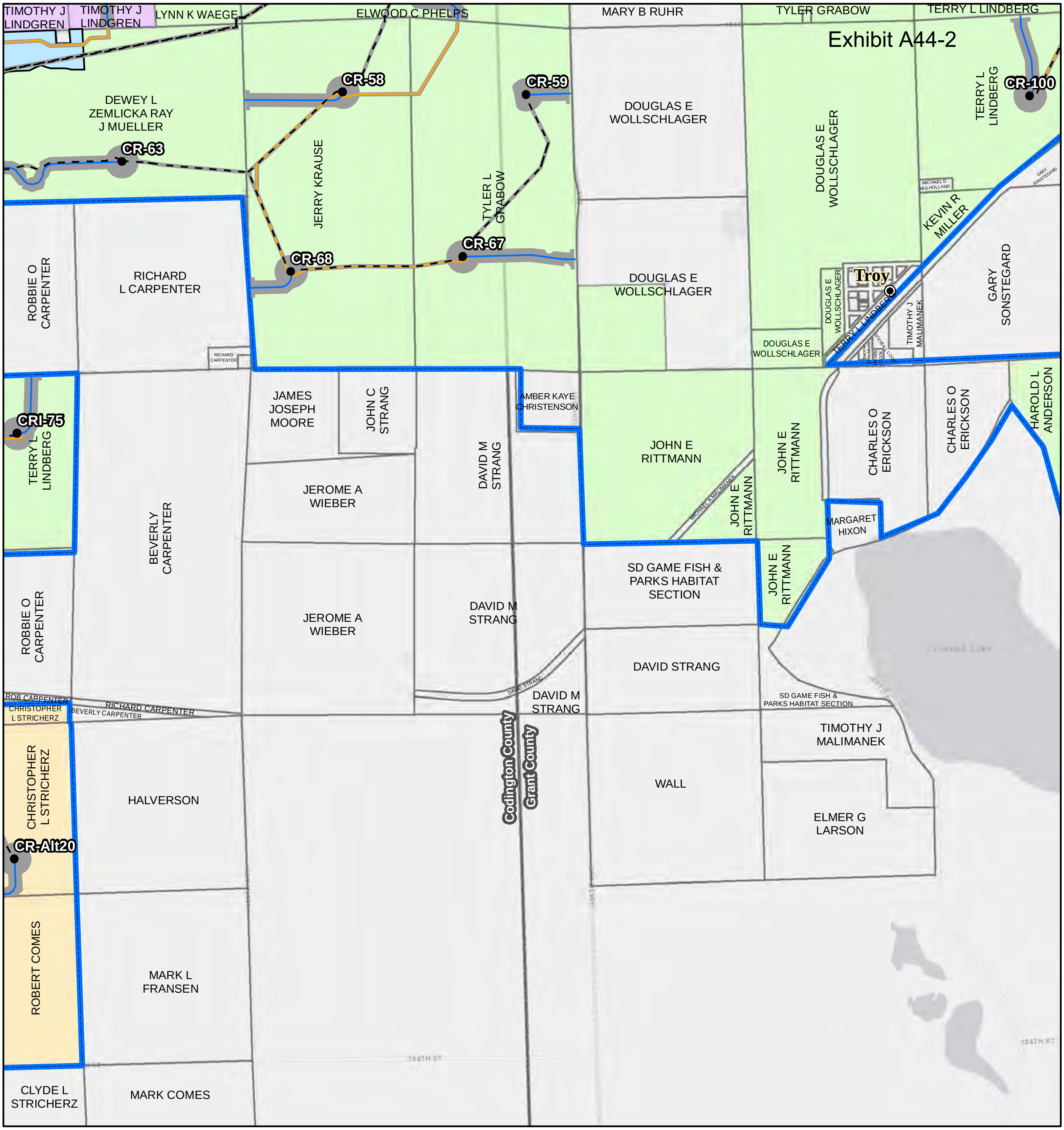
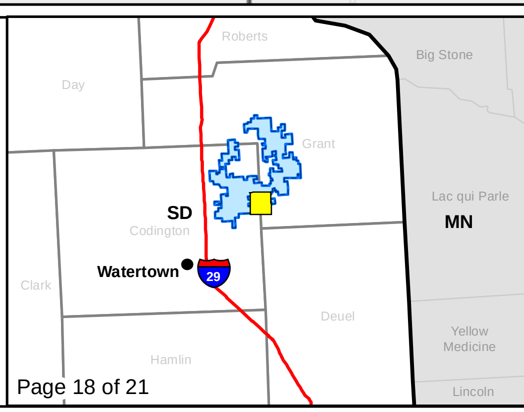


Figure 3a. Project Map

Crowned Ridge Wind Farm

Turbine	Construction Easement
MET Tower	Parcel Boundary
City	Project Boundary
Access Road	County Boundary
Collector Line	**Lease Status**
Crane Path	Leased, Signed
Railroad	Pending
O&M Facility/ Substation	Under Option but Likely to Expire/Not Resign
Batch Plant	
Laydown Yard	



Kilometers
0 0.5 1

Miles
0 0.25 0.5

Service Layer Credits: Esri, HERE, Garmin, © OpenStreetMap contributors, and the GIS user community
Quadrangle: South Shore (1973), Stockholm (1973)
Township/Range: T118N, R51W, T118N, R50W
Codington and Grant Counties, South Dakota

017301

Projection: NAD 1983 UTM Zone 14N

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Exhibit A44-2

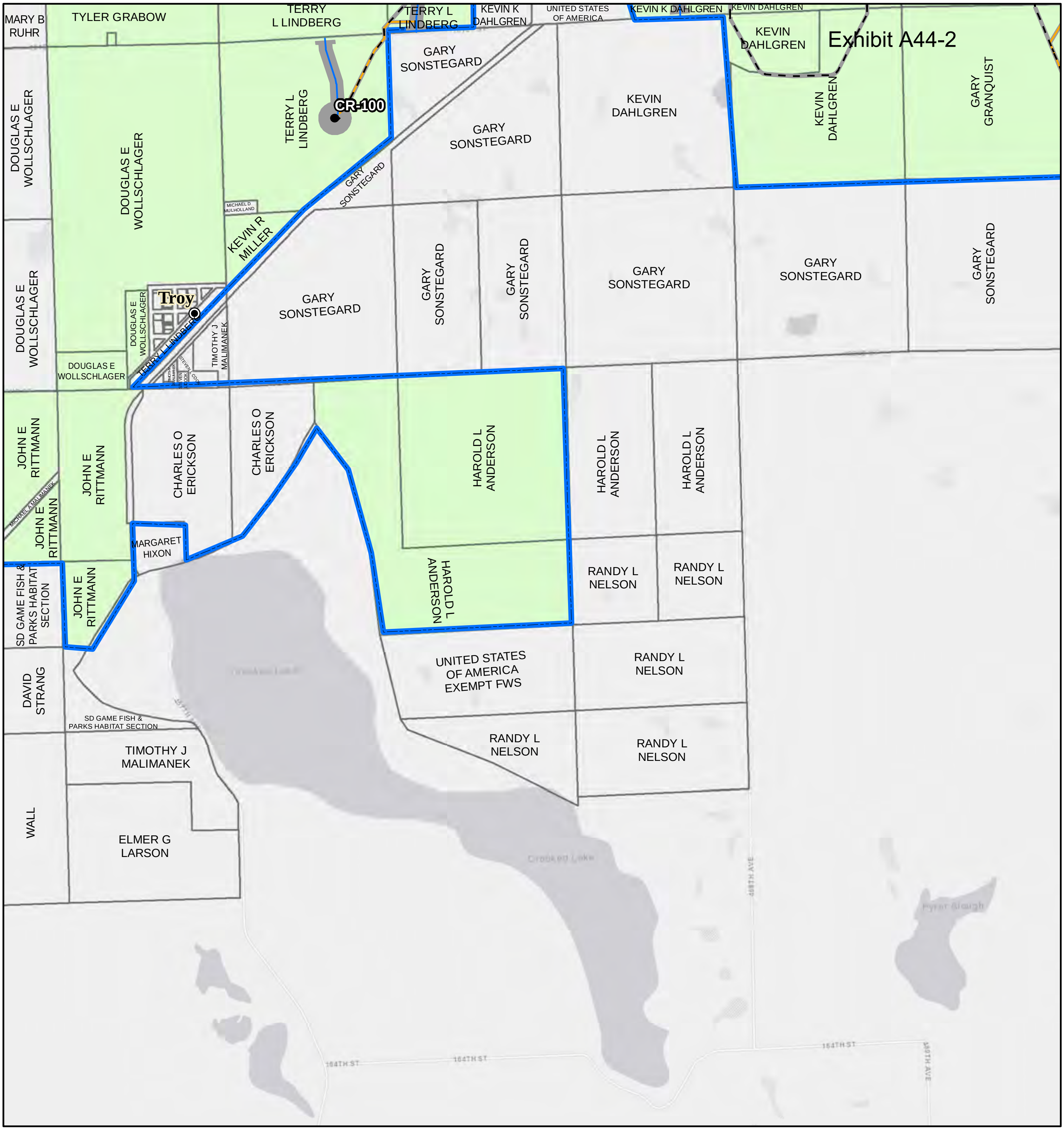


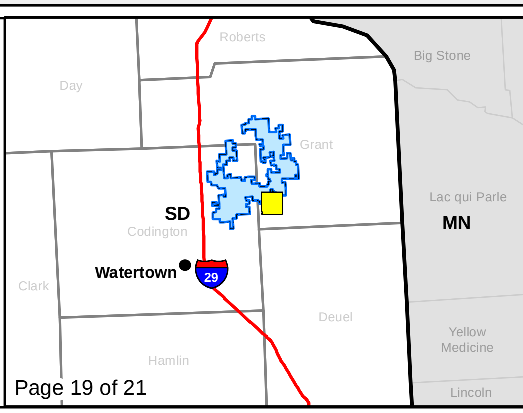
Figure 3a. Project Map

Crowned Ridge Wind Farm

- Turbine
- MET Tower
- City
- Access Road
- Collector Line
- Crane Path
- Railroad
- O&M Facility/ Substation
- Batch Plant
- Laydown Yard
- Construction Easement
- Parcel Boundary
- Project Boundary
- County Boundary

Lease Status

- Leased, Signed
- Pending
- Under Option but Likely to Expire/Not Resign



Kilometers
0 0.5 1

Miles
0 0.25 0.5

Service Layer Credits: Esri, HERE, Garmin, © OpenStreetMap contributors, and the GIS user community
Quadrangle: South Shore (1973), Stockholm (1973)
Township/Range: T118N, R50W

Grant County, South Dakota

Projection: NAD 1983 UTM Zone 14N

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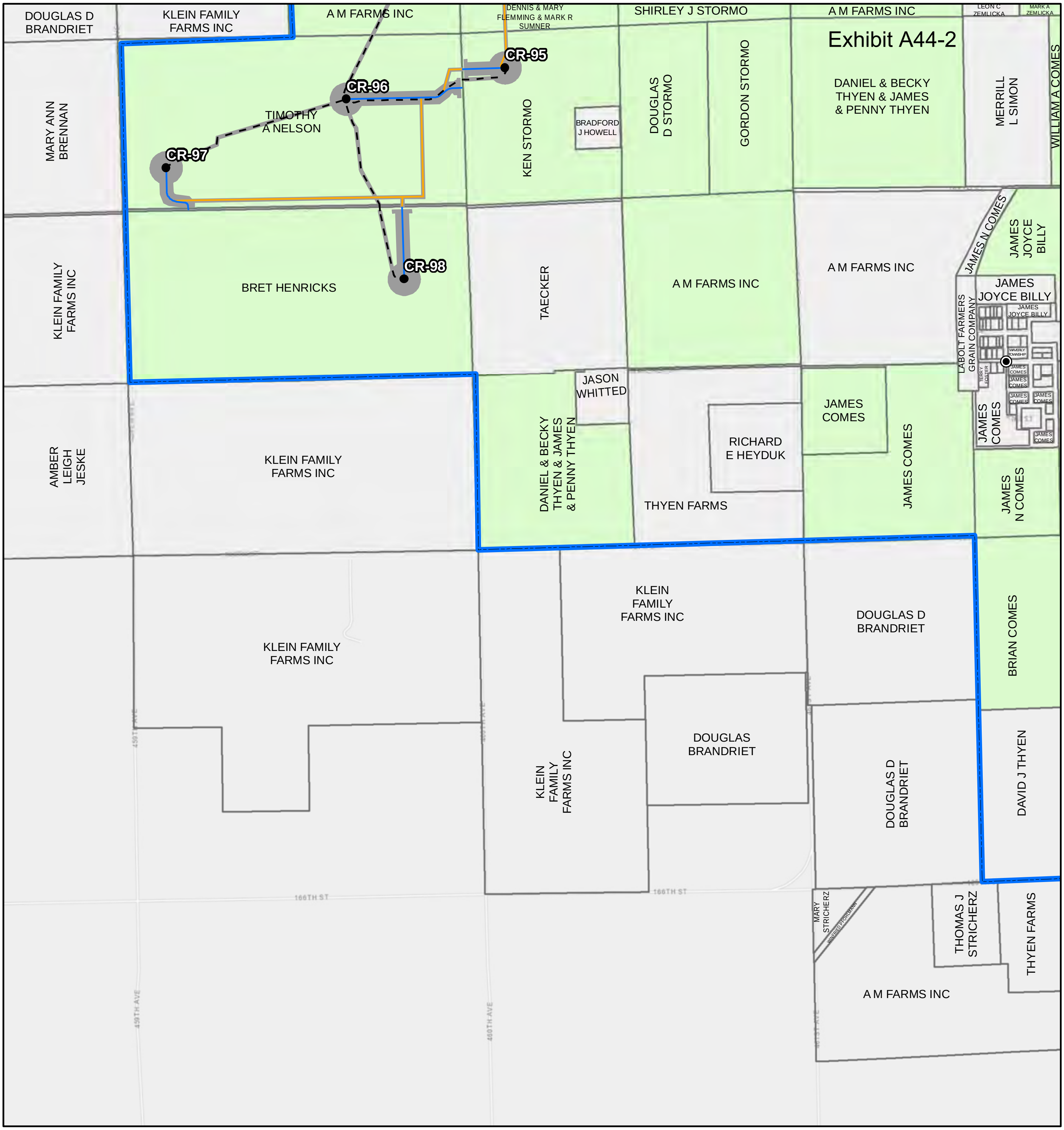


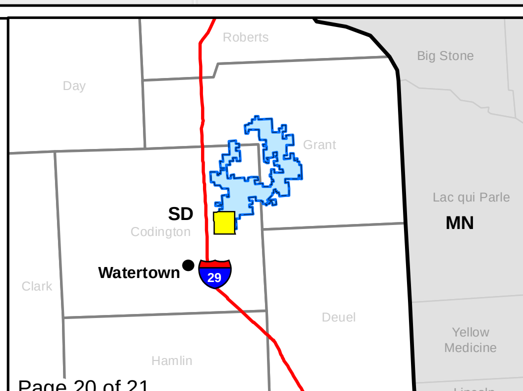
Figure 3a. Project Map

Crowned Ridge Wind Farm

- Turbine
- MET Tower
- City
- Access Road
- Collector Line
- Crane Path
- Railroad
- O&M Facility/ Substation
- Batch Plant
- Laydown Yard
- Construction Easement
- Parcel Boundary
- Project Boundary
- County Boundary

Lease Status

- Leased, Signed
- Pending
- Under Option but Likely to Expire/Not Resign



Kilometers
0 0.5 1

Miles
0 0.25 0.5

Service Layer Credits: Esri, HERE, Garmin, © OpenStreetMap contributors, and the GIS user community

Quadrangle: Still Lake SE (1970), Watertown East (1969), South Shore (1973), Kranzburg (1970)

Township/Range: T118N, R52W, T118N, R51W, T117N, R52W, T117N, R51W

Codington County, South Dakota

SWCA ENVIRONMENTAL CONSULTANTS

Projection: NAD 1983 UTM Zone 14N

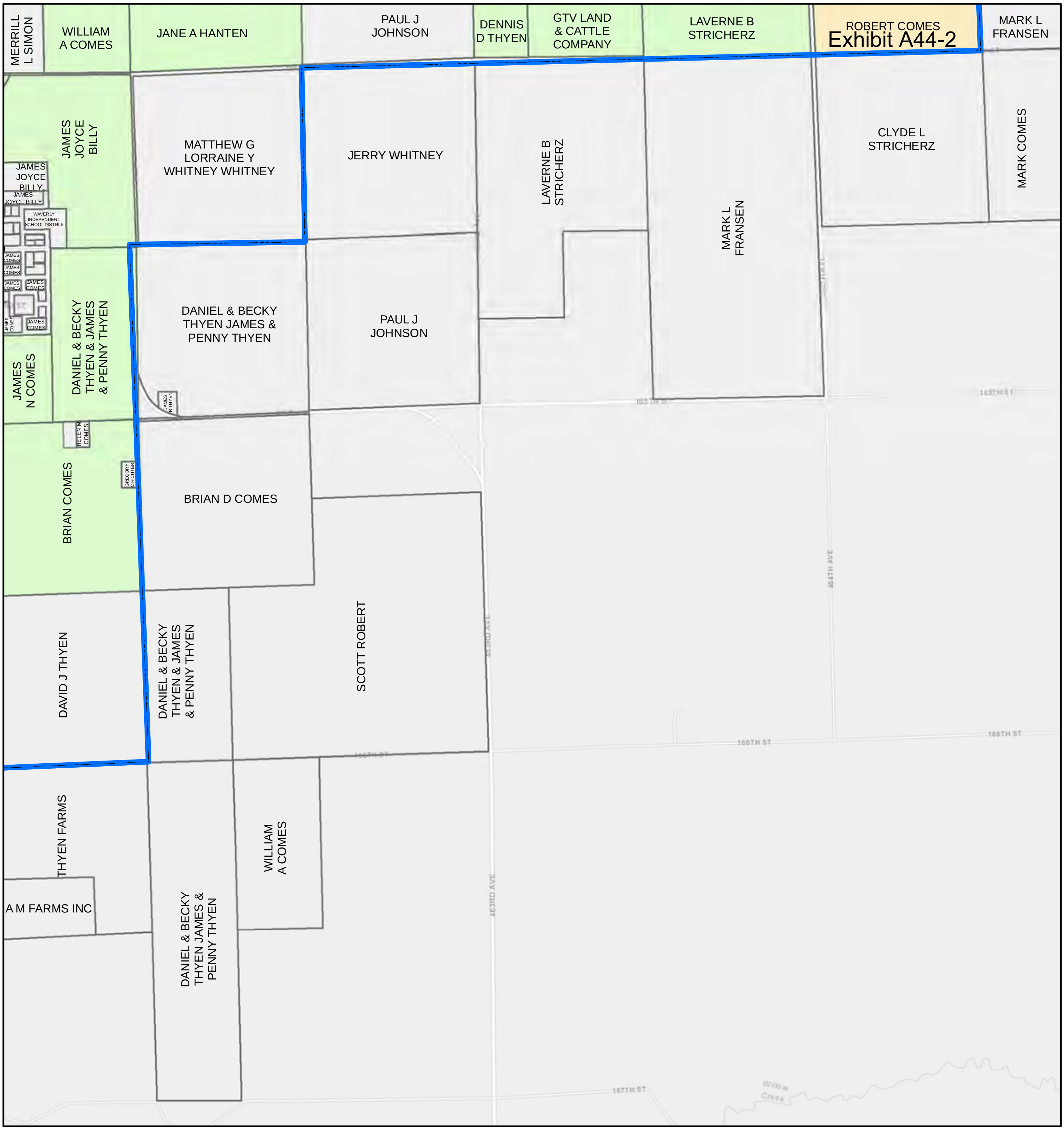
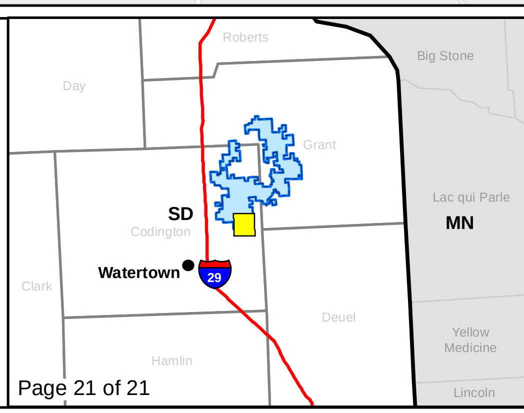


Figure 3a. Project Map

Crowned Ridge Wind Farm

Turbine	Construction Easement		
MET Tower	Parcel Boundary		
City	Project Boundary		
Access Road	County Boundary		
Collector Line	**Lease Status**		
Crane Path	Leased, Signed		
Railroad	Pending		
O&M Facility/ Substation	Under Option but Likely to Expire/Not Resign		
Batch Plant			
Laydown Yard			



Kilometers
0 0.5 1

Miles
0 0.25 0.5

Service Layer Credits: Esri, HERE, Garmin, © OpenStreetMap contributors, and the GIS user community
Quadrangle: South Shore (1973), Kranzburg (1970)
Township/Range: T118N, R51W, T117N, R51W
Codington County, South Dakota

Projection: NAD 1983 UTM Zone 14N

SWCA ENVIRONMENTAL CONSULTANTS

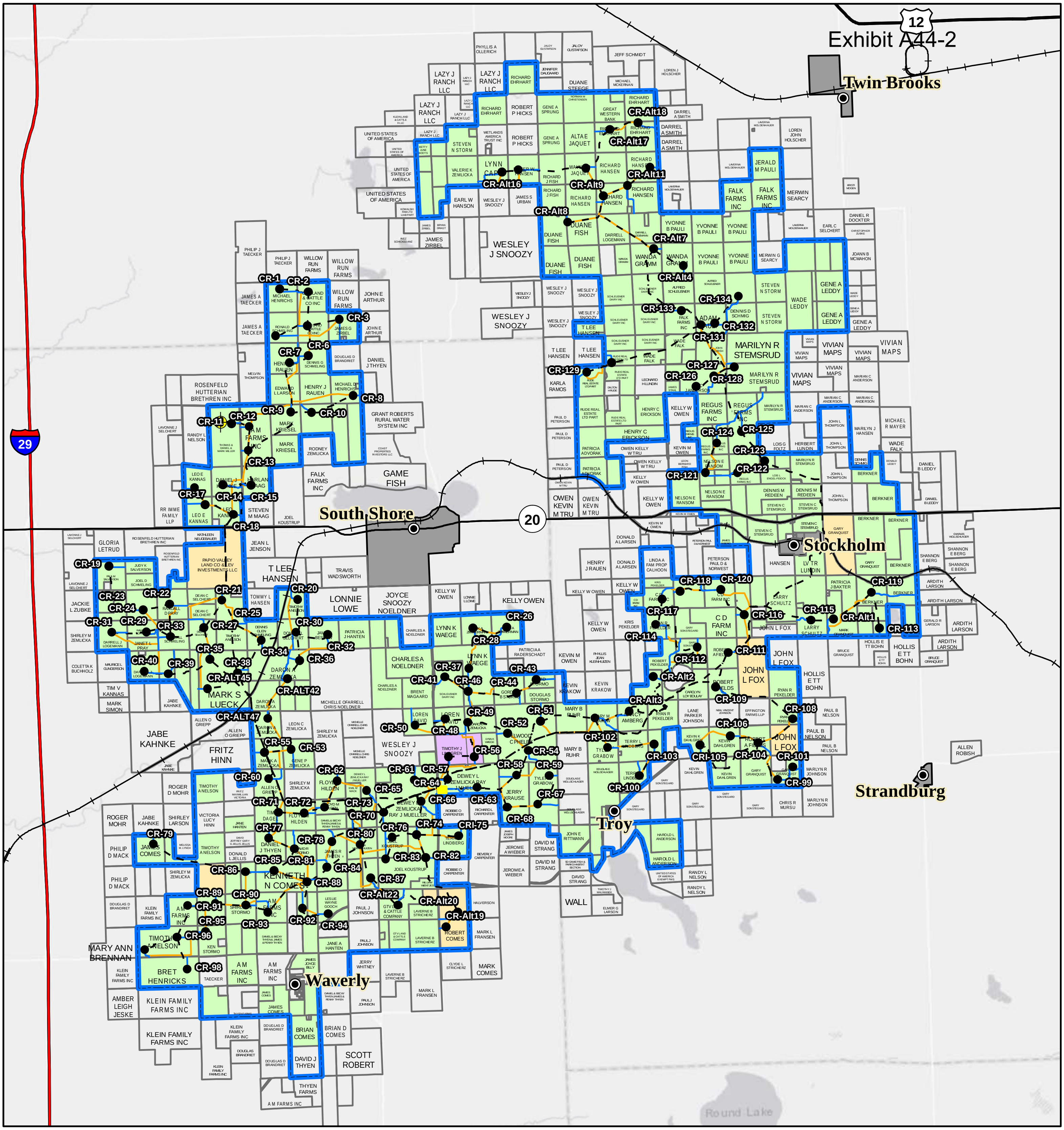


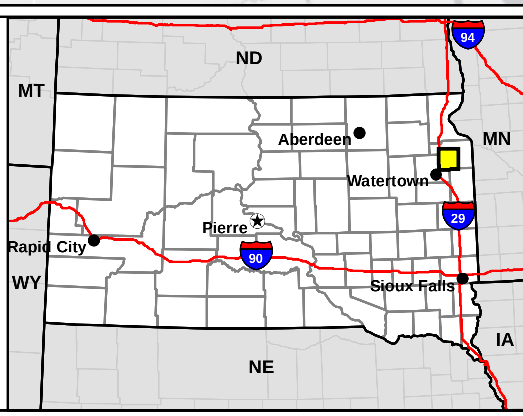
Figure 3a. Project Map

Crowned Ridge Wind Farm

- MET Tower
- Turbine
- City
- Access Road
- Collector Line
- Crane Path
- Railroad
- Interstate Highway
- U.S. Highway
- State Highway
- O&M Facility/ Substation
- Town Boundary
- Project Boundary
- Parcel Boundary

Lease Status

- Leased, Signed
- Pending Approval
- Under Option but Likely to Expire/Not Resign



Kilometers
0 2.5 5

Miles
0 2.5 5

Base Map: World Light Gray Canvas Base
Sources: Esri, HERE, Garmin, © OpenStreetMap contributors, and the GIS user community
Codington and Grant Counties, South Dakota

017305 Page 000024

SWCA ENVIRONMENTAL CONSULTANTS

Projection: NAD 1983 UTM Zone 14N

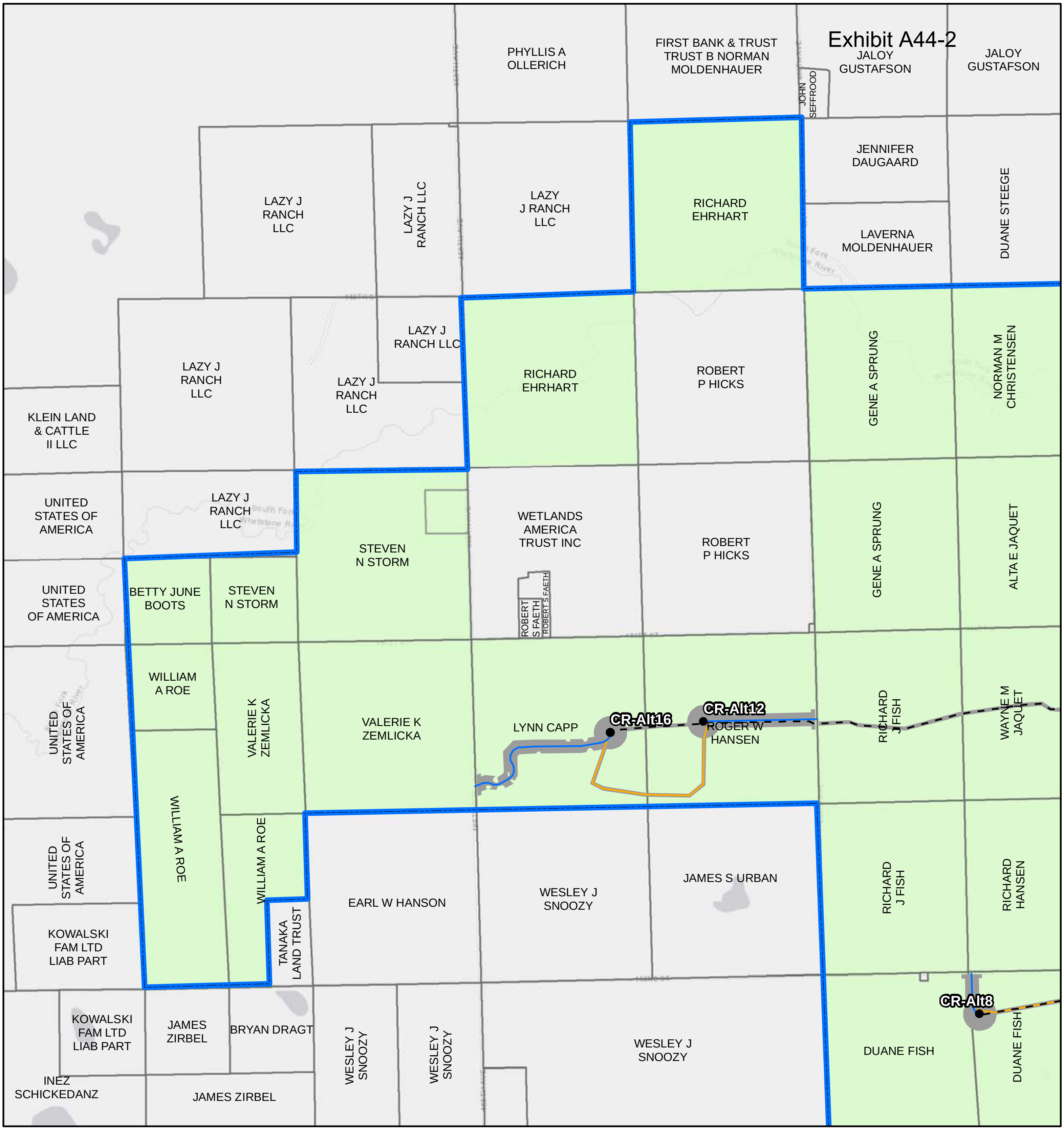


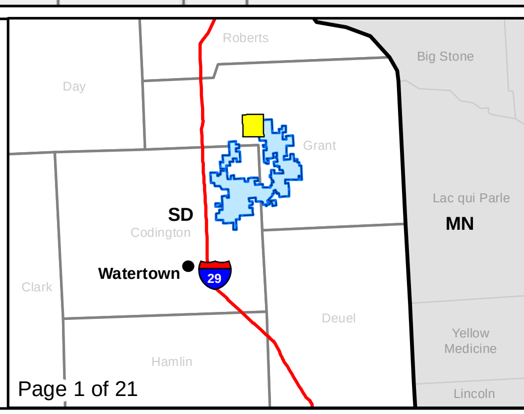
Figure 3a. Project Map

Crowned Ridge Wind Farm

- Turbine
- MET Tower
- City
- Access Road
- Collector Line
- Crane Path
- Railroad
- O&M Facility/ Substation
- Batch Plant
- Laydown Yard
- Construction Easement
- Parcel Boundary
- Project Boundary
- County Boundary

Lease Status

- Leased, Signed
- Pending
- Under Option but Likely to Expire/Not Resign



Page 1 of 21

Kilometers
0 0.5 1

Miles
0 0.25 0.5

Service Layer Credits: Esri, HERE, Garmin, © OpenStreetMap contributors, and the GIS user community
Quadrangle: Antelope Valley (1973), Twin Brooks (1973)
Township/Range: T120N, R51W, T120N, R50W
Grant County, South Dakota

017306

Page 000025

SWCA ENVIRONMENTAL CONSULTANTS

Projection: NAD 1983 UTM Zone 14N

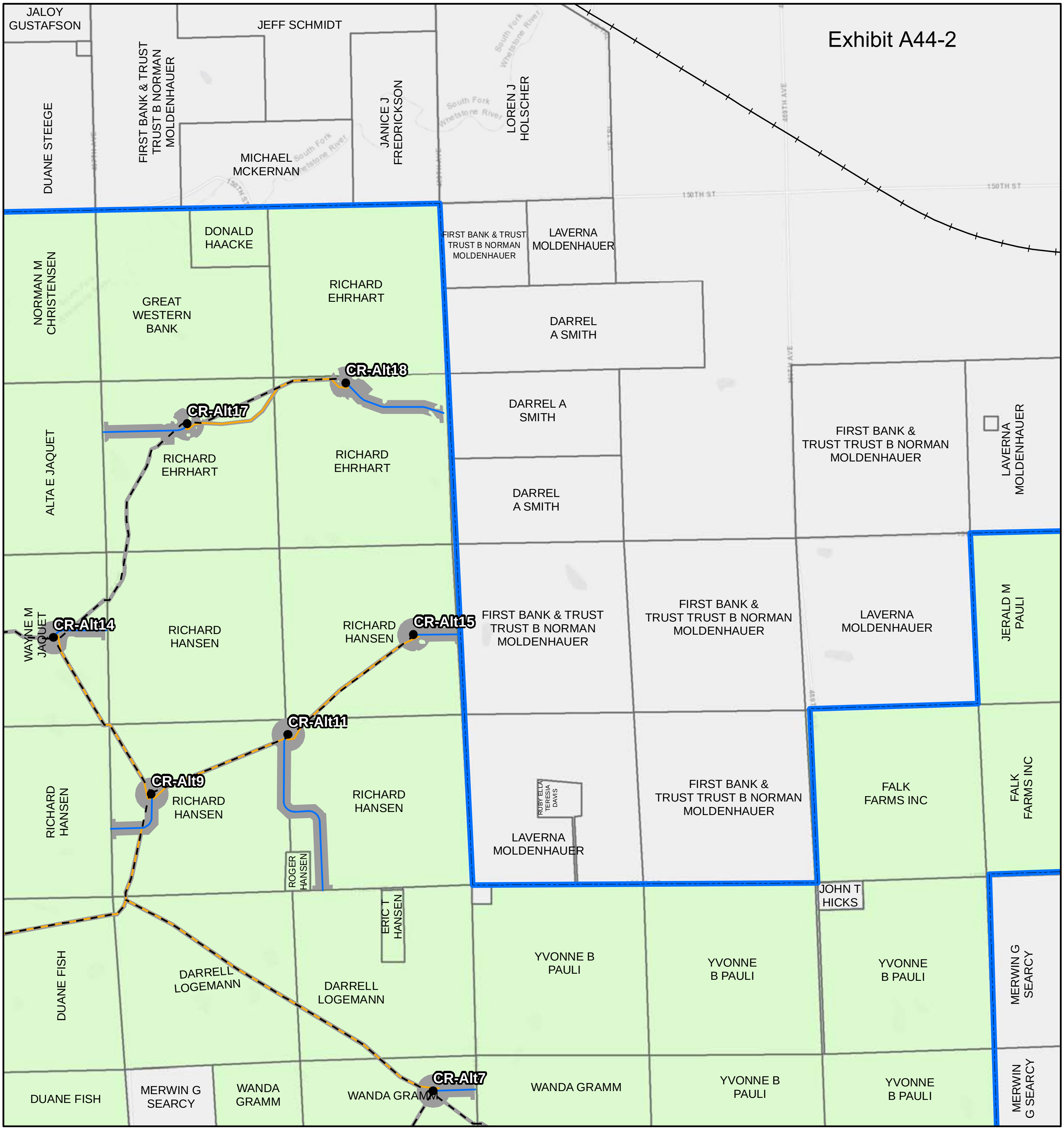


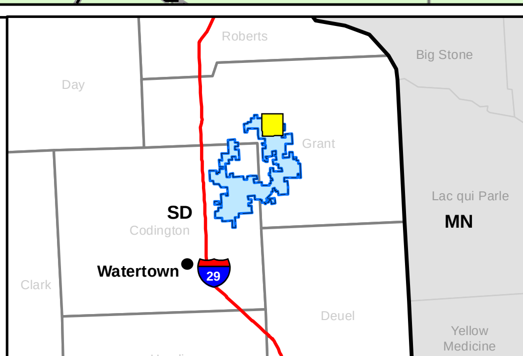
Figure 3a. Project Map

Crowned Ridge Wind Farm

- Turbine
- MET Tower
- City
- Access Road
- Collector Line
- Crane Path
- Railroad
- O&M Facility/ Substation
- Batch Plant
- Laydown Yard
- Construction Easement
- Parcel Boundary
- Project Boundary
- County Boundary

Lease Status

- Leased, Signed
- Pending
- Under Option but Likely to Expire/Not Resign



Kilometers
0 0.5 1

Miles
0 0.25 0.5

Service Layer Credits: Esri, HERE, Garmin, © OpenStreetMap contributors, and the GIS user community

Quadrangle: Twin Brooks (1973)

Township/Range: T120N, R50W

017307

Grant County, South Dakota

Projection: NAD 1983 UTM Zone 14N

SWCA ENVIRONMENTAL CONSULTANTS

Exhibit A44-2

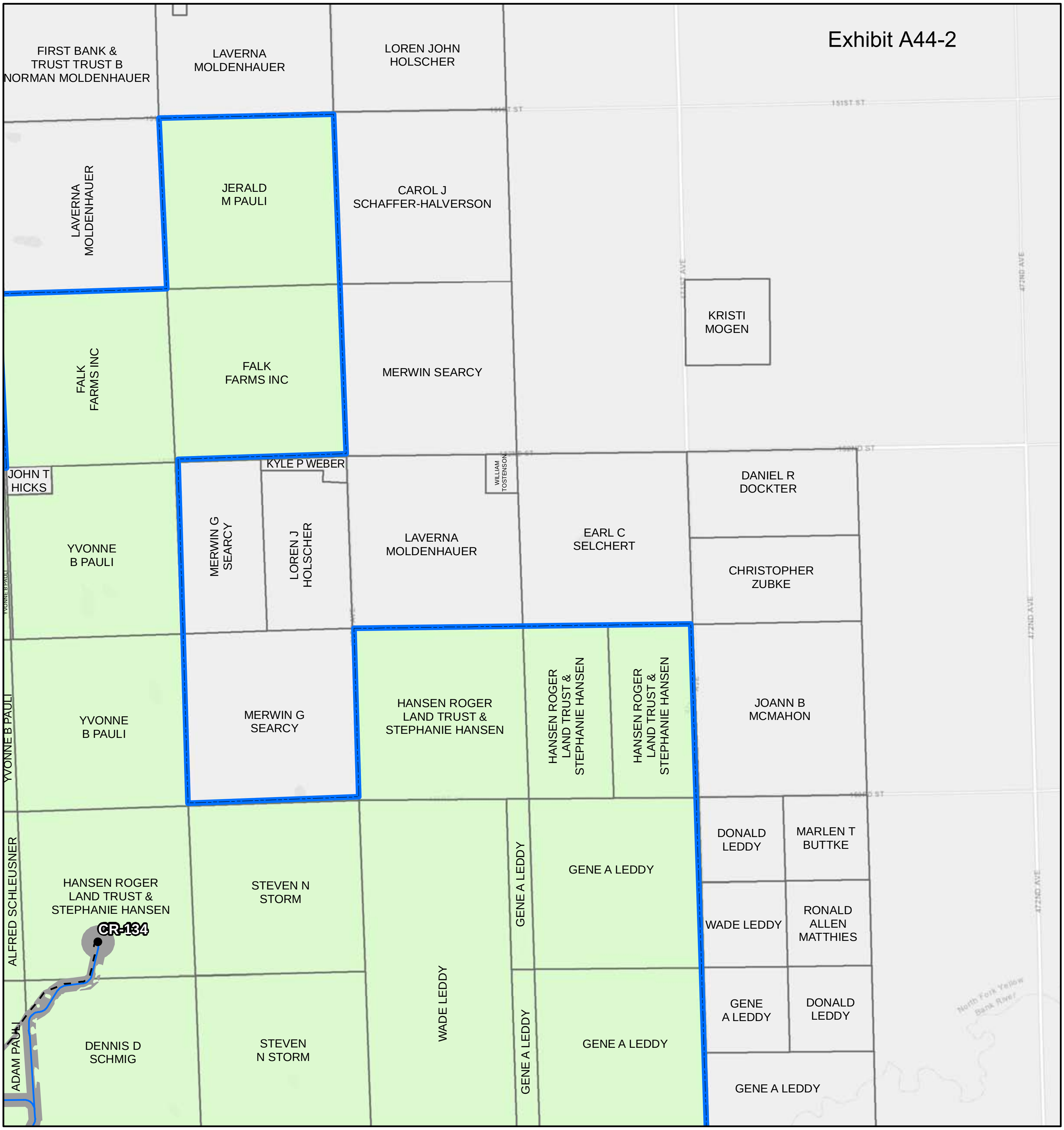


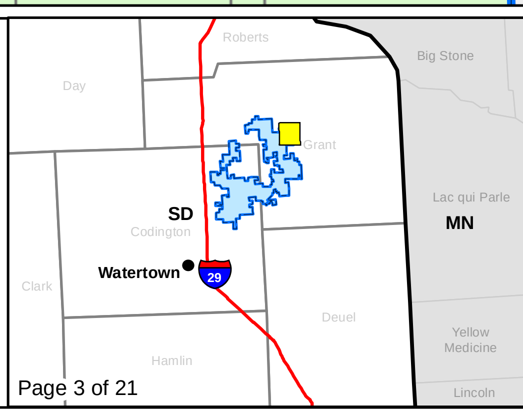
Figure 3a. Project Map

Crowned Ridge Wind Farm

- Turbine
- MET Tower
- City
- Access Road
- Collector Line
- Crane Path
- Railroad
- O&M Facility/ Substation
- Batch Plant
- Laydown Yard
- Construction Easement
- Parcel Boundary
- Project Boundary
- County Boundary

Lease Status

- Leased, Signed
- Pending
- Under Option but Likely to Expire/Not Resign



Kilometers
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Miles
0 0.25 0.5

N S E W

Service Layer Credits: Esri, HERE, Garmin, © OpenStreetMap contributors, and the GIS user community

Quadrangle: Twin Brooks (1973)

Township/Range: T120N, R50W

017308

Grant County, South Dakota

Projection: NAD 1983 UTM Zone 14N

SWCA ENVIRONMENTAL CONSULTANTS

Exhibit A44-2

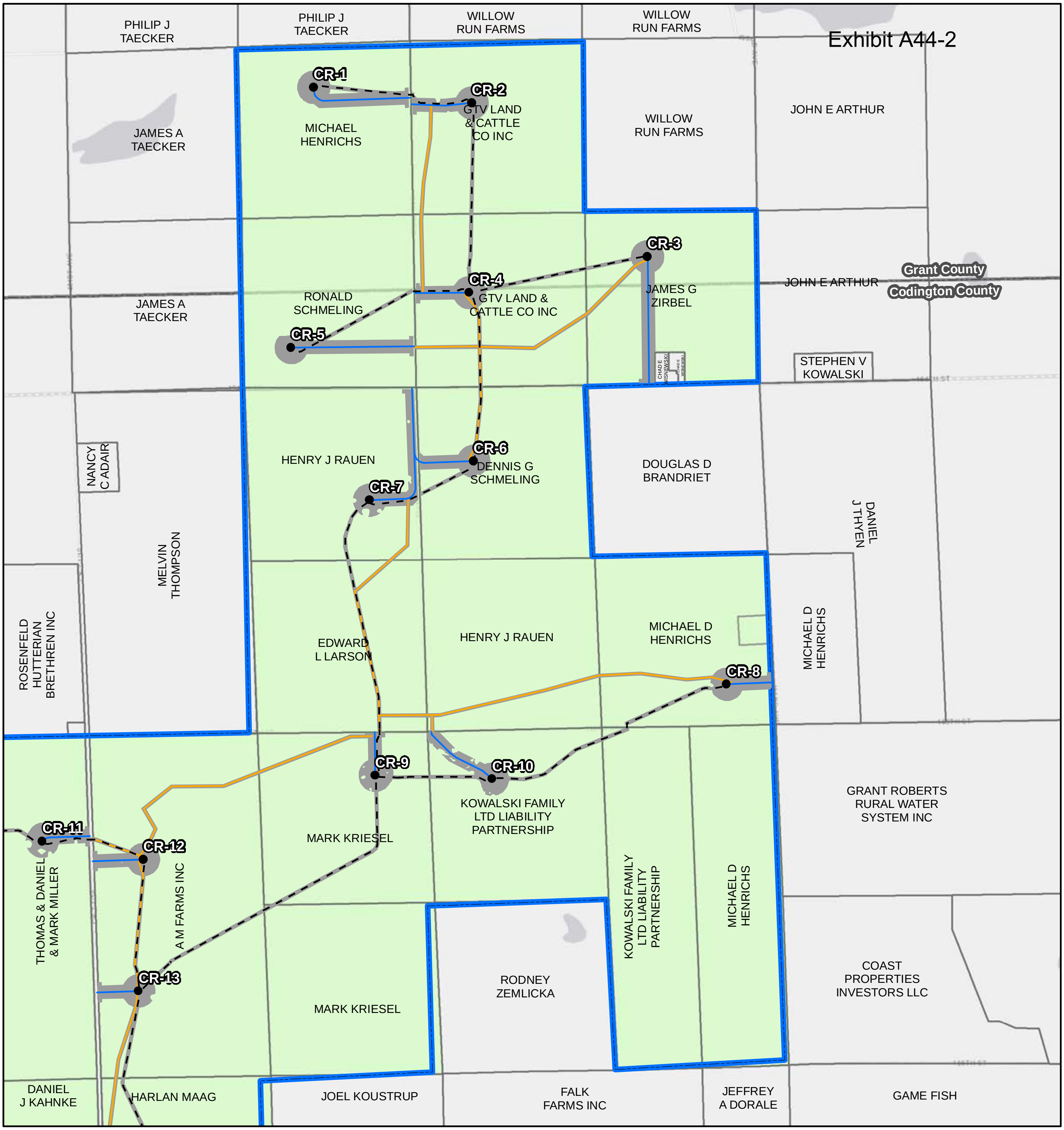
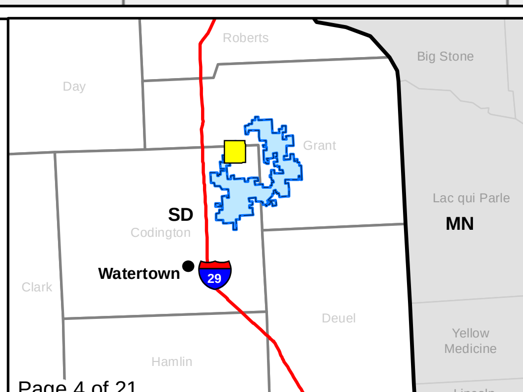


Figure 3a. Project Map

Crowned Ridge Wind Farm

Legend	
Turbine	Construction Easement
MET Tower	Parcel Boundary
City	Project Boundary
Access Road	County Boundary
Collector Line	**Lease Status**
Crane Path	Leased, Signed
Railroad	Pending
O&M Facility/ Substation	Under Option but Likely to Expire/Not Resign
Batch Plant	
Laydown Yard	



Kilometers
0 0.5 1
Miles
0 0.25 0.5

Service Layer Credits: Esri, HERE, Garmin, © OpenStreetMap contributors, and the GIS user community
Quadrangle: Antelope Valley (1973), South Shore (1973)
Township/Range: T120N, R51W, T119N, R51W,
Codington and Grant Counties, South Dakota

Projection: NAD 1983 UTM Zone 14N

SWCA ENVIRONMENTAL CONSULTANTS

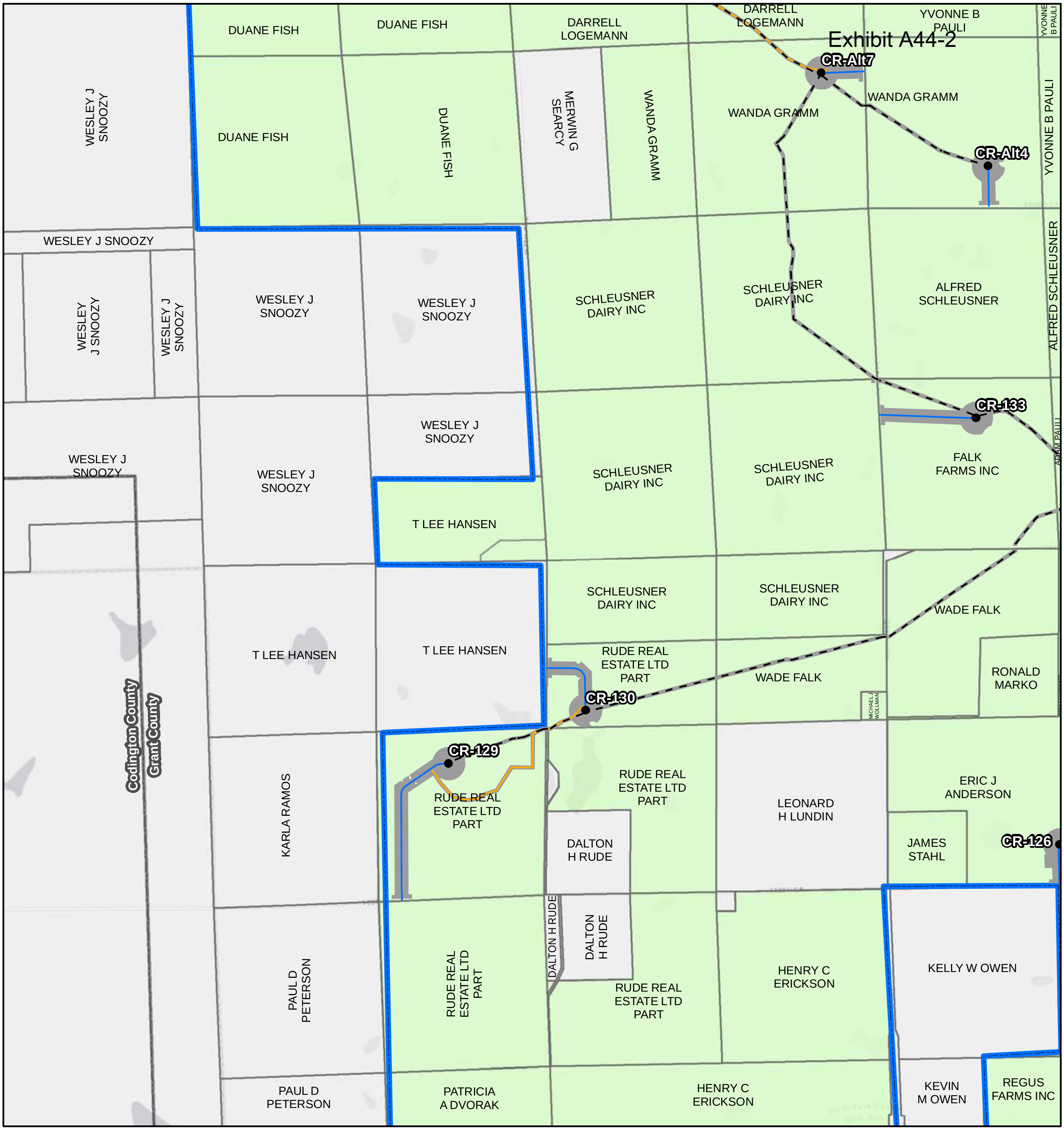


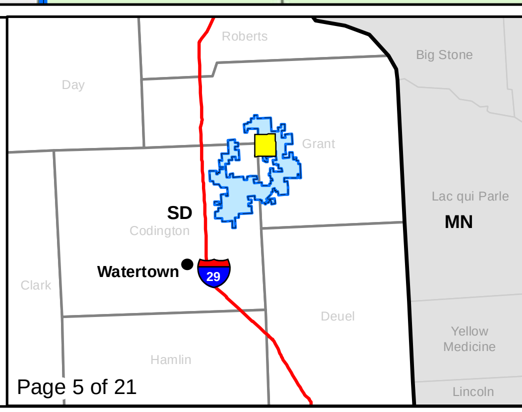
Figure 3a. Project Map

Crowned Ridge Wind Farm

- Turbine
- MET Tower
- City
- Access Road
- Collector Line
- Crane Path
- Railroad
- O&M Facility/ Substation
- Batch Plant
- Laydown Yard
- Construction Easement
- Parcel Boundary
- Project Boundary
- County Boundary

Lease Status

- Leased, Signed
- Pending
- Under Option but Likely to Expire/Not Resign



Kilometers

0 0.5 1

Miles

0 0.25 0.5

Service Layer Credits: Esri, HERE, Garmin, © OpenStreetMap contributors, and the GIS user community
Quadrangle: Antelope Valley (1973), Twin Brooks (1973)
Township/Range: T120N, R51W, T120N, R50W, T119N, R51W, T119N, R50W
Codington and Grant Counties, South Dakota

Projection: NAD 1983 UTM Zone 14N

SWCA ENVIRONMENTAL CONSULTANTS

Exhibit A44-2

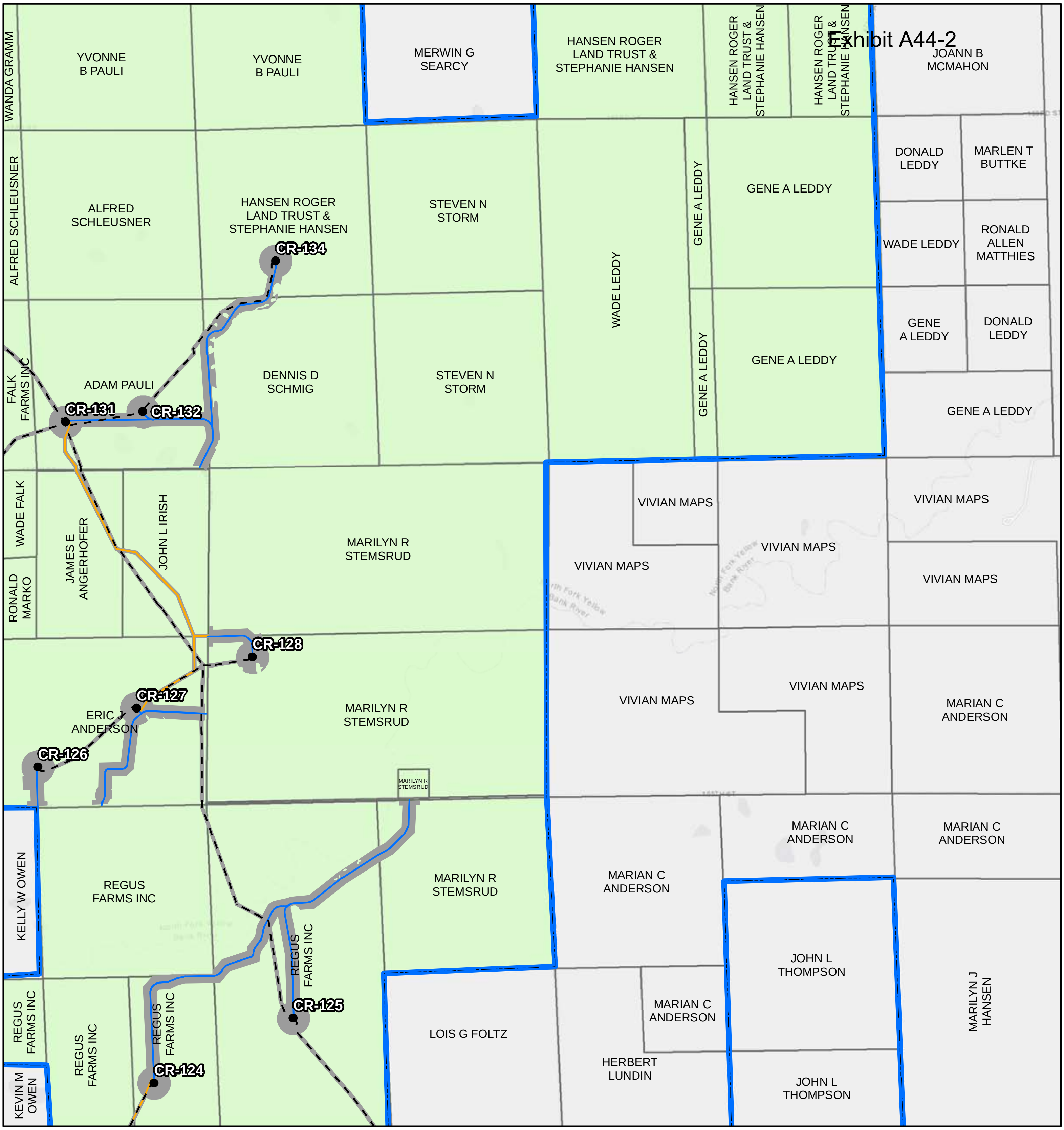
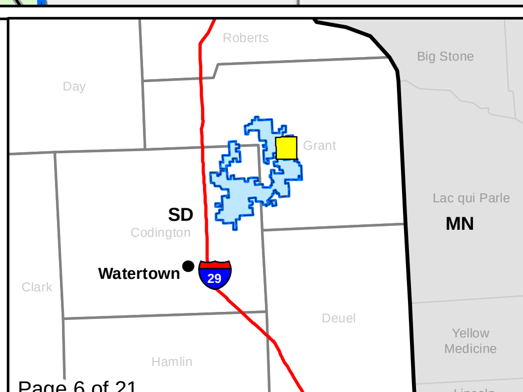


Figure 3a. Project Map

Crowned Ridge Wind Farm

Turbine	Construction Easement		
MET Tower	Parcel Boundary		
City	Project Boundary		
Access Road	County Boundary		
Collector Line	**Lease Status**		
Crane Path	Leased, Signed		
Railroad	Pending		
O&M Facility/ Substation	Under Option but Likely to Expire/Not Resign		
Batch Plant			
Laydown Yard			



Kilometers 0 0.5 1

Miles 0 0.25 0.5

Service Layer Credits: Esri, HERE, Garmin, © OpenStreetMap contributors, and the GIS user community
Quadrangle: Twin Brooks (1973), Stockholm (1973)
Township/Range: T120N, R50W, T119N, R50W
Grant County, South Dakota

017311

Projection: NAD 1983 UTM Zone 14N

SWCA ENVIRONMENTAL CONSULTANTS

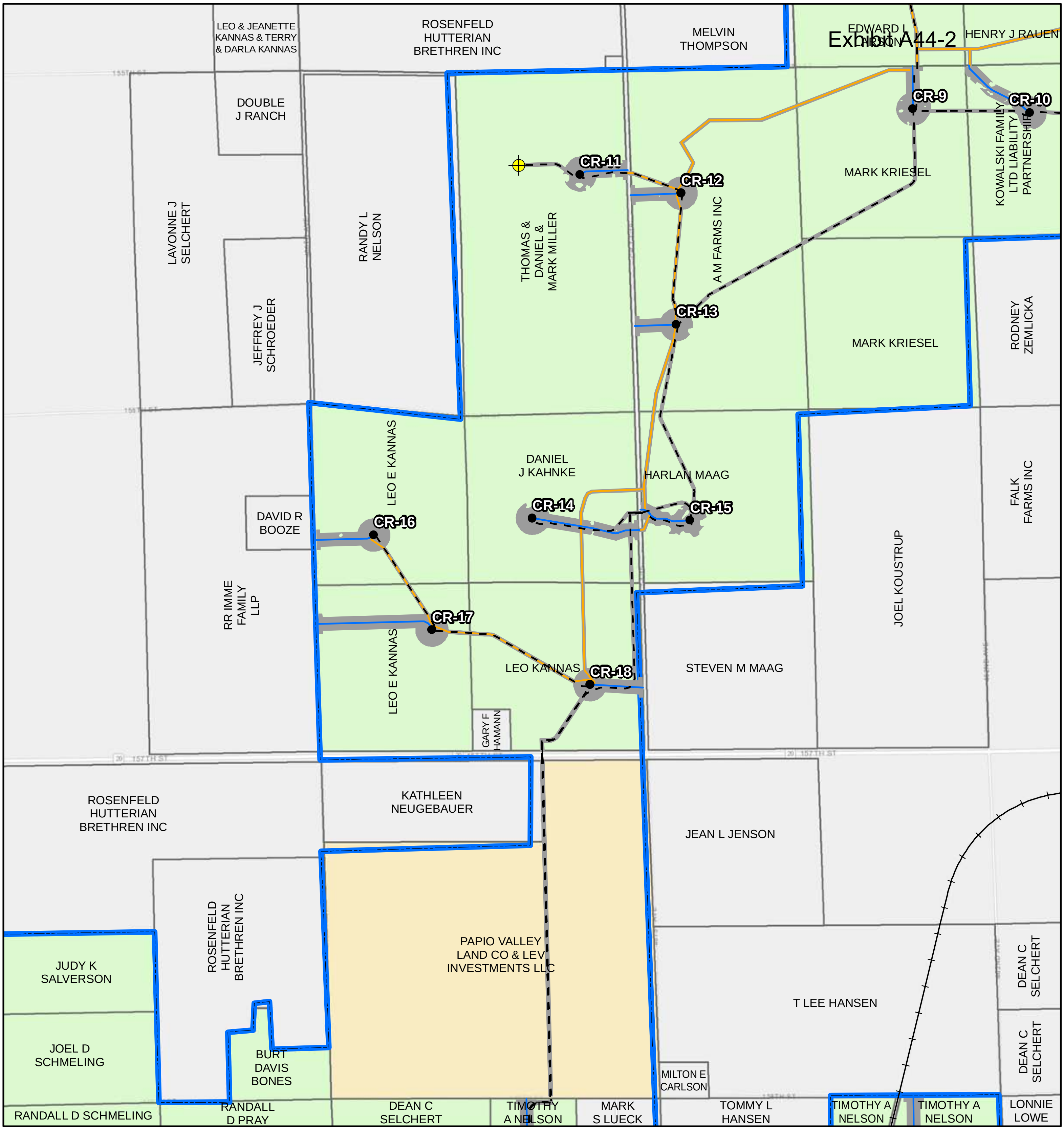
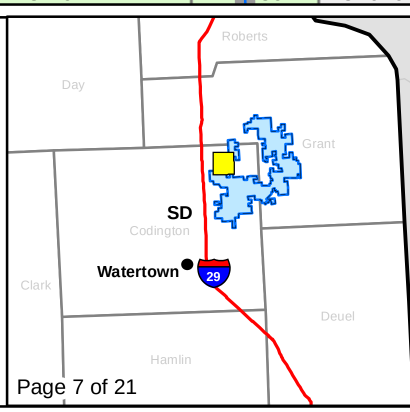


Figure 3a. Project Map

Crowned Ridge Wind Farm

●	Turbine		Construction Easement
	MET Tower		Parcel Boundary
	City		Project Boundary
	Access Road		County Boundary
	Collector Line	**Lease Status**	
	Crane Path		Leased, Signed
	Railroad		Pending
	O&M Facility/ Substation		Under Option but Likely to Expire/Not Resign
	Batch Plant		
	Laydown Yard		



Kilometers
0 0.5 1

Miles
0 0.25 0.5

Service Layer Credits: Esri, HERE, Garmin, © OpenStreetMap contributors, and the GIS user community
Quadrangle: Still Lake NE (1970), Antelope Valley (1973), Still Lake SE (1970), South Shore (1973)
Township/Range: T119N, R52W, T119N, R51W
Codington County, South Dakota

017312

Projection: NAD 1983 UTM Zone 14N

Exhibit A44-2

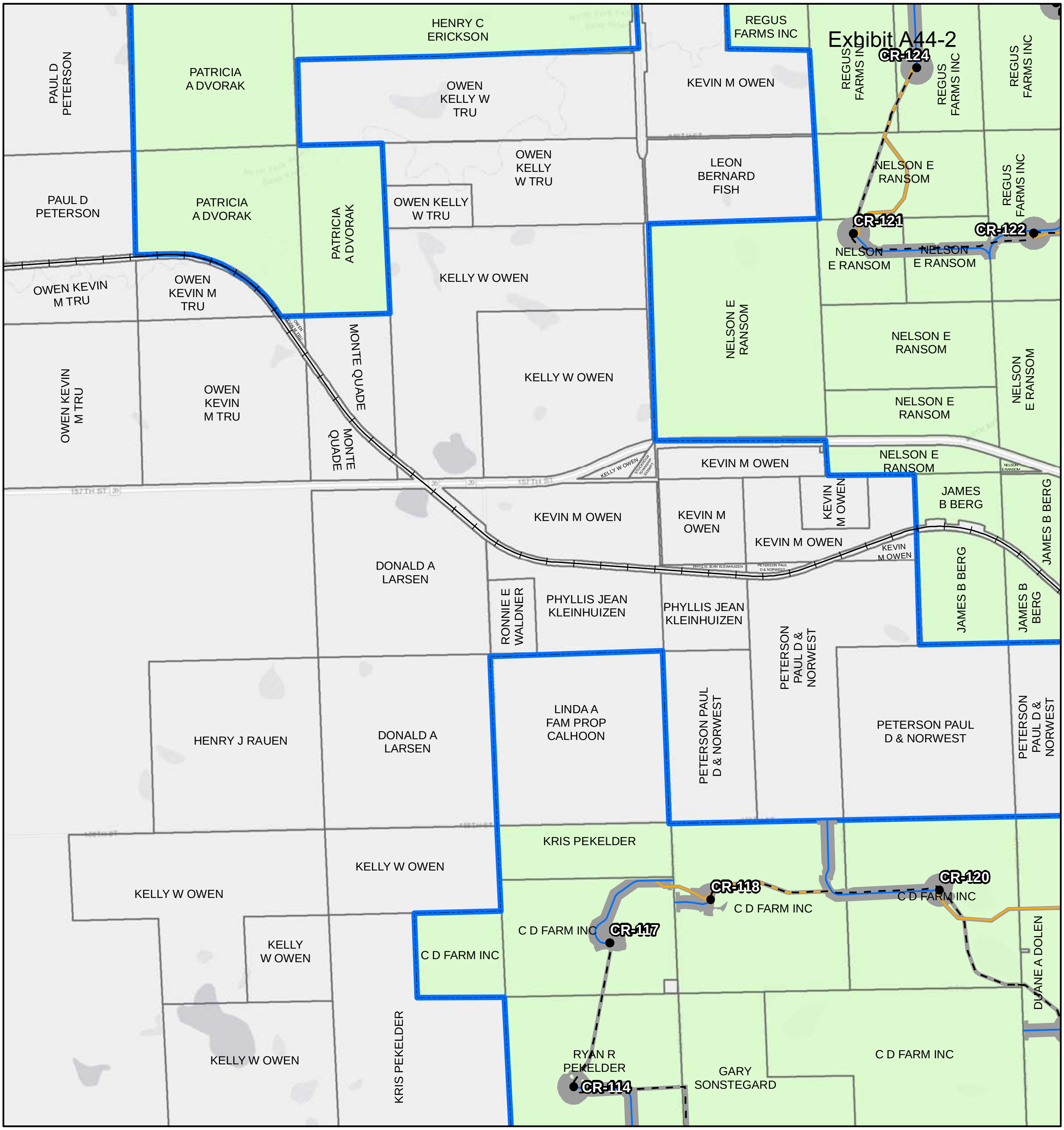


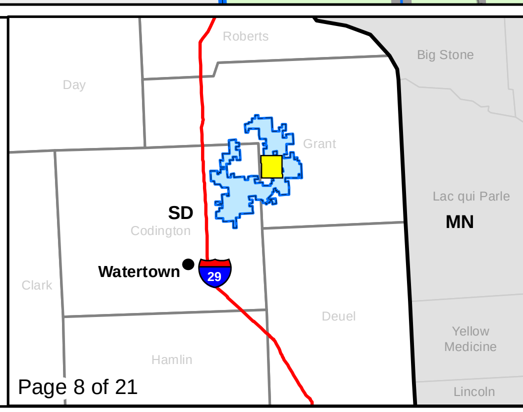
Figure 3a. Project Map

Crowned Ridge Wind Farm

- Turbine
- MET Tower
- City
- Access Road
- Collector Line
- Crane Path
- Railroad
- O&M Facility/ Substation
- Batch Plant
- Laydown Yard
- Construction Easement
- Parcel Boundary
- Project Boundary
- County Boundary

Lease Status

- Leased, Signed
- Pending
- Under Option but Likely to Expire/Not Resign



Kilometers
0 0.5 1

Miles
0 0.25 0.5

Service Layer Credits: Esri, HERE, Garmin, © OpenStreetMap contributors, and the GIS user community
Quadrangle: Stockholm (1973), Antelope Valley (1973), Twin Brooks (1973), South Shore (1973)
Township/Range: T119N, R50W

Grant County, South Dakota

Projection: NAD 1983 UTM Zone 14N

SWCA ENVIRONMENTAL CONSULTANTS

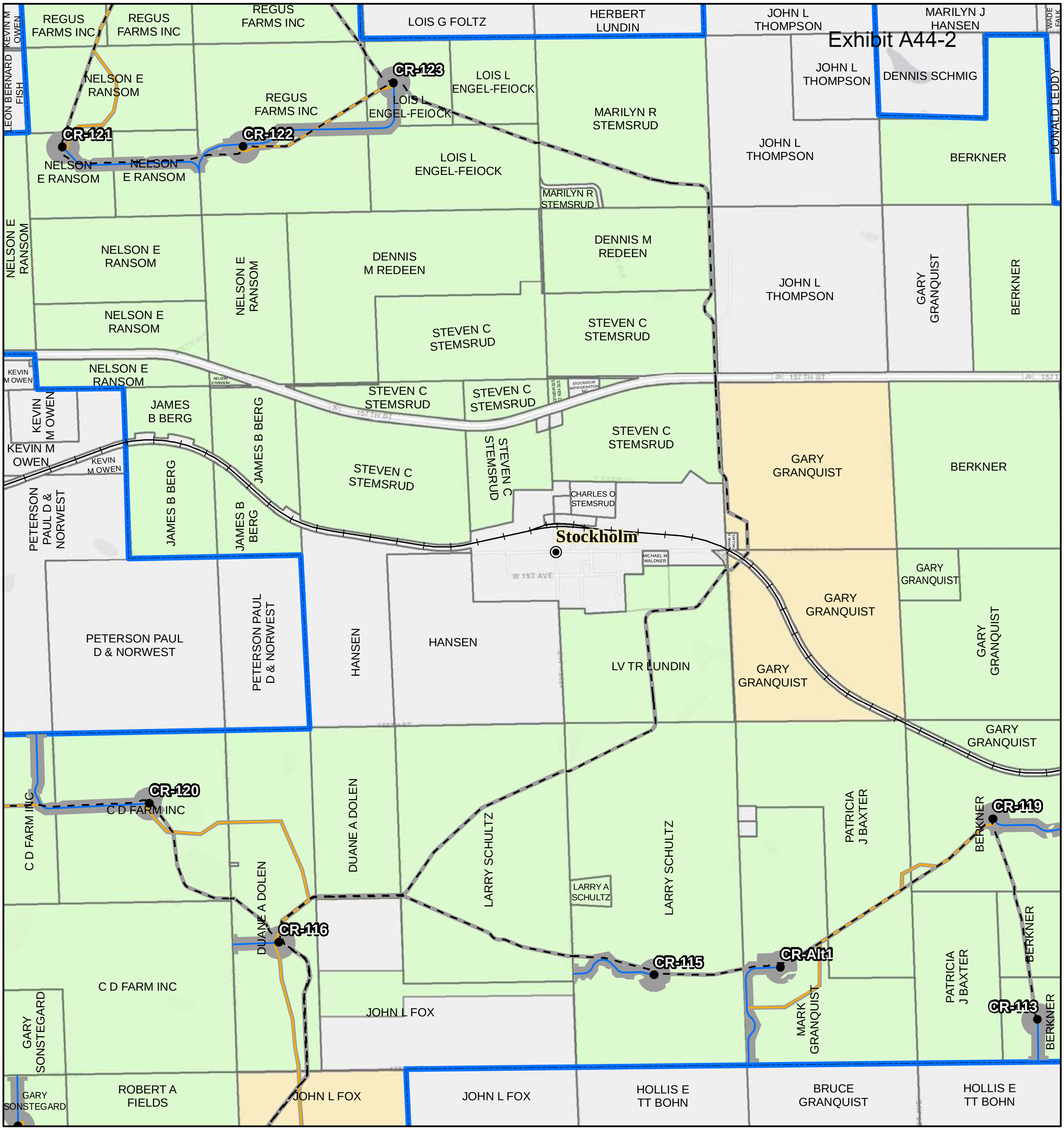


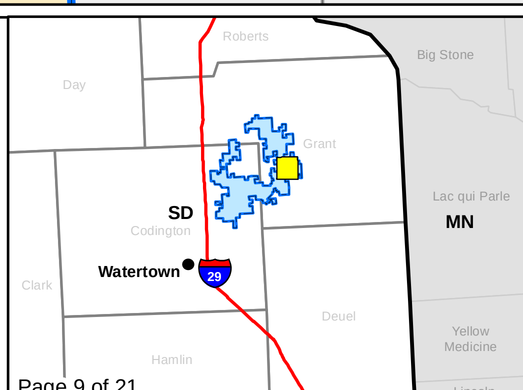
Figure 3a. Project Map

Crowned Ridge Wind Farm

- Turbine
- MET Tower
- City
- Access Road
- Collector Line
- Crane Path
- Railroad
- O&M Facility/ Substation
- Batch Plant
- Laydown Yard
- Construction Easement
- Parcel Boundary
- Project Boundary
- County Boundary

Lease Status

- Leased, Signed
- Pending
- Under Option but Likely to Expire/Not Resign



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Kilometers

0 0.5 1

Miles

0 0.25 0.5

Service Layer Credits: Esri, HERE, Garmin, © OpenStreetMap contributors, and the GIS user community

Quadrangle: Stockholm (1973)

Township/Range: T119N, R50W

Grant County, South Dakota

017314

Page 000033

Projection: NAD 1983 UTM Zone 14N

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Exhibit A44-2

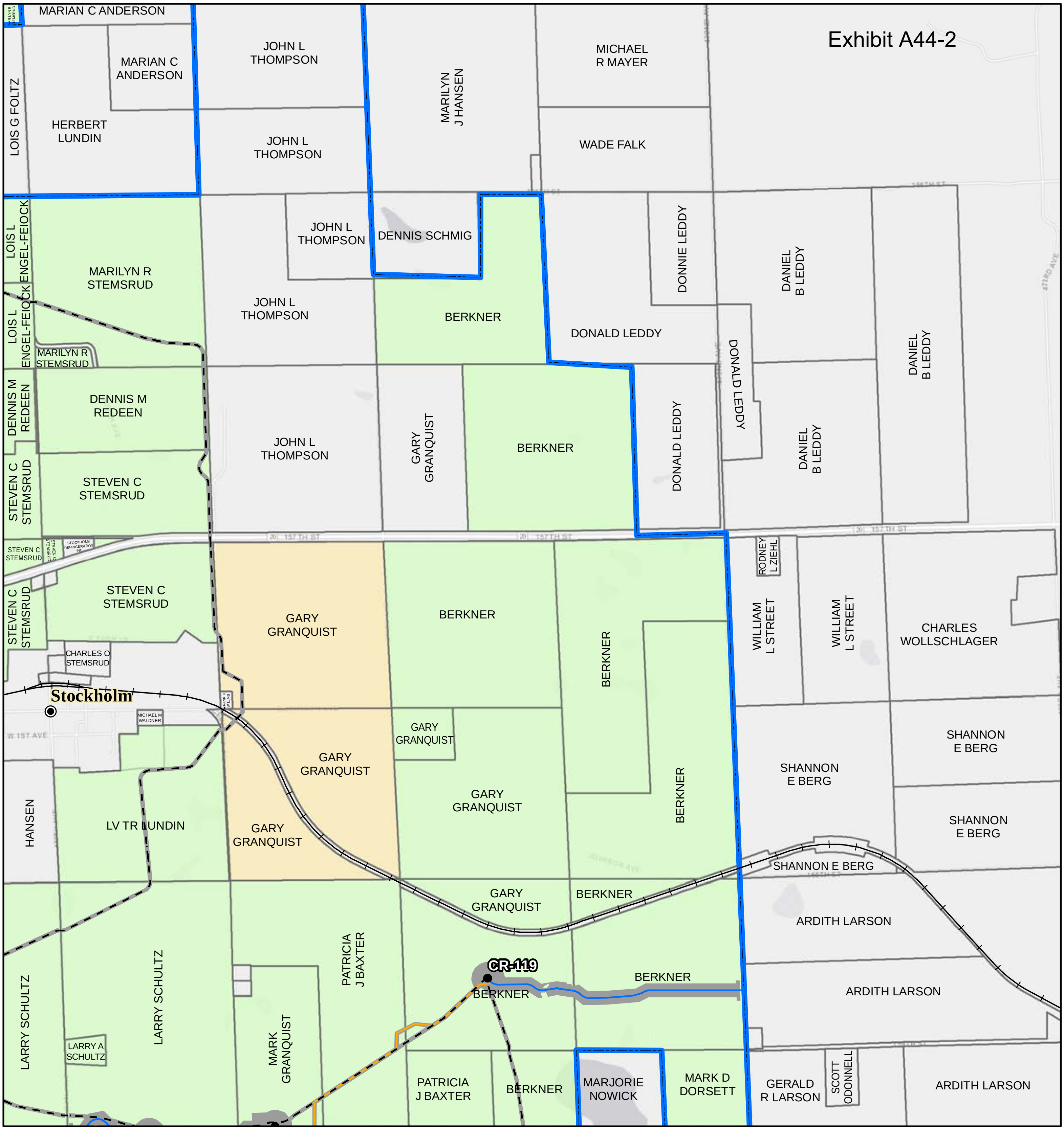


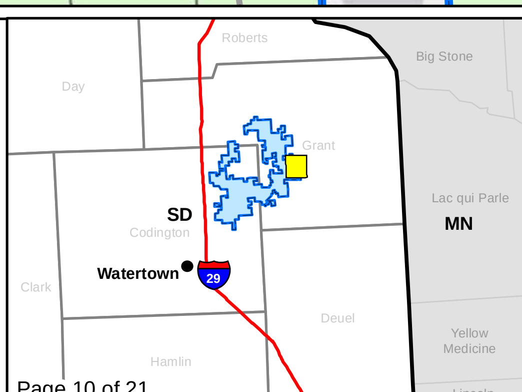
Figure 3a. Project Map

Crowned Ridge Wind Farm

- Turbine
- MET Tower
- City
- Access Road
- Collector Line
- Crane Path
- Railroad
- O&M Facility/ Substation
- Batch Plant
- Laydown Yard
- Construction Easement
- Parcel Boundary
- Project Boundary
- County Boundary

Lease Status

- Leased, Signed
- Pending
- Under Option but Likely to Expire/Not Resign



Kilometers
0 0.5 1

Miles
0 0.25 0.5

N W E S

Service Layer Credits: Esri, HERE, Garmin, © OpenStreetMap contributors, and the GIS user community
Quadrangle: Twin Brooks (1973), Stockholm (1973)
Township/Range: T119N, R50W, T119N, R49W
Grant County, South Dakota

017315

Projection: NAD 1983 UTM Zone 14N

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Exhibit A44-2

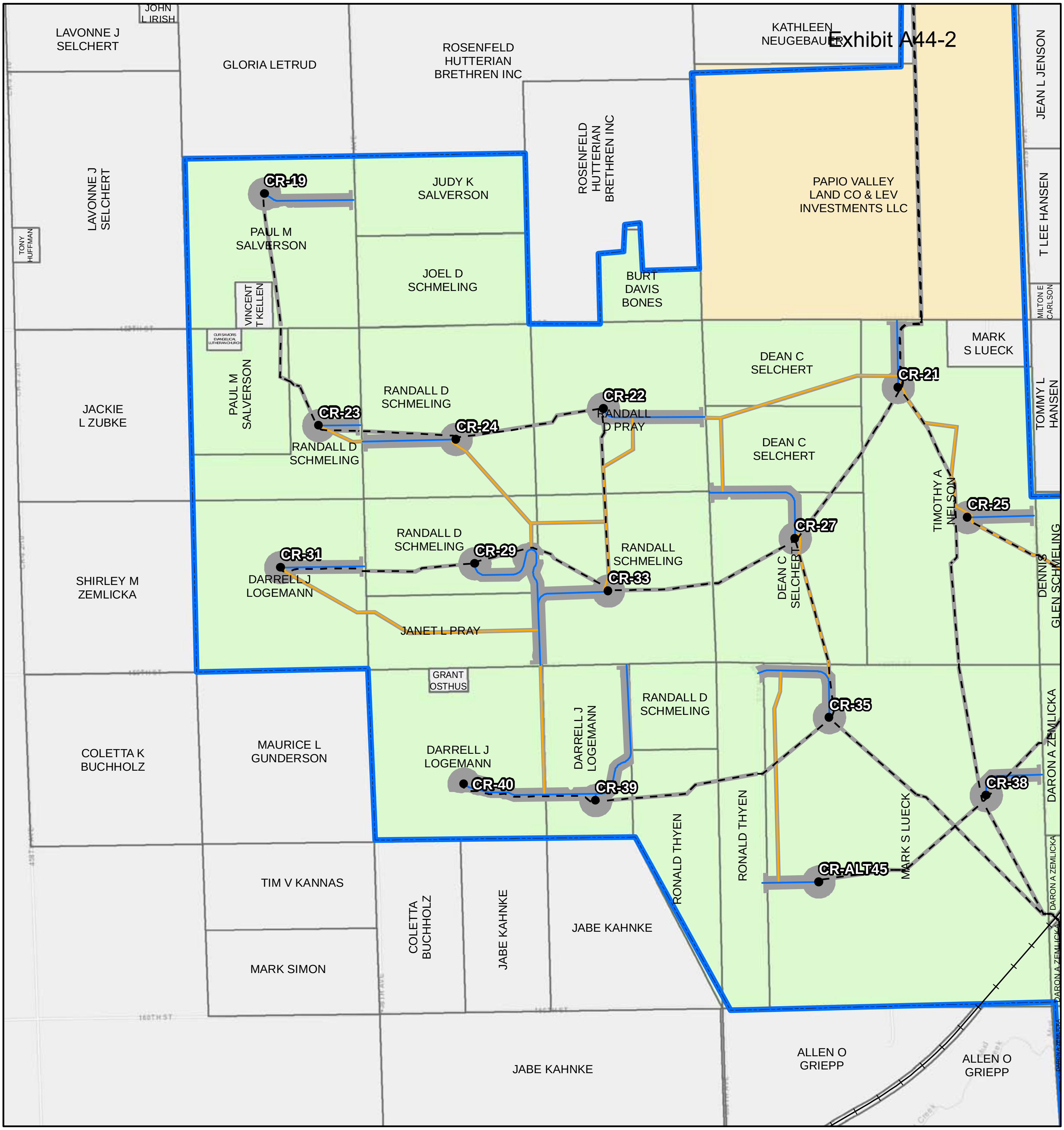


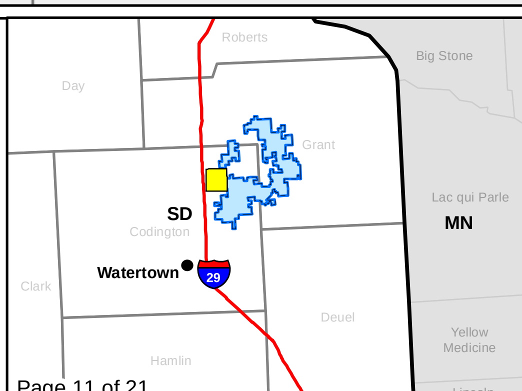
Figure 3a. Project Map

Crowned Ridge Wind Farm

- Turbine
- MET Tower
- City
- Access Road
- Collector Line
- Crane Path
- Railroad
- O&M Facility/ Substation
- Batch Plant
- Laydown Yard
- Construction Easement
- Parcel Boundary
- Project Boundary
- County Boundary

Lease Status

- Leased, Signed
- Pending
- Under Option but Likely to Expire/Not Resign



Kilometers
0 0.5 1

Miles
0 0.25 0.5

Service Layer Credits: Esri, HERE, Garmin, © OpenStreetMap contributors, and the GIS user community
Quadrangle: Still Lake SE (1970), South Shore (1973)
Township/Range: T119N, R52W, T119N, R51W, T118N, R52W, T118N, R51W
Codington County, South Dakota

Projection: NAD 1983 UTM Zone 14N

SWCA ENVIRONMENTAL CONSULTANTS

Exhibit A44-2

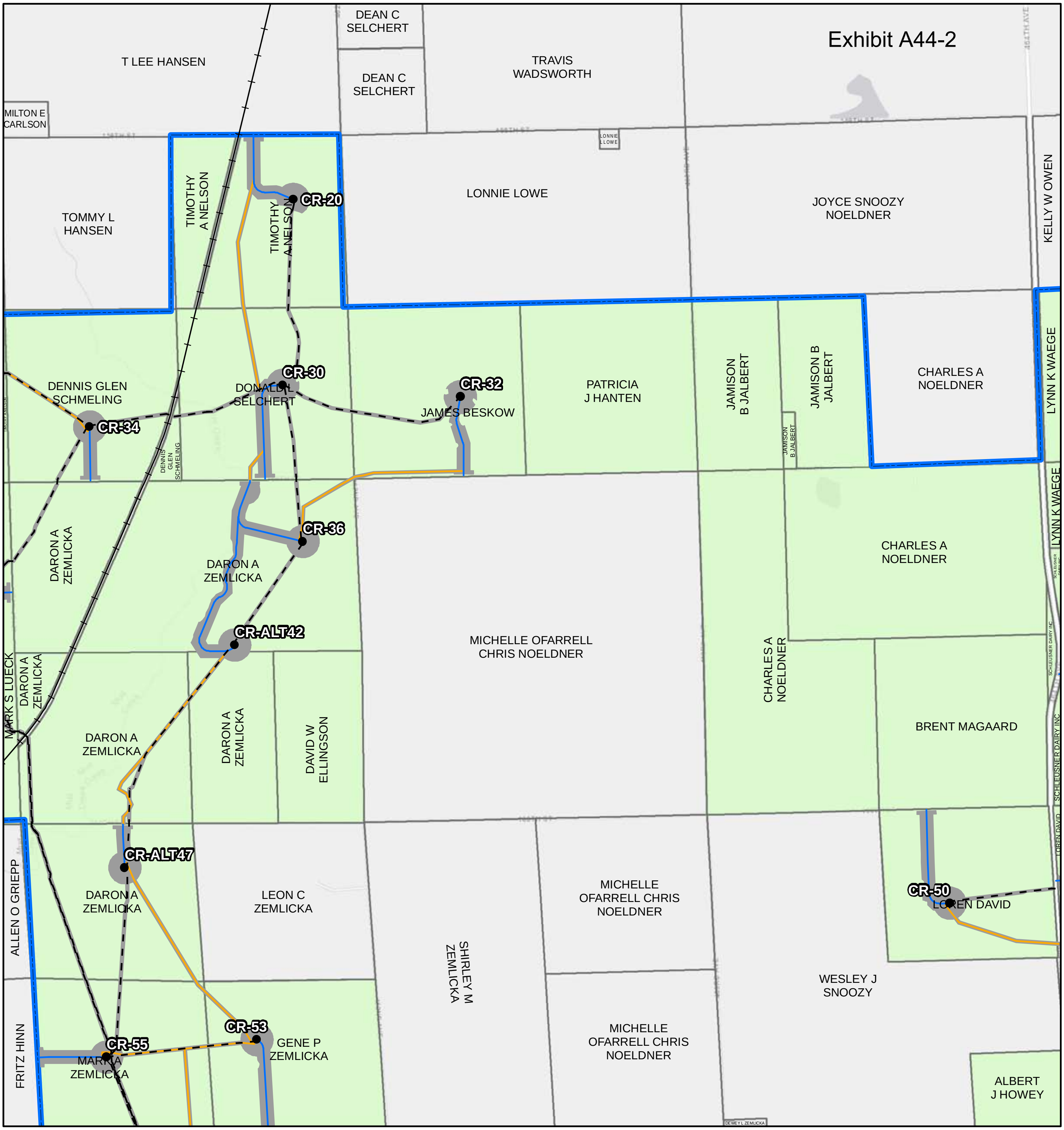


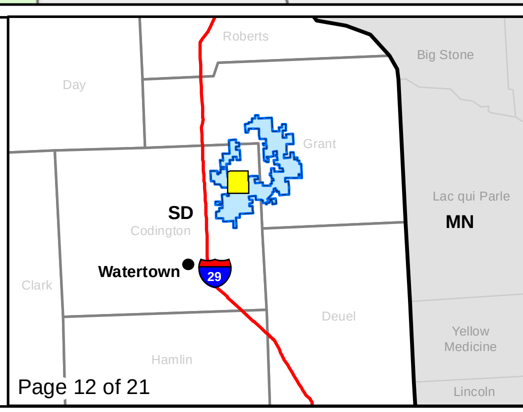
Figure 3a. Project Map

Crowned Ridge Wind Farm

- Turbine
- MET Tower
- City
- Access Road
- Collector Line
- Crane Path
- Railroad
- O&M Facility/ Substation
- Batch Plant
- Laydown Yard
- Construction Easement
- Parcel Boundary
- Project Boundary
- County Boundary

Lease Status

- Leased, Signed
- Pending
- Under Option but Likely to Expire/Not Resign



Kilometers
0 0.5 1

Miles
0 0.25 0.5

Service Layer Credits: Esri, HERE, Garmin, © OpenStreetMap contributors, and the GIS user community
Quadrangle: South Shore (1973)

Township/Range: T119N, R51W, T118N, R51W
Codington County, South Dakota

Projection: NAD 1983 UTM Zone 14N

017317

SWCA ENVIRONMENTAL CONSULTANTS

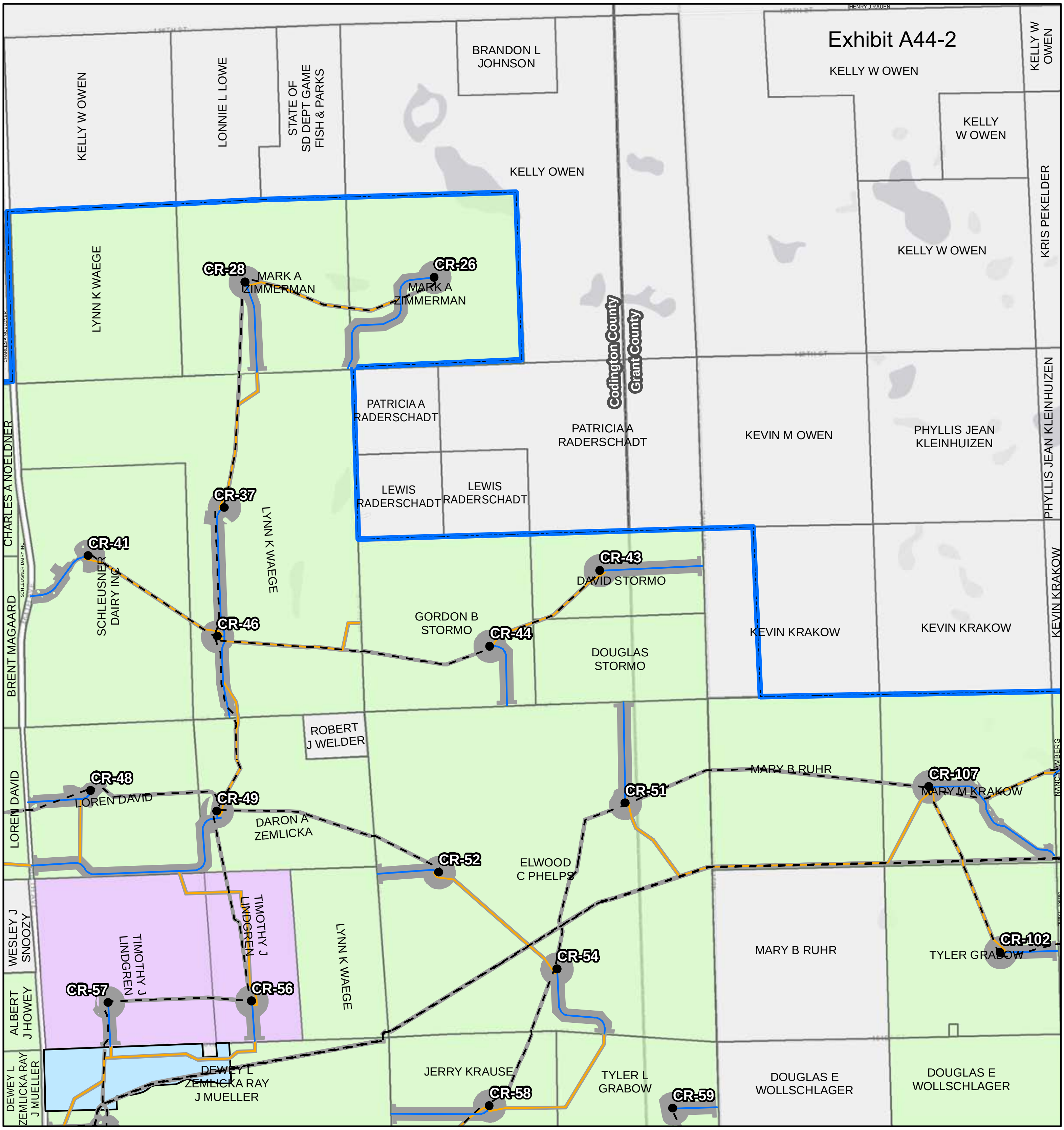


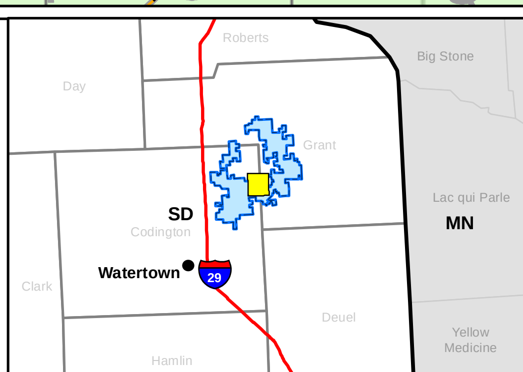
Figure 3a. Project Map

Crowned Ridge Wind Farm

- Turbine
- MET Tower
- City
- Access Road
- Collector Line
- Crane Path
- Railroad
- O&M Facility/ Substation
- Batch Plant
- Laydown Yard
- Construction Easement
- Parcel Boundary
- Project Boundary
- County Boundary

Lease Status

- Leased, Signed
- Pending
- Under Option but Likely to Expire/Not Resign



Kilometers
0 0.5 1

Miles
0 0.25 0.5

Service Layer Credits: Esri, HERE, Garmin, © OpenStreetMap contributors, and the GIS user community
Quadrangle: South Shore (1973), Stockholm (1973)
Township/Range: T119N, R51W, T119N, R50W, T118N, R51W, T118N, R50W
Codington and Grant Counties, South Dakota

SWCA ENVIRONMENTAL CONSULTANTS

Projection: NAD 1983 UTM Zone 14N

Exhibit A44-2

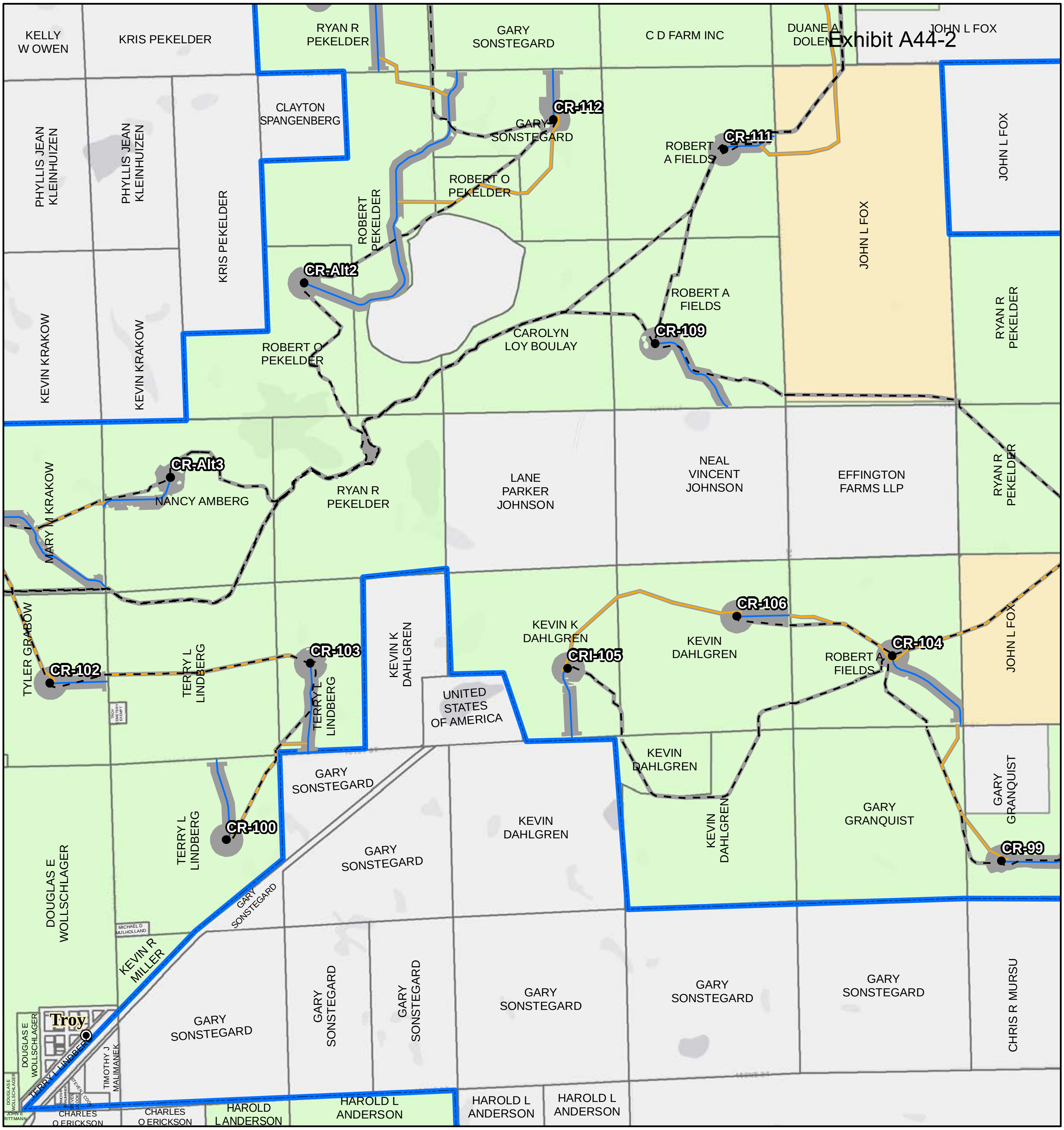


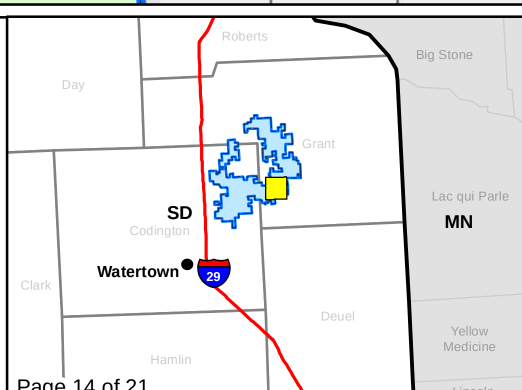
Figure 3a. Project Map

Crowned Ridge Wind Farm

- Turbine
- MET Tower
- City
- Access Road
- Collector Line
- Crane Path
- Railroad
- O&M Facility/ Substation
- Batch Plant
- Laydown Yard
- Construction Easement
- Parcel Boundary
- Project Boundary
- County Boundary

Lease Status

- Leased, Signed
- Pending
- Under Option but Likely to Expire/Not Resign



Kilometers
0 0.5 1

Miles
0 0.25 0.5

Service Layer Credits: Esri, HERE, Garmin, © OpenStreetMap contributors, and the GIS user community
Quadrangle: Stockholm (1973)

Township/Range: T119N, R50W, T118N, R50W
Grant County, South Dakota

017319

Page 000038

Projection: NAD 1983 UTM Zone 14N

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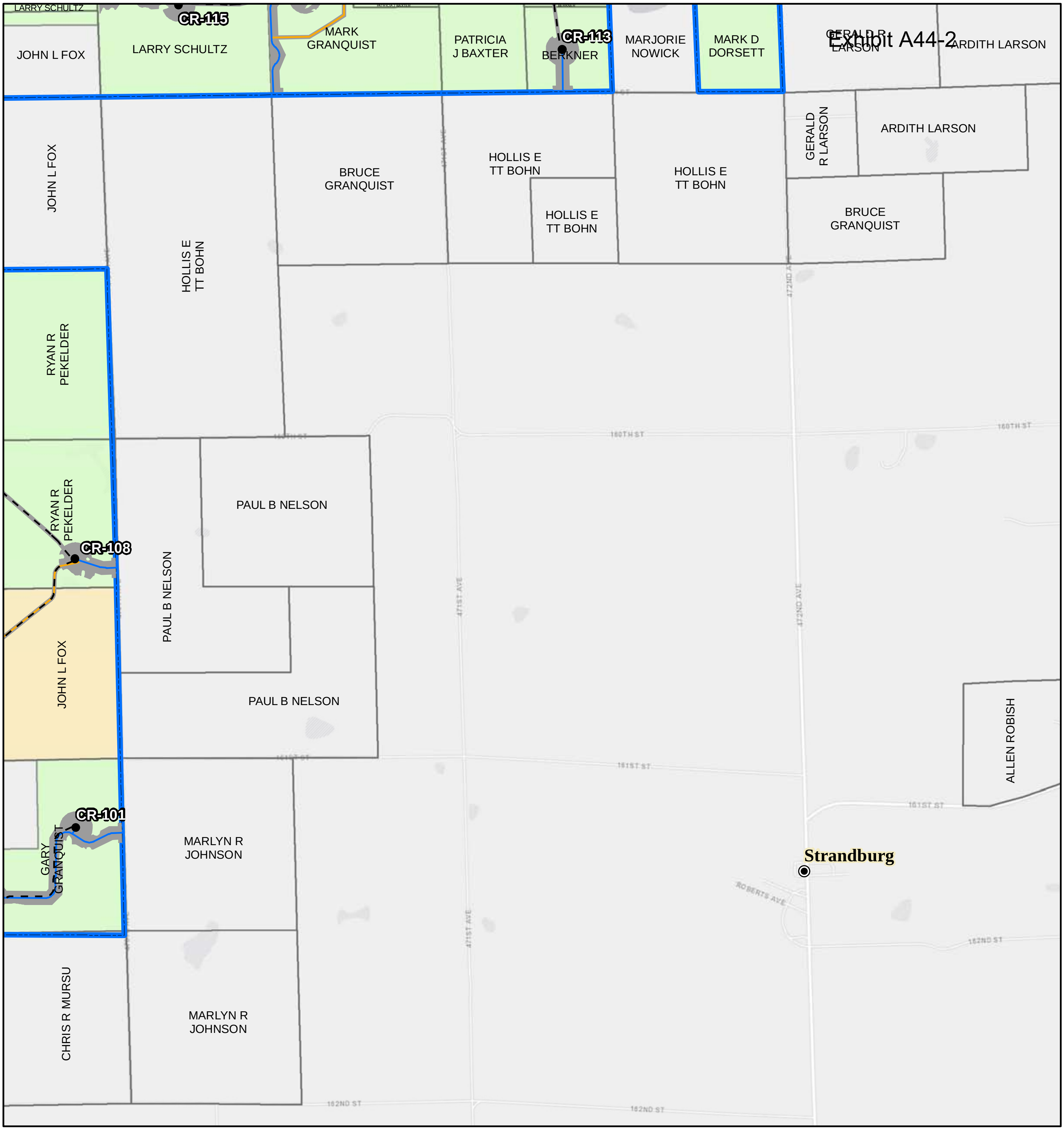


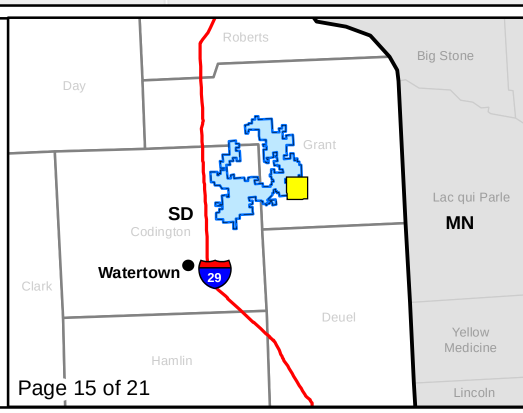
Figure 3a. Project Map

Crowned Ridge Wind Farm

- Turbine
- MET Tower
- City
- Access Road
- Collector Line
- Crane Path
- Railroad
- O&M Facility/ Substation
- Batch Plant
- Laydown Yard
- Construction Easement
- Parcel Boundary
- Project Boundary
- County Boundary

Lease Status

- Leased, Signed
- Pending
- Under Option but Likely to Expire/Not Resign



Kilometers
0 0.5 1

Miles
0 0.25 0.5

Service Layer Credits: Esri, HERE, Garmin, © OpenStreetMap contributors, and the GIS user community
Quadrangle: Stockholm (1973)

Township/Range: T119N, R50W, T118N, R50W
Grant County, South Dakota

017320

Projection: NAD 1983 UTM Zone 14N

SWCA ENVIRONMENTAL CONSULTANTS

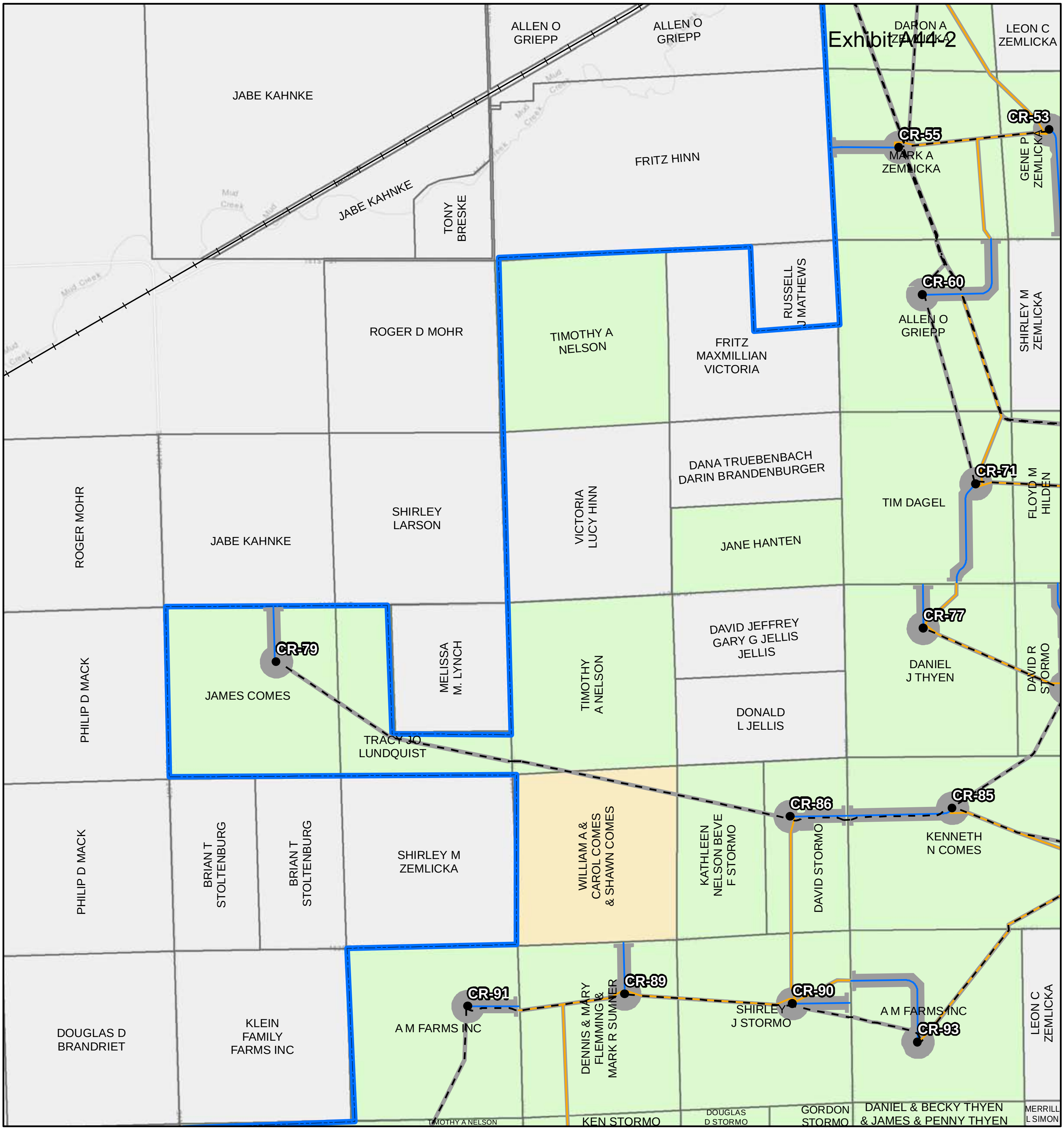


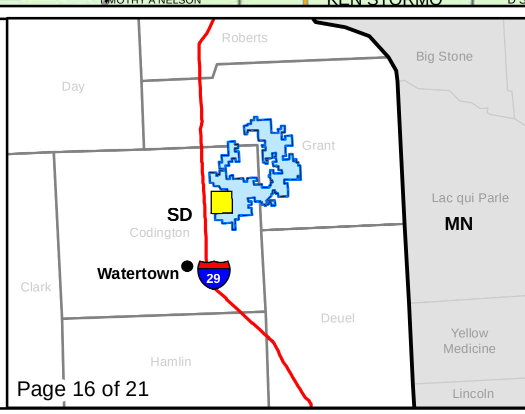
Figure 3a. Project Map

Crowned Ridge Wind Farm

- Turbine
- MET Tower
- City
- Access Road
- Collector Line
- Crane Path
- Railroad
- O&M Facility/ Substation
- Batch Plant
- Laydown Yard
- Construction Easement
- Parcel Boundary
- Project Boundary
- County Boundary

Lease Status

- Leased, Signed
- Pending
- Under Option but Likely to Expire/Not Resign



Kilometers
0 0.5 1

Miles
0 0.25 0.5

Service Layer Credits: Esri, HERE, Garmin, © OpenStreetMap contributors, and the GIS user community
Quadrangle: Still Lake SE (1970), South Shore (1973)
Township/Range: T118N, R52W, T118N, R51W
Codington County, South Dakota

017321

SWCA ENVIRONMENTAL CONSULTANTS

Projection: NAD 1983 UTM Zone 14N

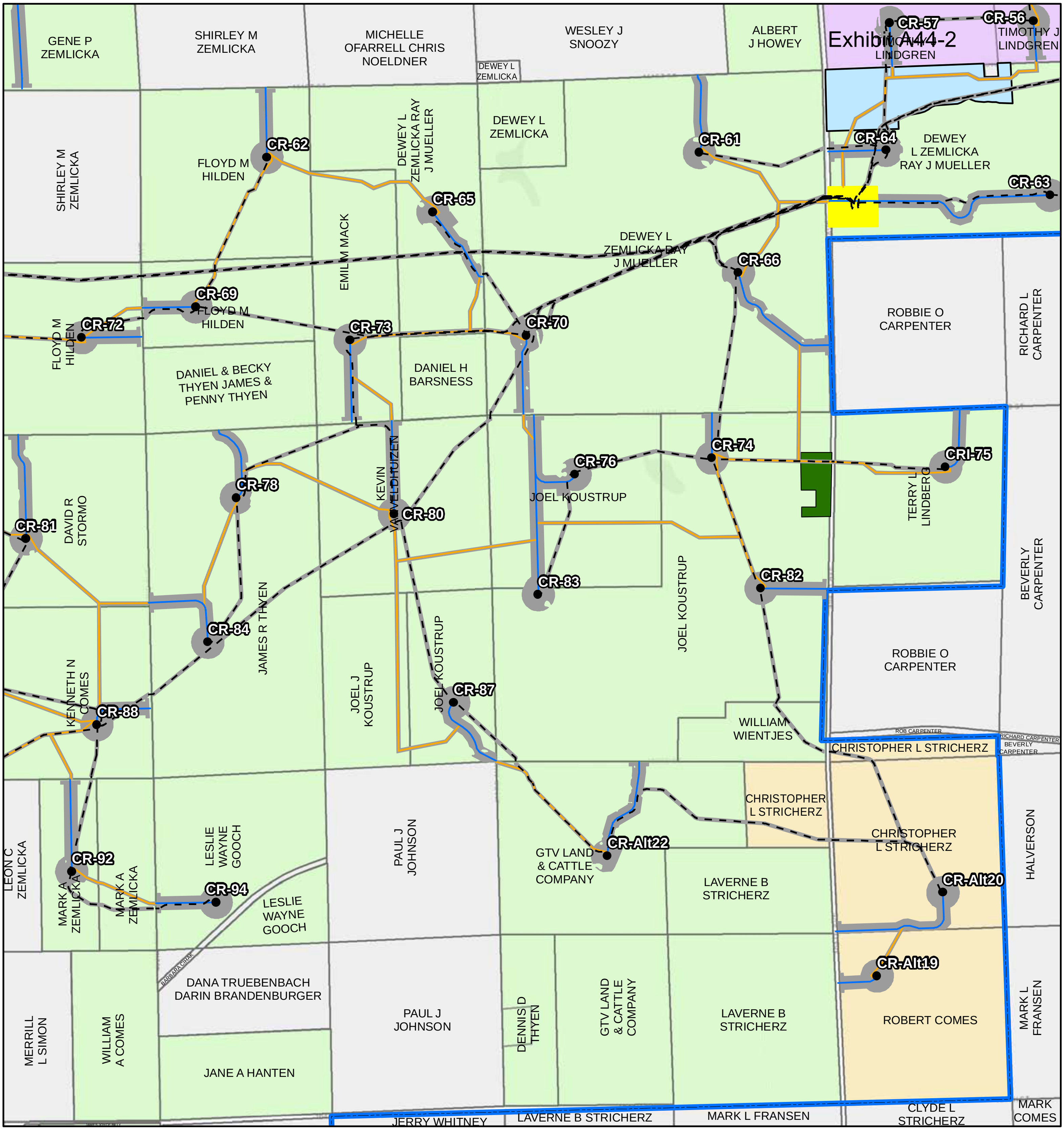


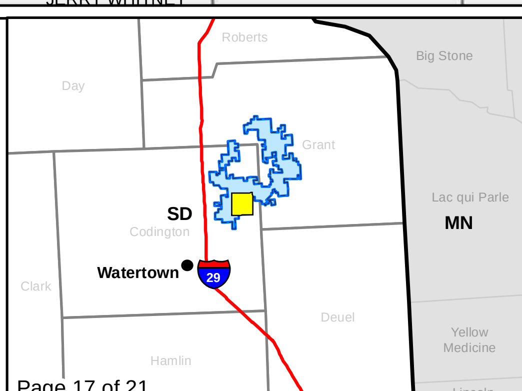
Figure 3a. Project Map

Crowned Ridge Wind Farm

- Turbine
- MET Tower
- City
- Access Road
- Collector Line
- Crane Path
- Railroad
- O&M Facility/ Substation
- Batch Plant
- Laydown Yard
- Construction Easement
- Parcel Boundary
- Project Boundary
- County Boundary

Lease Status

- Leased, Signed
- Pending
- Under Option but Likely to Expire/Not Resign



Kilometers: 0, 0.5, 1

Miles: 0, 0.25, 0.5

Service Layer Credits: Esri, HERE, Garmin, © OpenStreetMap contributors, and the GIS user community

Quadrangle: South Shore (1973)

Township/Range: T118N, R51W

017322

Codington County, South Dakota

Projection: NAD 1983 UTM Zone 14N

SWCA ENVIRONMENTAL CONSULTANTS

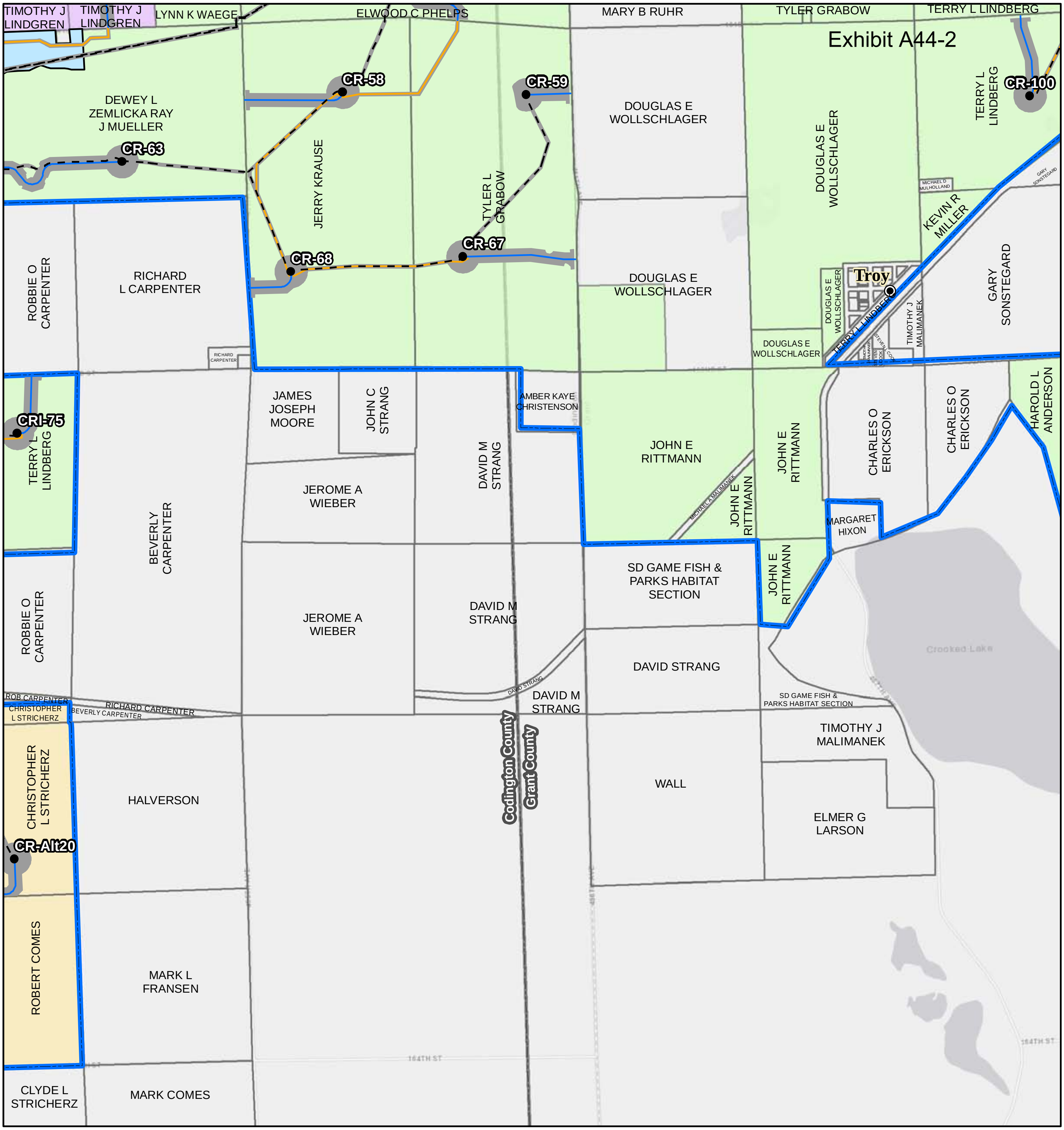


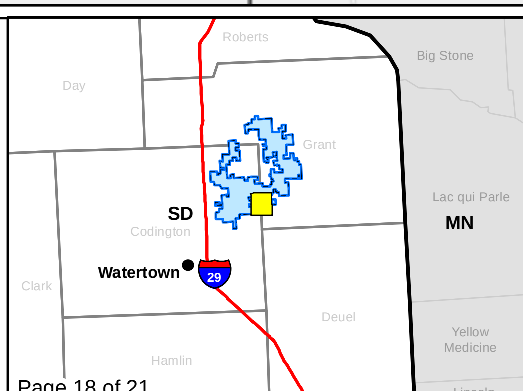
Figure 3a. Project Map

Crowned Ridge Wind Farm

- Turbine
- MET Tower
- City
- Access Road
- Collector Line
- Crane Path
- Railroad
- O&M Facility/ Substation
- Batch Plant
- Laydown Yard
- Construction Easement
- Parcel Boundary
- Project Boundary
- County Boundary

Lease Status

- Leased, Signed
- Pending
- Under Option but Likely to Expire/Not Resign



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Kilometers
0 0.5 1

Miles
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Service Layer Credits: Esri, HERE, Garmin, © OpenStreetMap contributors, and the GIS user community
Quadrangle: South Shore (1973), Stockholm (1973)
Township/Range: T118N, R51W, T118N, R50W
Codington and Grant Counties, South Dakota

017323

Page 000042

SWCA ENVIRONMENTAL CONSULTANTS

Projection: NAD 1983 UTM Zone 14N

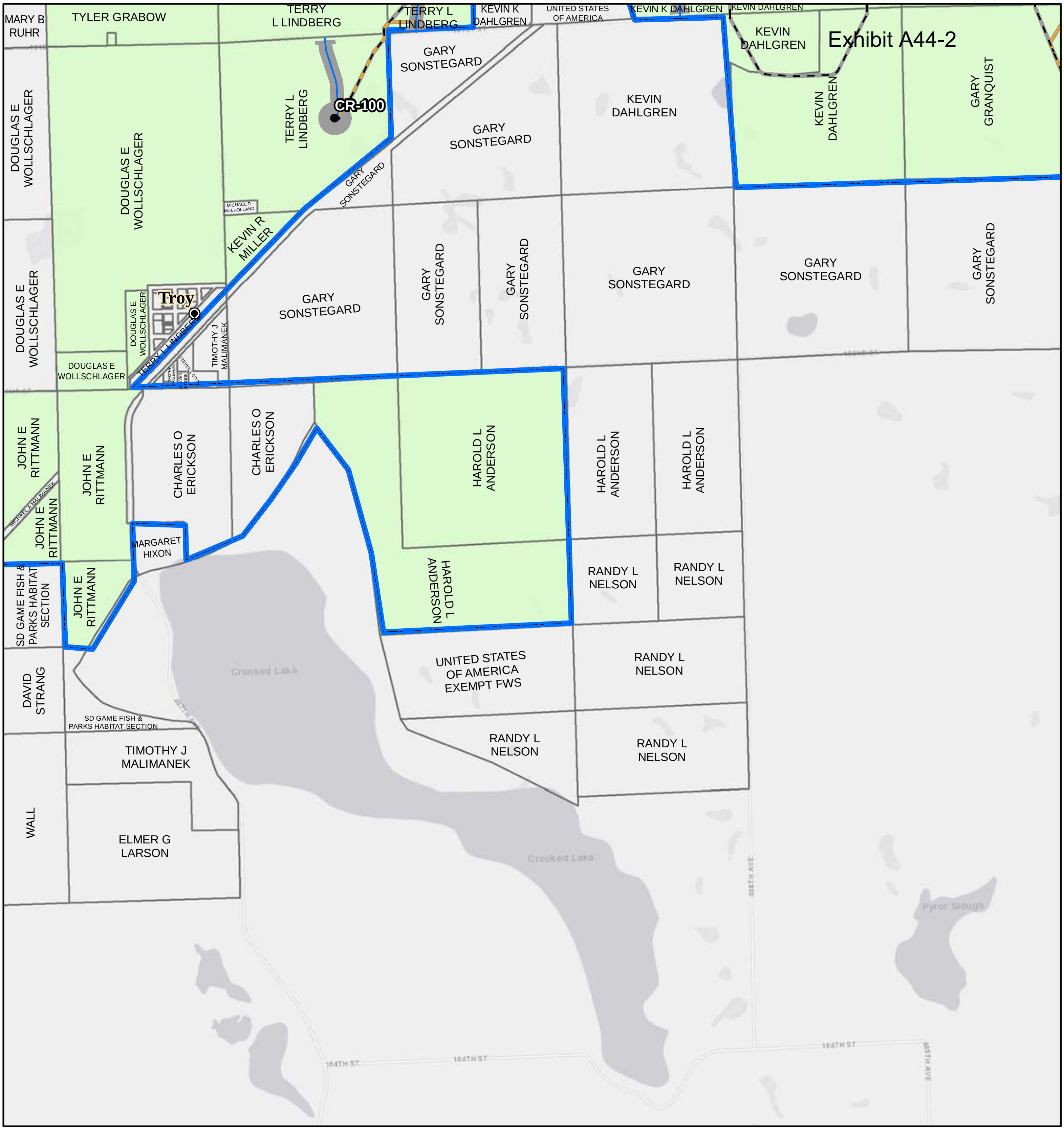


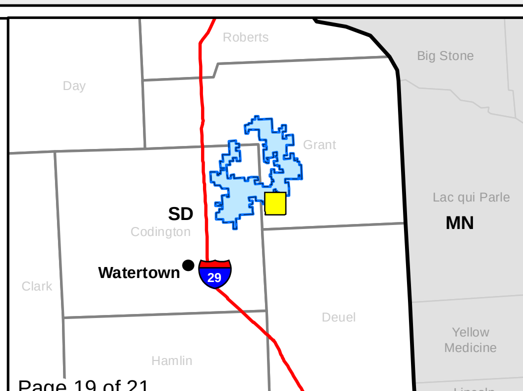
Figure 3a. Project Map

Crowned Ridge Wind Farm

- Turbine
- MET Tower
- City
- Access Road
- Collector Line
- Crane Path
- Railroad
- O&M Facility/ Substation
- Batch Plant
- Laydown Yard
- Construction Easement
- Parcel Boundary
- Project Boundary
- County Boundary

Lease Status

- Leased, Signed
- Pending
- Under Option but Likely to Expire/Not Resign



Kilometers: 0, 0.5, 1

Miles: 0, 0.25, 0.5

Service Layer Credits: Esri, HERE, Garmin, © OpenStreetMap contributors, and the GIS user community

Quadrangle: South Shore (1973), Stockholm (1973)

Township/Range: T118N, R50W 017324

Grant County, South Dakota

Projection: NAD 1983 UTM Zone 14N

SWCA ENVIRONMENTAL CONSULTANTS

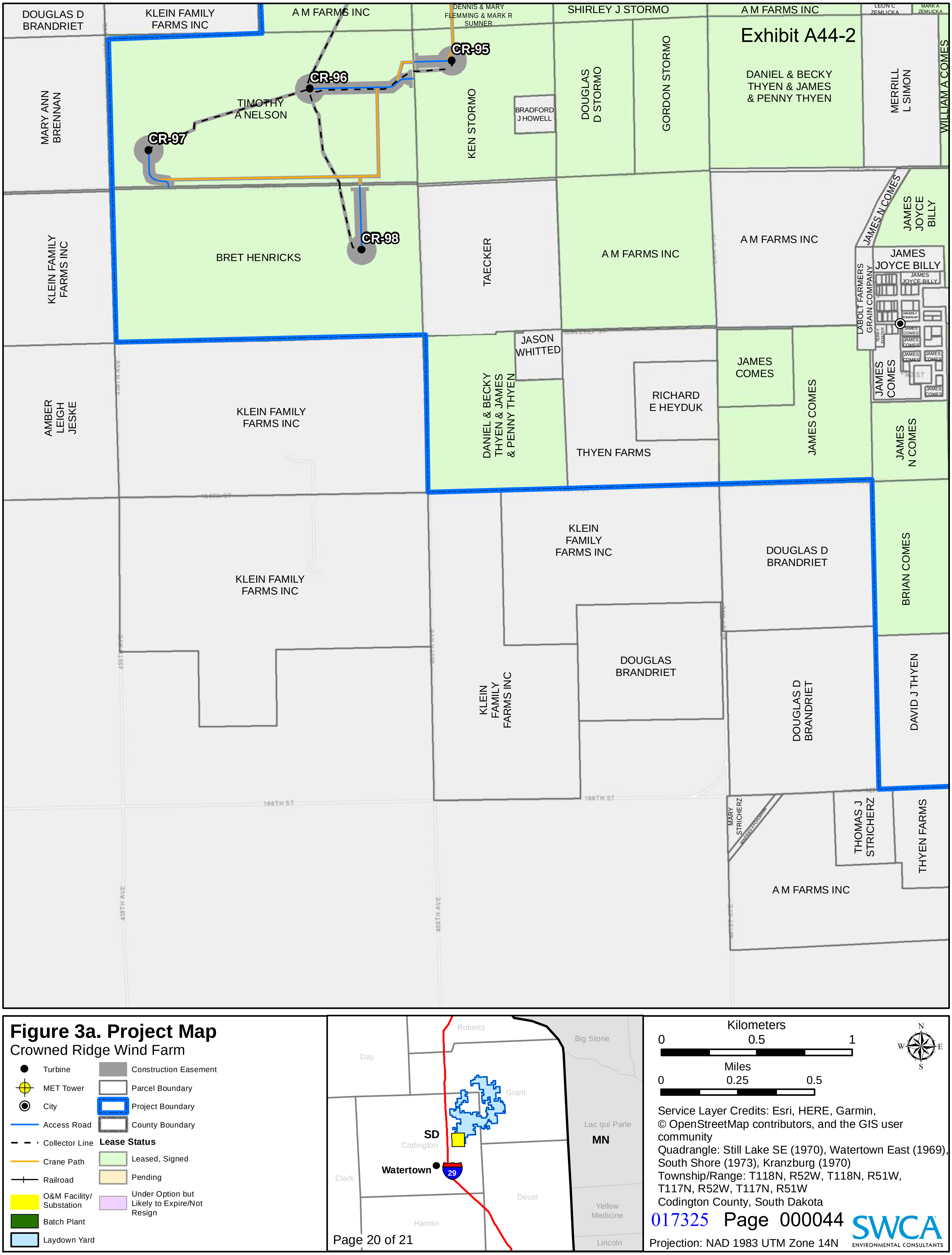


Figure 3a. Project Map

Crowned Ridge Wind Farm

Service Layer Credits: Esri, HERE, Garmin, © OpenStreetMap contributors, and the GIS user community

Quadrangle: Still Lake SE (1970), Watertown East (1969), South Shore (1973), Kranzburg (1970)

Township/Range: T118N, R52W, T118N, R51W, T117N, R52W, T117N, R51W

Codington County, South Dakota

Projection: NAD 1983 UTM Zone 14N

SWCA ENVIRONMENTAL CONSULTANTS

Exhibit A44-2

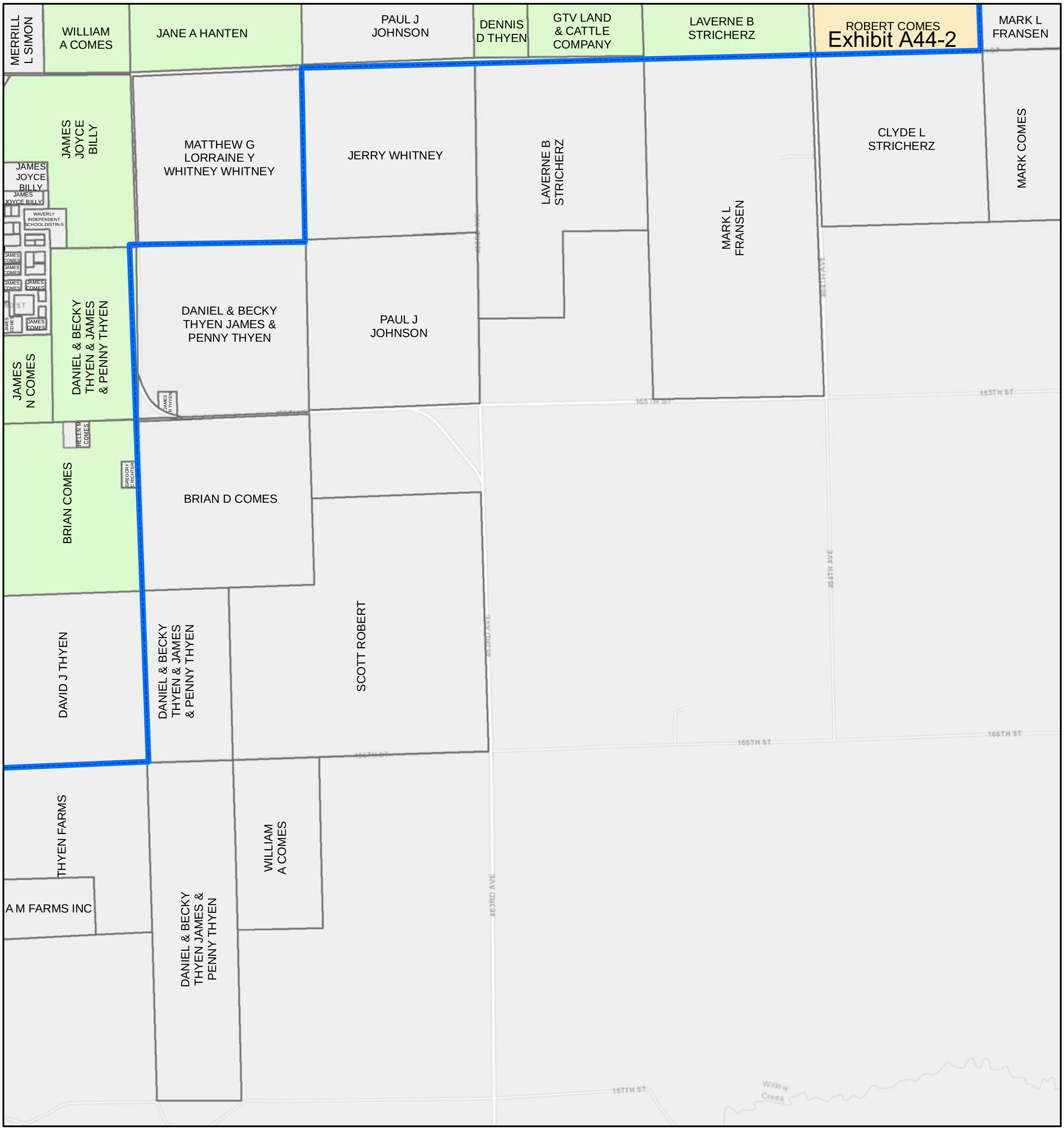


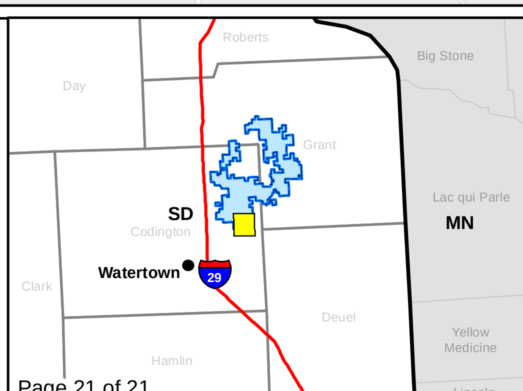
Figure 3a. Project Map

Crowned Ridge Wind Farm

- Turbine
- MET Tower
- City
- Access Road
- Collector Line
- Crane Path
- Railroad
- O&M Facility/ Substation
- Batch Plant
- Laydown Yard
- Construction Easement
- Parcel Boundary
- Project Boundary
- County Boundary

Lease Status

- Leased, Signed
- Pending
- Under Option but Likely to Expire/Not Resign



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Kilometers

0 0.5 1

Miles

0 0.25 0.5

Service Layer Credits: Esri, HERE, Garmin, © OpenStreetMap contributors, and the GIS user community

Quadrangle: South Shore (1973), Kranzburg (1970)

Township/Range: T118N, R51W, T117N, R51W

Codington County, South Dakota

Projection: NAD 1983 UTM Zone 14N

017326

SWCA ENVIRONMENTAL CONSULTANTS

BEFORE THE PUBLIC UTILITIES COMMISSION
OF THE STATE OF SOUTH DAKOTA

IN THE MATTER OF THE APPLICATION) BY CROWNED RIDGE WIND, LLC FOR A) PERMIT OF A WIND ENERGY FACILITY) IN GRANT AND CODINGTON COUNTIES))))	EL19-003 **APPLICANT'S RESPONSES TO INTERVENOR'S FIFTH SET OF DATA REQUESTS TO CROWNED RIDGE WIND, LLC**

Attached, please find Applicant's Responses to Intervenor's Fifth Set of Data Requests to Crowned Ridge Wind, LLC.

5-1) Please provide the details of the sounds pressure levels received at each of the property listed below for each of the five closet wind turbines to each property line reception point.

Intervenor Property ID List

<u>Intervenor Property ID List</u>

#	Receptor ID from Model
1	CR1-G7—NP or CR1-C70-NP confirm id number
2	CR1-C29-NP
3	CR1 or number for Kristi Mogen
4	CR1-C27-NP
5	CR1-C16-NP
6	Waverly School (319 Mary Pl., Waverly SD

For each of the receptor locations please provide the distances and sound emission levels from each of the five wind turbines closest to the nearest property line point of reception used in the model. Sound pressure emission levels shall be provided in 1/1 octave band detail (63Hz to 800Hz minimum) without any use of weighting filters plus the over all sound level in dBA and dBC sound level for each wind turbine. The bottom of the table shall show the sound pressure level of the combined impact of each set of five wind turbines. If 1/1 octave band sound pressure levels cannot be provided then, at a minimum, provide the dBA and dBC sound levels in the appropriate columns. The table below demonstrates the type of data requested and format desired for response.

	Intermediate calculations for receptor CR1-XX-NP										
	Showing impact of Five Closest Wnd Turbines										
#	Turbine	Distance	Turbine Ln contribution (dB) in frequency band (Hz)							Turbine SPL	Turbine SPL
n	e ID	e (M)	63	125	250	500	1000	2000	4000	8000	(dBA)	(dBC)
1	CR12	632	45	41	37	36	32	23	1	-54	37	52
2	CR21	875	42	38	34	32	28	18	-9	-86	33	48
3	CR5	1208	39	35	31	29	24	12	-23	-128	29	44
4	CR51	1546	37	33	28	26	20	6	-37	-170	27	42
5	CR55	1749	36	31	27	25	19	3	-44	-195	24	40
-	Sum of five WT		50	43	39	37	33	24	1	-	38	53

Please provide one table for each of the six receptor points.

Response: The noise levels and distances to the five nearest turbines for each of the six requested receptor locations are shown in the table below. The 1/3 octave turbine emission noise data is used as an input to the noise propagation model, however, the noise levels output from the model are only given as sound pressure levels in dBA, because octave information is not produced as an output.

Receptor	Turbine	Dist. (ft)	dBA	Turbine	Dist. (ft)	dBA	Turbine	Dist. (ft)	dBA	Turbine	Dist. (ft)	dBA	Turbine	Dist. (ft)	dBA
CR1-G70-NP	CRI-113	12,651	18.34	CRI-101	15,007	16.44	CRI-108	15,112	16.36	CRI-119	15,607	16.01	CRI-Alt1	15,866	15.82
CR1-C29-NP	CRI-67	2,457	36.8	CRI-68	4,252	30.71	CRI-59	4,675	29.65	CRI-58	5,577	27.62	CRII-131	7,372	26
Mogen	CRI-134	13,186	17.87	CRI-Alt4	15,522	16.06	CRI-132	16,273	15.53	CRI-Alt15	16,903	15.1	CRI-131	17,228	14.88
CR1-C27-NP	CRI-79	2,549	36.38	CRI-91	5,974	26.81	CRI-86	6,227	26.33	CRI-89	6,450	25.91	CRI-77	7,487	24.16
CR1-C16-NP	CRII-Alt4	3,127	36.11	CRI-Alt22	2,736	35.61	CRII-Alt3	4,465	32.07	CRI-94	4,259	30.7	CRI-87	4,311	30.56
Waverly School	CRII-Alt4	5,627	29.34	CRII-Alt5	5,892	28.78	CRI-94	6,207	26.37	CRI-92	6,224	26.34	CRI-93	6,535	25.77

Respondent: Jay Haley, Wind Engineer

5-2) Page 3 of Appendix M (telecommunications report), provide the 'no harm' latter referenced.

a.) Why does the telecommunications report include 266 turbines? This project has 130 turbines.

b.) On page 5 of Appendix M, the turbines are located north of Waverly use 1.7 MW turbines. Are 1.7 MW turbines being used in this project?

c.) How will that change affect the project or any reports?

d.) Did Codington County approve 1.7 MW or 2.3 MW around Waverly in the CUP?

Response: Please see Attachment 1 for the "No Harm" letter.

a.) The combined 266 turbines in the telecommunications report represent the proposed turbine locations for both the Project and the adjacent Crowned Ridge Wind II project. The Applicant opted to conduct the telecom report with both sites together. The microwave beam path results would not change if the study was to be conducted on a site by site analysis.

b.) No, at the time the telecom report was completed, the Project considered the use of GE 1.715-103-80 turbines. The Applicant is no longer considering the use of the GE 1.715-103-80 turbines.

c.) The turbine technology switch does not affect any of the beam path results as the microwave beams generated are not dependent on turbine technology.

d.) Codington County approved of both GE 1.715-103-80 turbines and GE2.3-116-90 turbines around Waverly in the Conditional Use Permit.

Respondent: Tyler Wilhelm, Project Manager

5-3) List all SD projects that Nextera or its affiliated [companies] have been involved with and to what extent.

Response: Crowned Ridge Wind objects to the data request as overly broad, not relevant to the scope of the proceeding, and not reasonably calculated to lead to the discovery of admissible evidence in this proceeding before the Commission. Subject to and without waiving these objections, Crowned Ridge Wind provides the following response:

See Section 3 of the Application and Amendment to Section 3.0. NextEra Energy Resources, LLC (NEER) or an affiliate, subsidiary of NEER is involved with the following development projects in the state of South Dakota:

Early to Late Stage development projects

- Crowned Ridge Wind, LLC;
- Crowned Ridge Wind II. LLC;

- Cattle Ridge Wind Farm, LLC;
- Day County II Wind, LLC;

Currently operating projects:

- Day County Wind, LLC;
- Wessington Wind Energy Center, LLC; and
- FPL Energy South Dakota Wind, LLC.

Respondent: Tyler Wilhelm, Project Manager

5-4) Appendix M does not take into account Data Truck, LLC. Can you please provide all correspondence with the company regarding this docket.

Response: There is no correspondence to provide between Data Truck and Crowned Ridge Wind.

Respondent: Tyler Wilhelm, Project Manager

5-5) Section 13.1.1, Land Use, of the application states, "Two action sand and gravel pits are located in T1 8N R51 W Section 15 and 16."

a. Please explain where sand and gravel will be extracted to support the project. For example, will the gravel just be extracted from the two active sand and gravel pits or will new sand and gravel pits be dug either in or near the project area? Please provide a map of all sand and gravel pit extraction locations to be utilized for this project. Detail whether the pit is a current pit or a new pit.

Response: The sand and gravel needed for the project will be extracted from three existing pits identified on the map titled "Sand and Gravel Pits". See Attachment 1. As Attachment 1 shows, the existing sand and gravel pits include Campbell Pit, Lowe Pit and Lindberg Pit. Sand. Also, gravel will be extracted from the new Johnson Pit, for which the required permits will be obtained before it is used.

Respondent: Mark Thompson, Manager Wind Engineering

5-6) If new sand and gravel pits will be dug to support this project, please describe the current state of the land (grassland including native, etc.)

a. Please explain how many acres of each type of land (grassland, native grassland, hayland, row crop, etc.) will be disturbed to extract the sand and gravel, including roads to the pit location.

Response: The Johnson Pit will be the only new sand and gravel pit. The excavation and access to the pit will affect 15 acres of native grassland. The other pits identified (Lindberg, Campbell and Lowe) are existing pits and will not cause any new disturbance.

Respondent: Mark Thompson, Manager Wind Engineering
Sarah Sappington, Director

5-7) Please provide an updated map 2a to include USFWS Grassland Easements, USFWS Wetland Easements, USFWS Conservation Easements.

Response:

Please see Attachment 1. Attachment 1 depicts a planned crane path between turbines CR-105 and CR-106 which intersects a USFWS grassland-wetland combination easement. This crane path will not be utilized. Crowned Ridge Wind, LLC currently is considering two options to avoid the USFWS grassland-wetland combination easement: 1) a reroute of the crane path, or 2) a crane breakdown to avoid a crane walk through this area.

Respondent: Sarah Sappington, Director; Tyler Wilhelm, Project Manager, and Mark Thompson, Manager of Wind Engineering.

5-8) Please provide correspondence including maps with USFWS and SDGFP related to the addition of Cattle Ridge.

Response: All correspondence from Crowned Ridge Wind to USFWS and SDGFP related to the addition of Cattle Ridge is included in Appendix C of the Application.

Respondent: Sarah Sappington, Director

5-9) Where and how will the damaged blades be disposed of during the construction, operation phases and at the time of decommissioning?

a. Please provide the material and chemical composition of the blades.

Response: During construction, blades rarely ever get damaged and disposed, as a damaged blade is repaired on site by professional fiberglass personnel. During the operating phase, damaged blades are also repaired on site. A blade that is damaged to the point that replacement is required, is cut into pieces and hauled off site by a local contractor, either to a local or remote land fill for disposal in accordance with applicable laws. The process would be same during decommissioning. See Section 2.2 of the Decommissioning Plan, which is Appendix L of the Application.

a. The blades are made with fiberglass infused with epoxy resin. The core materials for reinforcement are balsa and foam.

Respondent: Mark Thompson, Manager Wind Engineering

5-10) Has the applicant finalized where the water will be sourced?

Response: Crowned Ridge Wind is in the process of identifying the water sources. Prior to construction, the water sources will be identified and all applicable permits will be obtained prior to the use of the water. There is also a potential that during construction addition water sources will be needed, and, if so, the additional water sources will only be used after all applicable permits have been obtained.

Respondent: Mark Thompson, Manager Wind Engineering

5-11) How many gallons of water per day will be needed during the construction phase of the Crowned Ridge Wind Project?

a. What will the water be used for? Be all-inclusive, include dust control, concrete batch plant, cleaning vehicles, etc.
b. Provide methods for calculations.

Response: Average daily need will be approximately 203 Mgal

1 Mgal = 1000 gallons

a. Water will be used for dust control, compaction (back fill, subgrade, gravel, crane pads, site laydown), and concrete batch plant processing, grouting, and cleaning of vehicles and equipment, and horizontal borings.

b. Calculations – estimated usage are added as shown below.

- Backfill = 3440 Mgal
- Subgrade = 1415 Mgal
- Gravel = 4860 Mgal
- Sites = 1300 Mgal
- Crane pads = 560 Mgal
- Dust Control = 6240 Mgal
- Concrete/Grout = 4160 Mgal (8 gallons per CY)
- Cleaning Equipment = 600 Mgal (150 gallons per day)
- Horizontal Boring = 180 Mgal (300 gallons per day)

Total = 22,755 Mgal

1 Mgal = 1000 gallons

Respondent: Mark Thompson, Manager Wind Engineering

5-12) In Applicant's Response to the Third Data Request by Staff answered by Jay Haley, the answer to questions 3-6, includes turbine information regarding sound, flicker and distance for "Mr. Allen Robish; CR1-G70-NP: 42.1 dBA, 12:04 hr/yr, 1,955 ft". Please provide.

1. Location of the turbines (map and table information)
2. Sound map and table information regarding CR10G70-NP
3. Flicker map and table information regarding CR1-G70-NP
4. All other turbine information as listed above, for any turbines within 2 miles of Mr. Robish

Response: Requested maps are attached as Attachment 1. The response to the Third Data Request by Staff contained an error in the coordinates of the location of the receptor as it used CR1-C70-NP instead of CR1-G70-NP. The results for CR1-G70-NP are 28.8 dBA and 00:00 hr/yr. There are no turbines within 2 miles of CR1-G70-NP. The nearest turbine is CR1-101 which is 15,008 feet away.

Respondent: Jay Haley, Wind Engineer

Miles F. Schumacher
Attorneys for Applicant
Lynn, Jackson, Shultz & Lebrun, PC
110 N. Minnesota Ave., Suite 400
Sioux Falls, SD 57104

UNITED STATES DEPARTMENT OF COMMERCE
National Telecommunications and Information Administration
Washington, D.C. 20230

Mr. Joshua Burdick
Resource Modeling Analyst
WindLogics
700 Universe Blvd.
Juno Beach, FL 33408

Re: Crowned Ridge Project, Rev. 1: Codington, Grant and Deuel Counties, SD

Dear Mr. Burdick:

In response to your request on August 20, 2018, the National Telecommunications and Information Administration provided to the federal agencies represented in the Interdepartment Radio Advisory Committee (IRAC) the plans for the Crowned Ridge Wind Project, Revision One, located in Codington, Grant and Deuel Counties, South Dakota.

After a 45+ day period of review, one federal agency, the Department of Energy (DOE), identified concerns with turbine placement in this area. Their concerns are noted below:

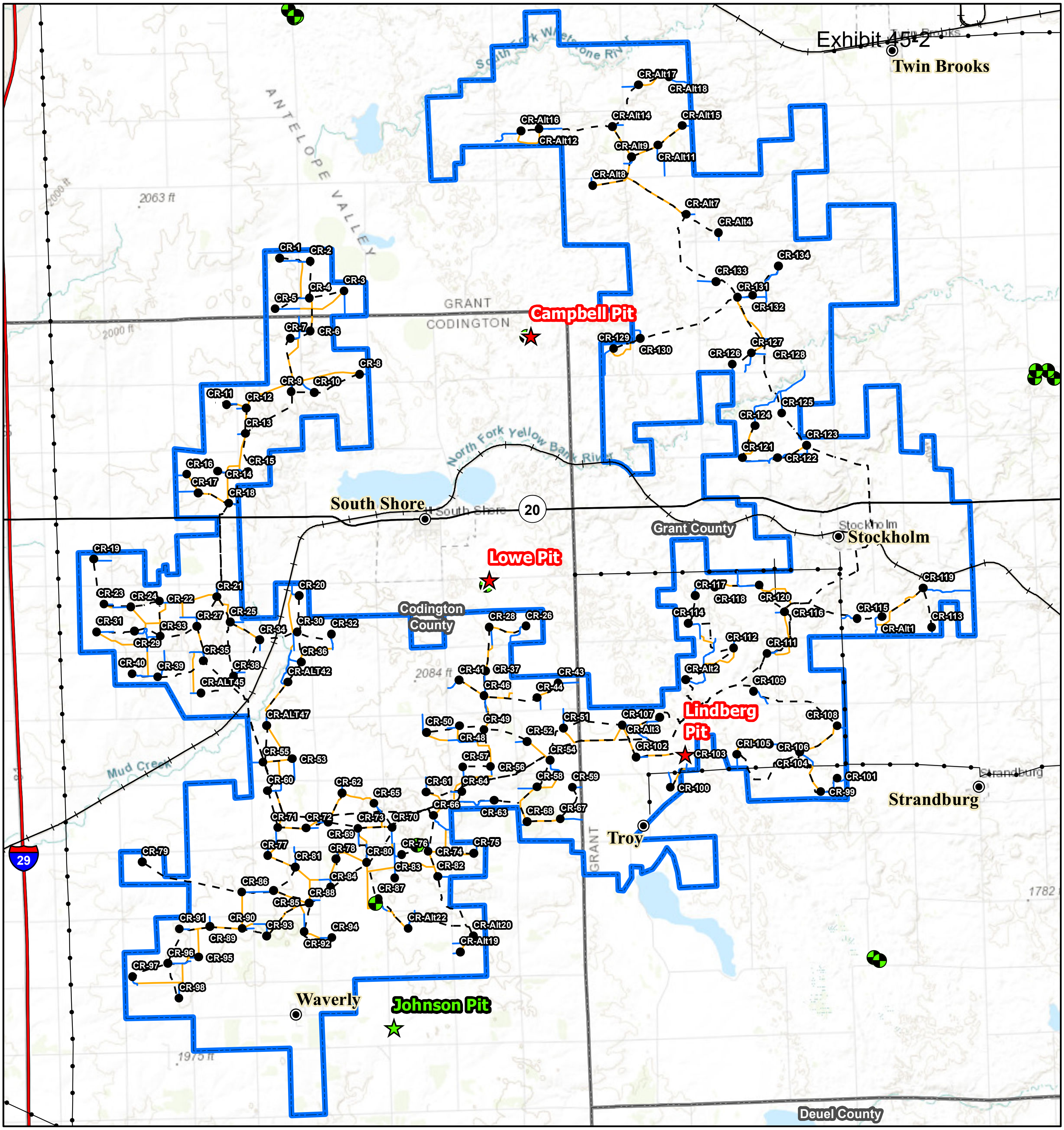
> The Crowned Ridge Wind Project, Rev. 1, in Codington, Grant and Deuel counties has the potential to adversely affect Western Area Power Administration operations. Energy requests the developer coordinate turbine placement directly with our Western Spectrum Manager. His contact information is included here: Scott E. Johnson; Sr. Telecom Engineer; Spectrum Program Manager; U.S. Dept. of Energy/Western Area Power Administration Headquarters; P.O. Box 281213, Lakewood, Colorado, 80228-8213; Phone: (720) 962-7380; Fax: (720) 962-4080; sjohnson@wapa.gov.

While the other IRAC agencies did not identify any concerns regarding radio frequency blockage, this does not eliminate the need for the wind energy facilities to meet any other requirements specified by law related to these agencies. For example, this review by the IRAC does not eliminate any need that may exist to coordinate with the Federal Aviation Administration concerning flight obstruction.

Thank you for the opportunity to review this proposal.

Sincerely,

John R. McFall
Deputy, Frequency Assignment Subcommittee
Office of Spectrum Management



Sand and Gravel Pits

Crowned Ridge Wind Farm

- City
- Turbine
- Existing Sand and Gravel Pit*

Sand and Gravel Pit to be used for Construction

- Existing
- Proposed
- Access Road
- Collector Line
- Crane Path
- Electrical Line
- Railroad
- Interstate Highway
- State Highway
- Project Boundary
- County Boundary

*Data Source: State of South Dakota GIS Data

Kilometers: 0 5 10

Miles: 0 2.5 5

N W E S

Base Map: World Topographic Map
Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community
Codington, Deuel, and Grant Counties, South Dakota

Projection: NAD 1983 UTM Zone 14N

017336

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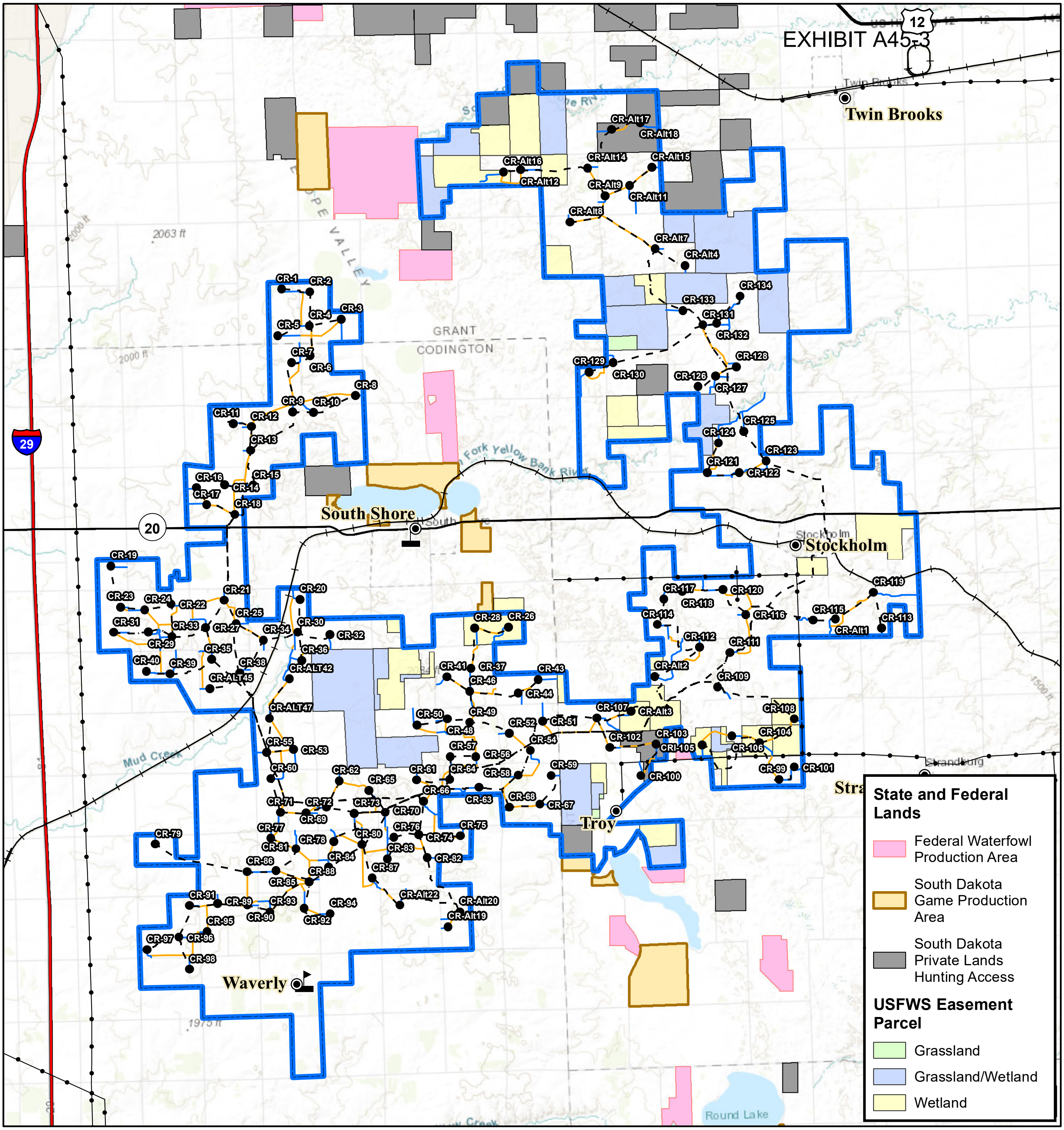


Figure 2. Public Land and Facilities

Crowned Ridge Wind Farm

City	Electrical Line
School	Railroad
Turbine	Interstate Highway
Collector Line	U.S. Highway
Access Road	State Highway
Crane Path	Project Boundary

Kilometers: 0, 5, 10

Miles: 0, 2.5, 5

N W E S

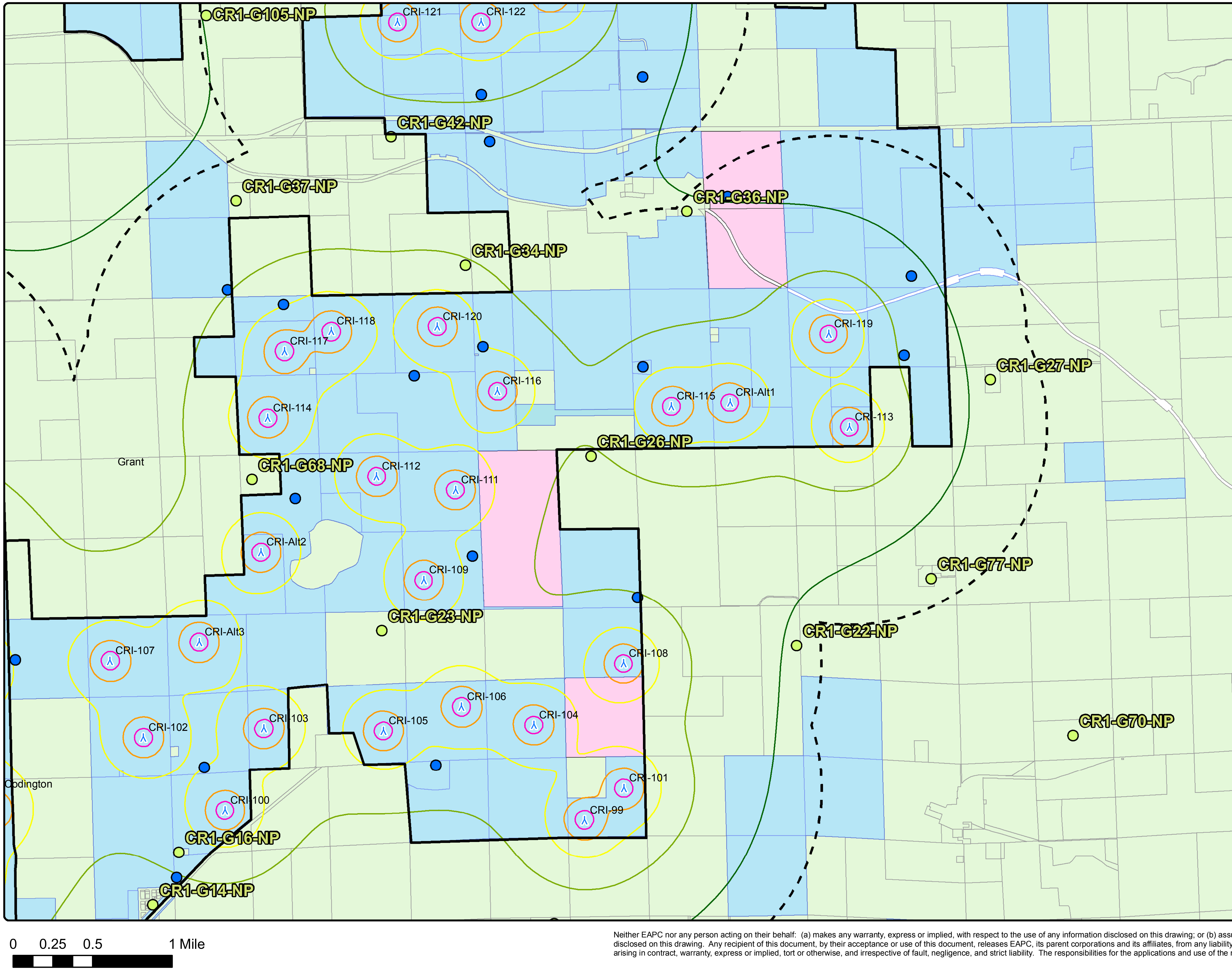
Base Map: World Topographic Map
Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community
Codington and Grant Counties, South Dakota

Projection: NAD 1983 UTM Zone 14N

017337

Page 000001

SWCA ENVIRONMENTAL CONSULTANTS



EAPC WIND ENERGY

www.eapc.net | 701.775.3000

Crowned Ridge Wind Farm
Sound Pressure Iso-Lines

Client

SWCA Environmental Consultants

Project Description

Wind turbine layout with occupied structures within 2 km as well as parcel boundaries.

Predicted sound pressure levels at existing residences and land parcel boundaries.

Additional 2 dBA added.

Location: *Watertown, SD*
Project #: *20174431*

Issue Dates

#	Description	Date
1	Original	2019.05.29

Drawn By: *AS* *Checked By:* *JH*

Legend

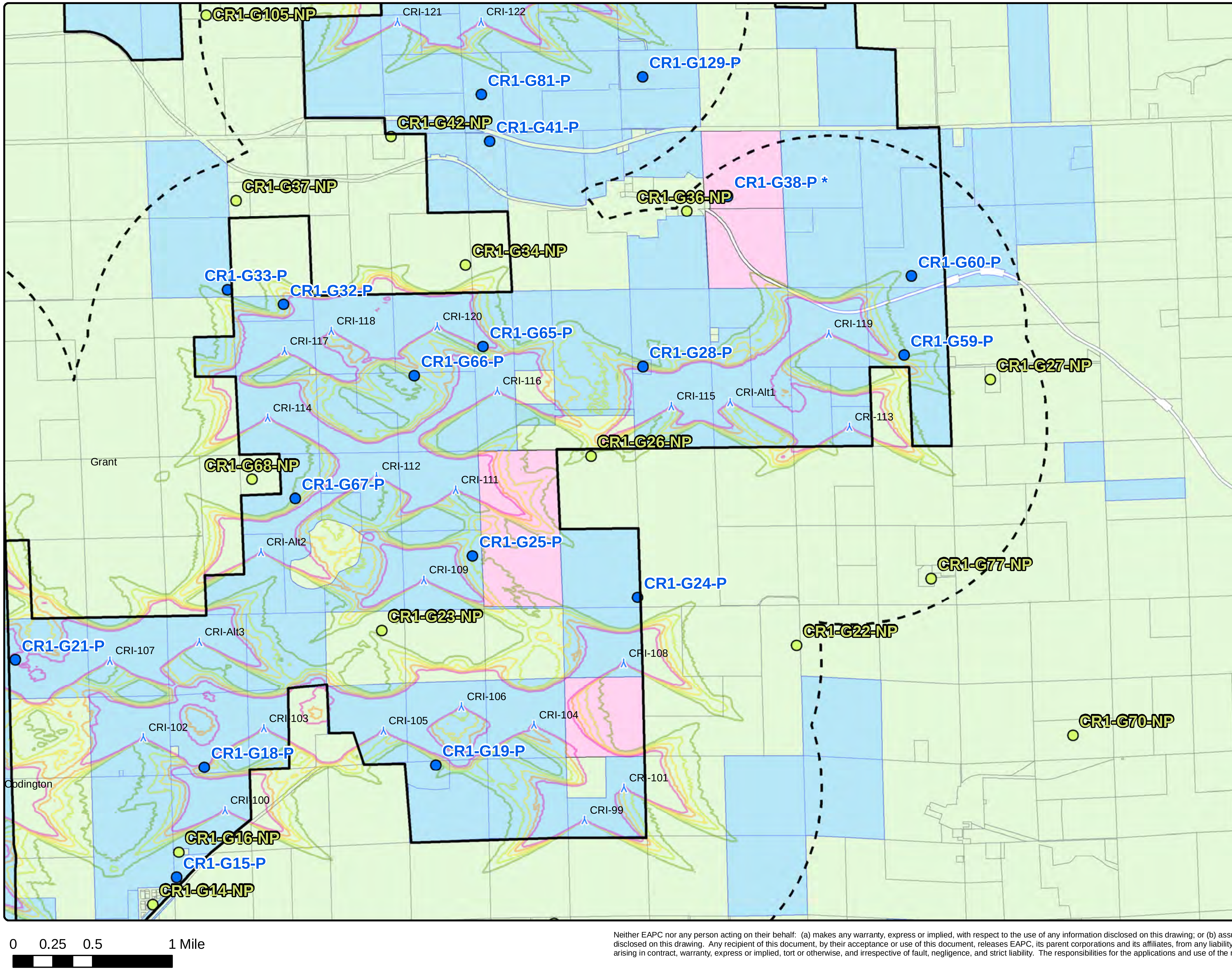
- Crowned Ridge Wind Turbines
- 2 km Turbine Buffer
- County Lines
- CR1 Project Boundary
- Non Participants
- Participants

Sound Pressure (dBA)

- 35
- 40
- 45
- 50
- 55
- Non-Participating Codington Parcels
- Participating Codington Parcels
- Participating Parcels
- Pending Parcels
- Non-Participating Parcels

N E S W

EXHIBIT A45-4



EAPC WIND ENERGY

www.eapc.net | 701.775.3000

Crowned Ridge Wind Farm Shadow Flicker Iso-Lines

Client

SWCA Environmental Consultants

Project Description

Wind turbine layout with land parcels within the project footprint and existing occupied strucures.

Codington County land parcels within 2 km of a wind turbine.

Location: Watertown, SD

Project #: 20174431

Issue Dates

#	Description	Date
1	Original	2019.05.29

Drawn By: AS *Checked By:* JH

Legend

- Crowned Ridge Wind Turbines
- 2 km Turbine Buffer
- County Lines
- CR1 Project Boundary
- Non Participants
- Participants

Shadow Flicker (hr/yr)

- 10
- 15
- 20
- 25
- 30
- Non-Participating Codington Parcels
- Participating Codington Parcels
- Participating Parcels
- Pending Parcels
- Non-Participating Parcels

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