

October 8, 2018

**VIA ELECTRONIC FILING**

Ms. Patricia Van Gerpen  
Executive Secretary  
South Dakota Public Utilities Commission  
500 E Capitol Ave  
Pierre, SD 57501-5070

**RE: In the Matter of the Application by Prevailing Wind Park, LLC for a Permit of a Wind Energy Facility in Bon Homme County, Charles Mix County and Hutchinson County, South Dakota, for the Prevailing Wind Park Project Docket EL18-026**

Dear Ms. Van Gerpen:

In connection with the above-referenced matter, enclosed please find the following exhibits and a Certificate of Service:

- Exhibit A3-2 - Updated Shadow Flicker Analysis;
- Exhibit A10-2 - Updated Sound Study;
- Exhibit A20-1 - Applicant's Responses to Staff's Fifth Set of Data Requests;
- Exhibit A20-2 - Applicant's Responses to Staff's Sixth Set of Data Requests;
- Exhibit A22-2 - Intervenors Gregg Hubner, Marsha Hubner, Paul Schoenfelder, and Lisa Schoenfelder's Responses to Applicant's Second Set of Data Requests;
- Exhibit A22-3 - Intervenors Gregg Hubner, Marsha Hubner, Paul Schoenfelder, and Lisa Schoenfelder's Responses to Applicant's Third Set of Data Requests;
- Exhibit A24 - Intervenor Kelli Pazour's Responses to Applicant's First Set of Data Requests;
- Exhibit A25 - Intervenor Karen Jenkins' Responses to Applicant's First Set of Data Requests;
- Exhibit A27 - Intervenor Sherman Fuerniss' Responses to Staff's Second Set of Data Requests;
- Exhibit A28 - Intervenors Gregg Hubner, Marsha Hubner, Paul Schoenfelder, and Lisa Schoenfelder's Responses to Staff's Second Set of Data Requests;
- Exhibit A29 – Figure 10;
- Exhibit A30 – Applicant's Supplemental Responses to Staff's Data Requests;
- Exhibit A31 – Applicant's Updated Responses to Intervenors' Data Requests;

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Ms. Patricia Van Gerpen  
October 8, 2018  
Page 2

- Exhibit A32 – Permit Conditions Jointly Proposed by Applicant and Staff;
- Exhibit A33 – Applicant's Proposed Conditions; and
- Certificate of Service.

If you have any questions, please let me know.

Sincerely,

*/s/ Mollie M. Smith*

Mollie M. Smith

*Attorney at Law*

**Direct Dial:** 612.492.7270

**Email:** [msmith@fredlaw.com](mailto:msmith@fredlaw.com)

Enclosures

cc: Certificate of Service/Service List



# Shadow Flicker Analysis



**Prevailing Wind Park**

**Prevailing Wind Park, LLC**

Prevailing Wind Park  
Project No. 105644

Revision 6a  
10/04/2018

# **Shadow Flicker Analysis**

prepared for

**Prevailing Wind Park, LLC  
Prevailing Wind Park  
Bon Homme/Charles Mix/Hutchinson Counties, SD**

**Project No. 105644**

**Revision 6a  
10/04/2018**

prepared by

**Burns & McDonnell Engineering Company, Inc.  
Kansas City, Missouri**

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**TABLE OF CONTENTS**

	<u><b>Page No.</b></u>
<b>1.0 INTRODUCTION .....</b>	<b>1-1</b>
1.1 Study Overview .....	1-1
1.2 Project Overview .....	1-1
1.3 Shadow Flicker Overview.....	1-1
1.4 Site Visit.....	1-2
 <b>2.0 MODELING PARAMETERS AND INPUTS .....</b>	 <b>2-1</b>
2.1 Modeling Overview .....	2-1
2.2 Turbine Coordinates.....	2-1
2.3 Turbine Dimensions.....	2-1
2.4 Receptors.....	2-1
2.5 Terrain.....	2-2
2.6 Obstacles .....	2-2
2.7 Turbine Operation.....	2-2
2.8 Flicker Relevance.....	2-3
2.9 Sun Angle.....	2-3
2.10 Sun Obstruction .....	2-3
2.11 Environment.....	2-3
 <b>3.0 RESULTS.....</b>	 <b>3-1</b>
 <b>APPENDIX A - PROJECT SITE LAYOUT</b>	
<b>APPENDIX B - INFRASTRUCTURE COORDINATES</b>	
<b>APPENDIX C - ON-SITE FREQUENCY DISTRIBUTION</b>	
<b>APPENDIX D - SUNSHINE PROBABILITY DATA</b>	
<b>APPENDIX E - POWER CURVE</b>	
<b>APPENDIX F - FLICKER RESULTS BY RECEPTOR</b>	
<b>APPENDIX G - SHADOW FLICKER DURATION MAP</b>	
<b>APPENDIX H - SHADOW FLICKER CALENDAR</b>	

**LIST OF TABLES**

	<b><u>Page No.</u></b>
Table 3-1: Summary of Results .....	3-1
Table B-1: Turbine Coordinates .....	B-1
Table B-2: Receptor Coordinates .....	B-3
Table C-1: Onsite Frequency Distribution, 111.5 magl .....	C-1
Table D-1: Monthly Sunshine Probability for Wagner, South Dakota .....	D-1
Table E-1: GE 3.8-137 Power Curve Values .....	E-1
Table F-1: Flicker Duration by Receptor .....	F-1

**LIST OF FIGURES**

	<b><u>Page No.</u></b>
Figure A-1: Project Site Layout with Flicker Buffer .....	A-1
Figure D-1: Monthly Sunshine Probability for Wagner, South Dakota .....	D-1
Figure G-1: Shadow Flicker Duration Map .....	G-1
Figure H-1: Shadow Flicker Calendar .....	H-1

**LIST OF ABBREVIATIONS**

<b><u>Abbreviation</u></b>	<b><u>Term/Phrase/Name</u></b>
Burns & McDonnell	Burns & McDonnell Engineering Company, Inc.
Developer	Prevailing Wind Park, LLC
GE	General Electric
kg/m <sup>3</sup>	Kilograms per cubic meter
m/s	Meters per second
MW	Megawatt
Project	Prevailing Wind Park
Project Site	Location of Prevailing Wind Park in South Dakota
Study	Shadow Flicker Analysis

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**REVISION HISTORY**

<b>Rev</b>	<b>Issue Date</b>	<b>Release Notes</b>
0	03-Apr-2018	Original release
1	09-Apr-2018	Revised wind turbine layout, incorporated client comments
2	11-Apr-2018	Added REC-138
3	16-Apr-2018	Revised wind turbine layout
4	27-Apr-2018	Revised wind turbine layout
5	25-May-2018	Included obstacles at select locations; added participant status to receptors
5a	27-May-2018	Revised Table 3-1, added Table 3-2
5b	28-May-2018	Incorporated client comments
5c	29-May-2018	Incorporated client comments
6	03-Oct-2018	Updated for new turbine layout; added receptor locations; GE3.8-137 layout
6a	04-Oct-2018	Incorporated client comments



## **1.0 INTRODUCTION**

### **1.1 Study Overview**

Burns & McDonnell Engineering Company, Inc. (“Burns & McDonnell”) was retained by Prevailing Wind Park, LLC (“Developer”) to conduct a shadow flicker analysis (the “Study”) for the proposed Prevailing Wind Park (the “Project”). The objective of the Study was to estimate the annual frequency of shadow flicker on occupied residences caused by Project wind turbines. No attempt was made in this Study to examine or opine on health effects related to shadow flicker.

### **1.2 Project Overview**

The proposed Prevailing Wind Park will be located in Bon Homme, Charles Mix, and Hutchinson Counties in South Dakota, approximately 10 miles east of the town of Wagner and approximately 75 miles southwest of the city of Sioux Falls, South Dakota (the “Project Site”). The Project will consist of up to 61 wind turbines with a maximum nameplate capacity of up to 219.6 megawatts (“MW”), although output at the point of interconnection will be limited to a maximum of 200 MW. The General Electric (“GE”) 3.8-137 with a 111.5-meter hub height turbine model was considered as part of this Study.

A map showing the general location and configuration of the Project Site is included as Appendix A. For purposes of this Study, a total of 62 turbine positions were evaluated, although only up to 61 turbines are expected to be installed.

### **1.3 Shadow Flicker Overview**

Shadow flicker occurs when wind turbine blades pass in front of the sun to create recurring shadows on an object. Such shadows occur only under very specific conditions, including sun position, wind direction, time of day, and other similar factors.

The intensity of shadow flicker varies significantly with distance, and as separation between a turbine and receptor increases, shadow flicker intensity correspondingly diminishes. Shadow flicker intensity for distances greater than 10 rotor diameters (i.e., 1370 meters) is generally low and considered imperceptible. At such distances, shadow flicker is typically only caused at sunrise or sunset, when cast shadows are sufficiently long.

Shadow flicker impacts are not currently regulated in applicable state or federal law, nor are there requirements in the current Charles Mix County (SD) or Hutchinson County (SD) ordinances. Section 1741 of the Bon Homme County (SD) zoning ordinance states the following:

*When determined appropriate by the County, a Shadow Flicker Control System shall be installed upon all turbines which will cause a perceived shadow effect upon a habitable residential dwelling. Such system shall limit blade rotation at those times when shadow flicker exceeds thirty (30) minutes per day or thirty (30) hours per year at perceivable shadow flicker intensity as confirmed by the Zoning Administrator are probable.*

In addition to providing the modeling results, this report identifies those receptors that may experience shadow flicker more than 30 hours per year and/or 30 minutes per day.

#### **1.4 Site Visit**

Burns & McDonnell visited the Project Site in September 2018 to visually confirm the location of occupied receptors for this Study. Beyond this visit, the contents of this evaluation are based exclusively upon desktop analysis by Burns & McDonnell.

## **2.0 MODELING PARAMETERS AND INPUTS**

### **2.1 Modeling Overview**

Shadow flicker was modeled at the Project Site using WindPRO, an industry-leading software package for the design and planning of wind energy projects. This package models the sun's path with respect to every turbine location during every minute over a complete year. Any shadow flicker caused by each turbine is then aggregated for each receptor for the entire year.

The following sections are summaries of the inputs utilized in the WindPRO model for this Study.

### **2.2 Turbine Coordinates**

Shadow flicker intensity is partially dependent upon the distance from a receptor to the turbine causing the shadow. The Developer-provided coordinates of each turbine are presented in Appendix B, and the location of each turbine is presented graphically in Appendix A. For purposes of this Study, a total of 62 turbine positions were evaluated, although only up to 61 turbines are expected to be installed.

### **2.3 Turbine Dimensions**

The size of a wind turbine, including both hub height and rotor diameter, contributes to the length and width of the shadows that may be cast by that turbine. The GE 3.8-137 wind turbine generators were each modeled with a rotor diameter of 137 meters and a hub height of 111.5 meters.

### **2.4 Receptors**

A quantity of 149 receptors were modeled at the Project Site, including two (2) cemeteries. The coordinates of each receptor are presented in Appendix B and the location of each receptor is presented graphically in Appendix A. Coordinates for each receptor were provided by Developer, although Burns & McDonnell visited the Project Site in September 2018 to visually confirm the location of occupied receptors for this Study.

Each receptor was modeled in "green house" mode within the WindPRO model. This approach provides a conservative estimate of the amount of time when shadow flicker could occur by modeling each receptor as having windows on all sides and effectively causing the home to be susceptible to flicker effects in all directions.

## 2.5 Terrain

The WindPRO model utilizes topography data to place turbines and receptors at the proper elevations. This information is also used by the model to consider any natural land features between a turbine and a receptor that may block shadows from being seen at a receptor.

Publicly-available terrain data was downloaded from the National Elevation Dataset, a product of the United States Geological Survey. The 10-meter resolution digital elevation model DEM was exported at 10-foot intervals for use in the WindPRO model. Elevations were assigned by Burns & McDonnell to each turbine and each receptor using this data.

## 2.6 Obstacles

Obstacles located between a receptor and a turbine, such as trees or buildings, may significantly reduce or eliminate the duration and/or intensity of shadow flicker. Burns & McDonnell included obstacles in the WindPRO model, including trees and outbuildings, for only those receptors that exceeded 30 hours per year and/or 30 minutes per day. Such receptors are indicated by an asterisk (\*) in Appendix B and Appendix F, respectively. No obstacles were considered or modeled for any other receptors.

WindPRO models obstacles utilizing a cubic volume, where each obstacle is assigned a height, width, depth, and porosity level. The obstacles near the applicable receptors were reviewed by Burns & McDonnell and the type and characteristics of each obstacle were visually estimated using publicly-available desktop aerial imagery. Trees and groups of trees were assumed to be 12 meters tall, barns and other outbuildings were assumed to be 4 meters tall, and grain bins were assumed to be 6 meters tall. Only obstacles in reasonably close proximity to a receptor were considered (i.e., those that might be expected to influence flicker durations).

Burns & McDonnell did not make any in-person verifications regarding the existence, size, or influence of obstacles. The obstacles were modeled exclusively through desktop analysis of aerial imagery.

## 2.7 Turbine Operation

Shadow flicker is contingent upon the movement of the turbine blades. Shadow flicker can only occur when the turbine is in operation (i.e., when the turbine blades are rotating). Moreover, shadow flicker is generally most notable when a turbine is facing a receptor, as this results in the widest-possible shadow being cast. To more accurately reflect the periods of operation of each Project wind turbine, on-site hub-height wind data was provided by Developer and used to indicate the periods when the turbines are inactive due to wind speeds below the turbine cut-in speed or above the turbine cut-out speed, at which time the turbine rotor is not in motion and no shadow flicker will occur.

Project Site-specific wind data was also utilized to model the actual orientation of the turbines relative to each receptor. The Developer-provided wind data includes data collected by an on-site meteorological mast between September 2013 and September 2018. The provided data is shown in Appendix C.

Power curves for the proposed turbines were provided by Developer. These power curves were added to the WindPRO model to more accurately reflect the turbine's operational characteristics. The Developer-provided power curves are shown in Appendix E.

## **2.8 Flicker Relevance**

At distances beyond 10 rotor diameters, shadow flicker effects are generally considered low, as shadows diffuse and become imperceptible. Thus, a distance equal to 10 times the rotor diameter of each turbine (i.e., 1370 meters) was modeled as the maximum distance at which shadow flicker was considered relevant; receptors greater than this distance from a given turbine were not evaluated. The proximity of this buffer relative to each receptor is presented graphically in Appendix A.

## **2.9 Sun Angle**

The sun's path with respect to each turbine location is calculated by the WindPRO model to determine the cast shadow paths during every minute over a complete year. However, at very low sun angles, the light must pass through more atmosphere and becomes too diffused to form a coherent shadow. Thus, a value of three (3) degrees was utilized for the height at which the sun would not cause noticeable flicker.

## **2.10 Sun Obstruction**

The percentage of the turbine blade covering the sun disc is calculated by the WindPRO model to determine the size of shadow cast during every minute over a complete year. By default, the WindPRO model calculates shadow flicker only when at least 20 percent of the sun disc is covered by the turbine blades. When less than 20 percent of the sun disc is masked by the blades, the shadow will be too diffuse to cause a coherent shadow.

## **2.11 Environment**

Shadow flicker is only caused when the sun is shining. Sunshine probability data (see Appendix D) was obtained by Burns & McDonnell from [www.city-data.com](http://www.city-data.com). This data represents the percentage of hours each month that the sun is expected to be shining during daylight hours, with consideration given for cloud cover, rainy days, fog, or other similar occurrences that may diminish the potential occurrence or severity of shadow flicker.

### 3.0 RESULTS

Using the inputs and parameters defined in Section 2.0, the WindPRO model was used to calculate shadow flicker for the receptors at the Project Site. Table 3-1 presents a summary of these results by landowner status for the applicable receptor. Detailed tables are included within Appendix F that present shadow flicker durations by receptor, including estimated hours per year and maximum minutes per day. Additionally, maps are provided in Appendix G which illustrate the shadow flicker vectors (in hours per year) caused by each Project turbine.

**Table 3-1: Summary of Results**

<b>Landowner Status</b>	<b>No. of Turbines</b>	<b>No. of Receptors</b>	<b>No. of Receptors, Flicker <math>\geq</math> 30 hr/yr</b>	<b>No. of Receptors, Flicker <math>\geq</math> 30 min/day</b>
Participating	62	48	2	13
Non-participating		101	1	14

The following is a set of key observations from the results of the Study:

- With the current layout, 3 of the 149 known receptors exceed 30 hours per year of shadow flicker. Additionally, 25 of the 149 known receptors exceed 30 minutes per day of shadow flicker, although approximately one quarter (7 of 25) exceed this daily threshold by only 5 or fewer minutes and more than half (13 of 25) exceed this daily threshold by only 10 or fewer minutes. Refer to Appendix F for a complete listing of results.
- The majority of observed shadow flicker on each receptor occurs during early morning and/or late afternoon and evening hours (see Appendix H).
- For purposes of this Study, a total of 62 turbine positions were evaluated, although Burns & McDonnell understands that only up to 61 turbines are expected to be installed. Depending on the turbine location(s) that are eliminated, flicker durations at impacted receptors are likely to decrease from those presented herein.
- The Study was performed using a conservative modeling approach with Project Site-specific conditions. For example, the Study modeled each receptor as a “green house”, meaning each receptor was modeled as having windows on all sides and effectively causing the home to be susceptible to flicker effects in all directions. Further, the majority of the receptor locations were modeled as if no obstacles were present, including trees or buildings, which may significantly reduce or eliminate the duration and/or intensity of shadow flicker at a receptor. Due to the conservative approach of the Study, the actual duration and intensity of shadow flicker experienced at each receptor is expected to be less than those reported in the Study.

- Notwithstanding any shadow flicker which may occur at the Project Site, mitigation techniques may be utilized to reduce these effects. Common techniques include planting vegetation, awning installation, and/or reduced turbine operation.

The following is an overview of the shadow flicker characteristics at receptors where obstacles were considered but impacts were not fully mitigated:

- REC-008 is receiving shadow flicker from 1B.10 to the east. While there are a few buildings in the vicinity, the area to the east is largely exposed to this source. Thus, no reduction in flicker duration was observed when considering obstacles at this receptor.
- REC-009 is receiving shadow flicker from 1A.07 to the southwest. The area to the west-southwest is generally exposed, with insufficient geometry to fully mitigate shadow flicker. Thus, no reduction in flicker duration was observed when considering obstacles at this receptor.
- REC-014 is receiving shadow flicker from 2A.21 to the southeast. While obstacles exist to the east of the receptor it is largely exposed to shadow flicker to the southeast. A reduction in flicker duration of approximately 6 hours/year was observed when considering obstacles at this receptor.
- REC-015 is receiving shadow flicker from 2A.21 to the southeast. This receptor is largely exposed to shadow flicker to the east and southeast. A reduction in flicker duration of approximately 7 hours/year was observed when considering obstacles at this receptor.
- REC-017 is receiving shadow flicker from 3A.32 to the east and 3A.33 to the northeast. Some trees and buildings reduce shadow impact, but the greatest exposure to shadow flicker is from the east where the receptor is partially exposed. Thus, no reduction in flicker duration was observed when considering obstacles at this receptor.
- REC-024 is receiving shadow flicker from 3B.43 to the east. The receptor is largely exposed to the south and partially to the southeast. Thus, no reduction in flicker duration was observed when considering obstacles at this receptor.
- REC-031 receiving shadow flicker from 3B.39 to the east. The receptor is largely exposed to the east. Thus, no reduction in flicker duration was observed when considering obstacles at this receptor.
- REC-032 is receiving shadow flicker from 4B.50 to the southeast. Some buildings to the south reduce flicker, however the receptor is largely exposed to the south. Thus, no reduction in flicker duration was observed when considering obstacles at this receptor.

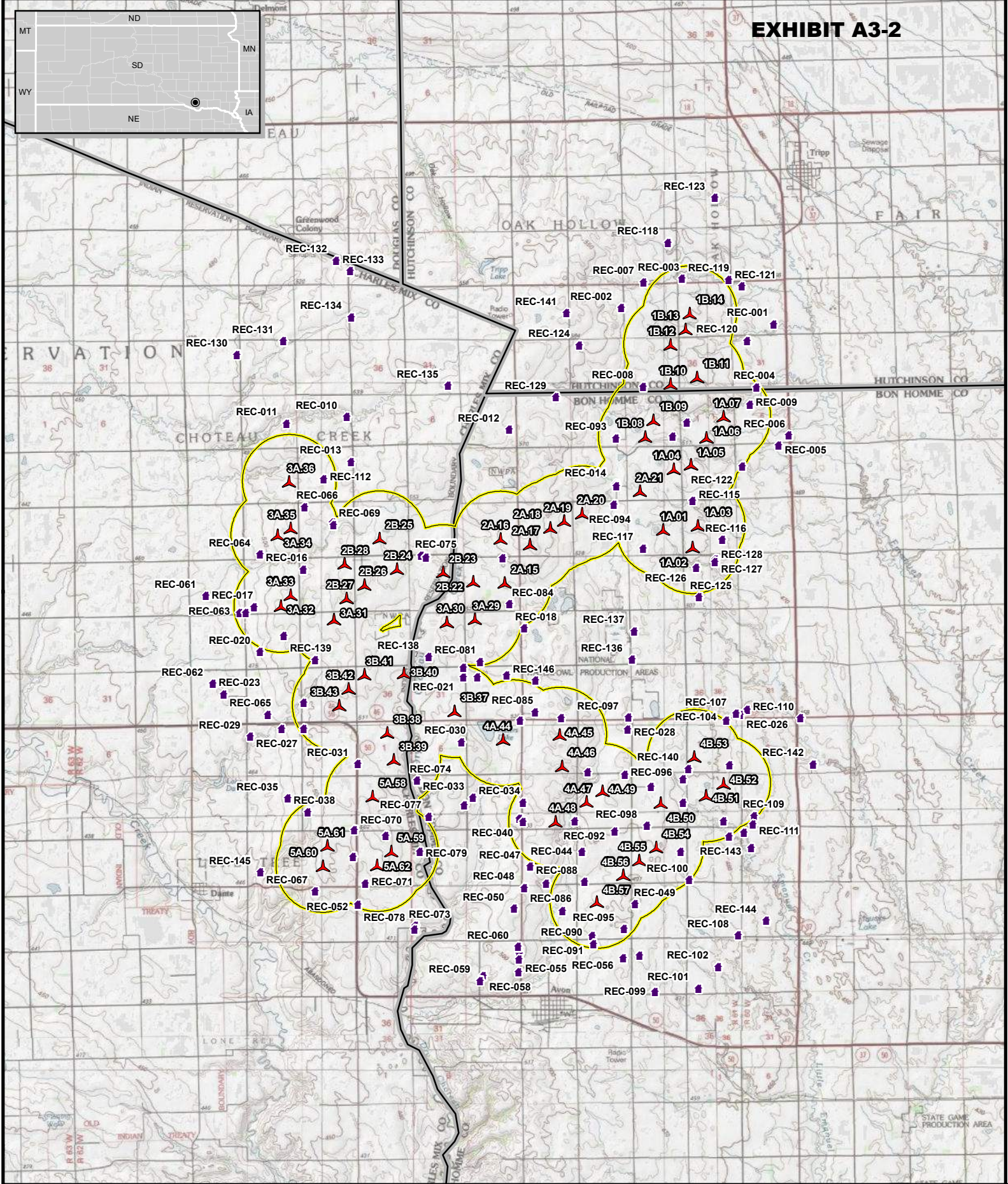
- REC-040 is receiving shadow flicker from 4A.48 to the east. Some obstacles are in line of flicker impact, but the area to the east-southeast is largely exposed. Thus, no reduction in flicker duration was observed when considering obstacles at this receptor.
- REC-041 is receiving shadow flicker from 4A.48 to the west. While several obstacles are within close proximity to this receptor, there is direct exposure to the west. Thus, no reduction in flicker duration was observed when considering obstacles at this receptor.
- REC-042 is receiving shadow flicker from 4B.50 to the southwest, from 4B.51 to the southeast, and from 4B.52 to the east-southeast. This receptor has several obstacles nearby to the north but is largely exposed to the east, west, and south. Thus, no reduction in flicker duration was observed when considering obstacles at this receptor.
- REC-045 is receiving shadow flicker from 4B.54 to the west. While several obstacles are in the vicinity, the geometry of the obstacles is insufficient to fully reduce flicker impact. A reduction in flicker duration of approximately 3.5 hours/year was observed when considering obstacles at this receptor.
- REC-046 is receiving shadow flicker from 5A.60 and 5A.61 to the west and from 5A.59 and 5A.62 to the east. Several obstacles are in the vicinity; however, the receptor is largely exposed to the south and east. Thus, no reduction in flicker duration was observed when considering obstacles at this receptor.
- REC-051 is receiving shadow flicker from 4B.57 to the northeast. This receptor is largely exposed to the east. Thus, no reduction in flicker duration was observed when considering obstacles at this receptor.
- REC-070 is receiving shadow flicker from 5A.61 to the southwest. While some obstacles are in the vicinity, the geometry is insufficient to fully reduce flicker impacts to the west and southwest. A reduction in flicker duration of approximately 5.5 hours/year and 24 minutes/day was observed when considering obstacles at this receptor.
- REC-075 is receiving shadow flicker from 2B.23 to the southeast. While there are several obstacles in the vicinity, the receptor is exposed to the southeast. A reduction in flicker duration of approximately 23 hours/year and 22 minutes/day was observed when considering obstacles at this receptor.
- REC-076 is receiving shadow flicker from 2B.23 to the southeast and 2B.24 to the southwest and is largely exposed to the east and south, with some exposure to the west. Thus, no reduction in flicker duration was observed when considering obstacles at this receptor.



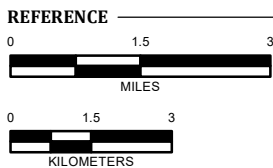
- REC-082 is receiving shadow from 2B.22 to the southwest. This receptor has several obstacles in the vicinity but is partially exposed to the southwest. A reduction in flicker duration of approximately 13 hours/year and 6 minutes/day when considering obstacles at this receptor.
- REC-089 is receiving shadow flicker from 4A.46 to the northwest and 4A.49 to the southeast. While there are several obstacles in the vicinity, the geometry is insufficient to fully mitigate shadow flicker impacts. Thus, no reduction in flicker duration was observed when considering obstacles at this receptor.
- REC-093 is receiving shadow flicker from 1B.08 to the east and 1B.09 to the northeast. This receptor is largely exposed to the east and south. Thus, no reduction in flicker duration was observed when considering obstacles at this receptor.
- REC-094 is receiving shadow flicker from 2A.20 to the southwest and 2A.21 to the northeast. This receptor has some obstacles in the vicinity, but there remains sparse coverage to the east, south, and southeast. A reduction in flicker duration of approximately 6 hours/year was observed when considering obstacles at this receptor.
- REC-096 is receiving shadow flicker from 4B.50 to the southeast and 4A.49 to the southwest. Several obstacles are in the vicinity, but there remains exposure to the east and southeast. Thus, no reduction in flicker duration was observed when considering obstacles at this receptor.
- REC-112 is receiving shadow flicker from 3A.36 to the east where there are some obstacles present; however, the geometry is insufficient to fully mitigate shadow flicker impact. Thus, no reduction in flicker duration was observed when considering obstacles at this receptor.
- REC-113 is receiving shadow flicker from 1B.08 to the east. This receptor is exposed to the east and south. A reduction in flicker duration of approximately 11 hours/year and 33 minutes /day was observed when considering obstacles at this receptor.
- REC 114 is receiving shadow flicker from 1B.08 to the southwest, 1A.06 to the southeast, and 1B.09 to the east and is exposed to the east, with some exposure to the west and partial exposure to the south. A reduction in flicker duration of approximately 8 hours/year and 10 minutes/day was observed when considering obstacles at this receptor.

**APPENDIX A - PROJECT SITE LAYOUT**





- LEGEND**
- County Boundary
  - Wind Turbine
  - Receptor
  - Wind Turbine Buffer (1370m)



**PREVAILING WIND PARK**  
Project Site Layout - GE 3.8-137 Flicker Buffer

LOCATION: Charles Mix/Bonne Homme/Hutchinson Cty, SD  
CLIENT: Prevailing Wind Park, LLC  
PROJ. NO.: 105644  
CREATED: 10/03/2018



**APPENDIX B - INFRASTRUCTURE COORDINATES**

**Table B-1: Turbine Coordinates**

<b>Turbine Number</b>	<b>Easting [m]</b>	<b>Northing [m]</b>
1A.01	579,956	4,775,946
1A.02	580,807	4,775,443
1A.03	580,970	4,776,074
1A.04	580,259	4,777,725
1A.05	580,759	4,777,855
1A.06	581,221	4,778,640
1A.07	581,719	4,779,255
1B.08	579,428	4,778,668
1B.09	579,671	4,779,153
1B.10	580,170	4,780,211
1B.11	580,939	4,780,407
1B.12	580,170	4,781,359
1B.13	580,604	4,781,811
1B.14	580,727	4,782,275
2A.15	575,324	4,774,400
2A.16	575,201	4,775,693
2A.17	576,064	4,775,521
2A.18	576,650	4,776,014
2A.19	577,060	4,776,210
2A.20	577,580	4,776,426
2A.21	579,275	4,777,079
2B.22	574,404	4,774,437
2B.23	573,519	4,774,711
2B.24	572,179	4,774,804
2B.25	571,662	4,775,700
2B.26	571,219	4,774,346
2B.27	570,700	4,773,949
2B.28	570,639	4,774,959
3A.29	574,452	4,773,338
3A.30	573,634	4,773,249
3A.31	570,336	4,773,327
3A.32	568,781	4,773,724
3A.33	569,071	4,774,045
3A.34	568,691	4,775,793
3A.35	569,074	4,775,995

<b>Turbine Number</b>	<b>Easting [m]</b>	<b>Northing [m]</b>
3A.36	569,026	4,777,349
3B.37	573,856	4,770,651
3B.38	571,896	4,770,015
3B.39	572,076	4,769,232
3B.40	572,380	4,771,753
3B.41	571,220	4,771,721
3B.42	570,763	4,771,308
3B.43	570,487	4,770,821
4A.44	575,275	4,769,819
4A.45	576,925	4,769,963
4A.46	576,997	4,769,043
4A.47	577,718	4,768,001
4A.48	576,805	4,767,428
4A.49	578,173	4,768,318
4B.50	579,886	4,767,974
4B.51	581,200	4,768,190
4B.52	581,716	4,768,536
4B.53	580,860	4,769,311
4B.54	579,755	4,766,668
4B.55	579,255	4,766,296
4B.56	578,787	4,765,862
4B.57	578,011	4,765,079
5A.58	571,464	4,768,160
5A.59	572,004	4,766,553
5A.60	570,006	4,766,129
5A.61	570,143	4,766,716
5A.62	571,597	4,766,151

**Notes:**

[1] All coordinates presented in UTM NAD83 Zone 14N (meters)

[2] All coordinates provided by Developer in "PWIND - 62x GE38137 111p5m v180925-02" on 20180925

**Table B-2: Receptor Coordinates**

<b>Receptor Name</b>	<b>Easting [m]</b>	<b>Northing [m]</b>	<b>County Name</b>	<b>Participating Status</b>
REC-001	583,179	4,781,949	Hutchinson	Non-participating
REC-002	578,731	4,782,429	Hutchinson	Participating
REC-003	580,507	4,783,274	Hutchinson	Non-participating
REC-004	582,679	4,780,105	Hutchinson	Non-participating
REC-005	583,327	4,778,397	Bon Homme	Non-participating
REC-006	583,615	4,778,695	Bon Homme	Non-participating
REC-007	579,386	4,783,172	Hutchinson	Non-participating
REC-008*	579,365	4,780,123	Hutchinson	Non-participating
REC-009*	582,486	4,779,597	Bon Homme	Non-participating
REC-010	570,706	4,779,233	Charles Mix	Non-participating
REC-011	568,955	4,779,050	Charles Mix	Non-participating
REC-012	575,451	4,778,870	Bon Homme	Non-participating
REC-013	570,834	4,777,924	Charles Mix	Non-participating
REC-014*	578,568	4,777,265	Bon Homme	Non-participating
REC-015*	578,579	4,777,228	Bon Homme	Non-participating
REC-016	569,438	4,774,776	Charles Mix	Participating
REC-017*	568,000	4,773,684	Charles Mix	Non-participating
REC-018	575,894	4,773,069	Bon Homme	Participating
REC-019	568,870	4,772,838	Charles Mix	Participating
REC-020	568,171	4,772,373	Charles Mix	Non-participating
REC-021	574,123	4,771,642	Bon Homme	Participating
REC-022	574,118	4,771,913	Bon Homme	Non-participating
REC-023	567,115	4,771,132	Charles Mix	Non-participating
REC-024*	569,456	4,770,886	Charles Mix	Non-participating
REC-025	582,410	4,770,691	Bon Homme	Participating
REC-026	582,206	4,770,538	Bon Homme	Non-participating
REC-027	569,451	4,770,123	Charles Mix	Non-participating
REC-028	578,916	4,770,107	Bon Homme	Participating
REC-029	567,890	4,769,897	Charles Mix	Non-participating
REC-030	574,058	4,769,738	Bon Homme	Non-participating
REC-031*	571,038	4,769,100	Charles Mix	Non-participating
REC-032*	579,595	4,768,434	Bon Homme	Participating
REC-033	574,388	4,768,112	Bon Homme	Non-participating
REC-034*	575,857	4,767,969	Bon Homme	Non-participating
REC-035	568,988	4,768,088	Charles Mix	Non-participating

<b>Receptor Name</b>	<b>Easting [m]</b>	<b>Northing [m]</b>	<b>County Name</b>	<b>Participating Status</b>
REC-036	574,140	4,767,903	Bon Homme	Non-participating
REC-037*	580,535	4,767,956	Bon Homme	Participating
REC-038	569,571	4,767,694	Charles Mix	Non-participating
REC-039*	575,754	4,767,512	Bon Homme	Non-participating
REC-040*	575,854	4,767,409	Bon Homme	Non-participating
REC-041*	577,366	4,767,429	Bon Homme	Participating
REC-042*	580,535	4,768,650	Bon Homme	Non-participating
REC-043	582,314	4,767,105	Bon Homme	Non-participating
REC-044	577,582	4,766,535	Bon Homme	Participating
REC-045*	580,460	4,766,528	Bon Homme	Participating
REC-046*	570,892	4,766,384	Charles Mix	Participating
REC-047	576,072	4,766,099	Bon Homme	Non-participating
REC-048	575,888	4,765,484	Bon Homme	Non-participating
REC-049	579,136	4,765,004	Bon Homme	Non-participating
REC-050	575,594	4,764,878	Bon Homme	Participating
REC-051*	577,015	4,764,806	Bon Homme	Participating
REC-052	571,035	4,764,976	Charles Mix	Non-participating
REC-053	575,752	4,763,554	Bon Homme	Non-participating
REC-054	579,261	4,763,509	Bon Homme	Non-participating
REC-055	575,738	4,763,383	Bon Homme	Non-participating
REC-056	578,784	4,763,423	Bon Homme	Non-participating
REC-057	575,729	4,763,021	Bon Homme	Non-participating
REC-058	574,690	4,762,906	Bon Homme	Non-participating
REC-059	574,609	4,762,765	Bon Homme	Non-participating
REC-060	575,719	4,763,759	Bon Homme	Non-participating
REC-061	566,590	4,774,005	Charles Mix	Non-participating
REC-062	566,795	4,771,446	Charles Mix	Non-participating
REC-063	567,576	4,773,523	Charles Mix	Non-participating
REC-064	568,170	4,775,222	Charles Mix	Non-participating
REC-065	568,402	4,770,548	Charles Mix	Non-participating
REC-066	569,475	4,776,605	Charles Mix	Participating
REC-067	569,782	4,765,374	Charles Mix	Non-participating
REC-068	570,301	4,776,152	Charles Mix	Non-participating
REC-069	570,321	4,776,086	Charles Mix	Non-participating
REC-070*	570,931	4,767,169	Charles Mix	Non-participating
REC-071	571,247	4,765,598	Charles Mix	Non-participating



Receptor Name	Easting [m]	Northing [m]	County Name	Participating Status
REC-072	571,848	4,767,001	Charles Mix	Participating
REC-073	572,712	4,764,371	Charles Mix	Non-participating
REC-074	572,760	4,768,610	Bon Homme	Non-participating
REC-075*	572,875	4,775,184	Charles Mix	Participating
REC-076*	573,024	4,775,138	Charles Mix	Non-participating
REC-077	573,104	4,767,559	Bon Homme	Non-participating
REC-078	572,690	4,764,270	Charles Mix	Non-participating
REC-079*	572,840	4,766,532	Charles Mix	Participating
REC-080	574,527	4,771,635	Bon Homme	Participating
REC-081	574,606	4,772,084	Bon Homme	Participating
REC-082*	575,265	4,775,117	Bon Homme	Participating
REC-083	575,384	4,771,696	Bon Homme	Participating
REC-084	575,460	4,773,772	Bon Homme	Participating
REC-085*	576,210	4,770,611	Bon Homme	Participating
REC-086	576,538	4,765,598	Bon Homme	Participating
REC-087	576,971	4,770,447	Bon Homme	Participating
REC-088	577,660	4,765,661	Bon Homme	Participating
REC-089*	577,747	4,768,860	Bon Homme	Participating
REC-090	577,878	4,764,079	Bon Homme	Non-participating
REC-091	577,916	4,763,844	Bon Homme	Non-participating
REC-092	578,532	4,767,119	Bon Homme	Participating
REC-093*	578,576	4,778,619	Bon Homme	Participating
REC-094*	578,515	4,776,677	Bon Homme	Participating
REC-095	578,804	4,764,275	Bon Homme	Non-participating
REC-096*	578,828	4,768,793	Bon Homme	Non-participating
REC-097	578,943	4,770,455	Bon Homme	Non-participating
REC-098	579,475	4,767,289	Bon Homme	Non-participating
REC-099	579,721	4,762,442	Bon Homme	Participating
REC-100	580,720	4,765,706	Bon Homme	Non-participating
REC-101	580,992	4,762,541	Bon Homme	Non-participating
REC-102	581,560	4,763,175	Bon Homme	Non-participating
REC-103	581,721	4,767,420	Bon Homme	Participating
REC-104	581,794	4,770,381	Bon Homme	Non-participating
REC-105*	581,891	4,769,063	Bon Homme	Non-participating
REC-106	581,883	4,766,985	Bon Homme	Participating
REC-107	582,090	4,770,568	Bon Homme	Non-participating

<b>Receptor Name</b>	<b>Easting [m]</b>	<b>Northing [m]</b>	<b>County Name</b>	<b>Participating Status</b>
REC-108	582,148	4,764,102	Bon Homme	Participating
REC-109	582,610	4,767,583	Bon Homme	Non-participating
REC-110	583,963	4,770,430	Bon Homme	Non-participating
REC-111	582,578	4,767,332	Bon Homme	Non-participating
REC-112*	570,034	4,777,429	Charles Mix	Non-participating
REC-113*	580,226	4,778,670	Bon Homme	Participating
REC-114*	580,644	4,779,066	Bon Homme	Participating
REC-115	580,813	4,776,798	Bon Homme	Participating
REC-116*	581,676	4,775,654	Bon Homme	Participating
REC-117	579,368	4,775,404	Bon Homme	Participating
REC-118	580,095	4,784,337	Hutchinson	Non-participating
REC-119	581,868	4,783,246	Hutchinson	Non-participating
REC-120	582,411	4,781,467	Hutchinson	Non-participating
REC-121	582,256	4,783,055	Hutchinson	Non-participating
REC-122	582,261	4,777,793	Bon Homme	Participating
REC-123	581,461	4,785,646	Hutchinson	Non-participating
REC-124	577,505	4,781,336	Hutchinson	Non-participating
REC-125	580,996	4,773,976	Bon Homme	Non-participating
REC-126	580,916	4,774,830	Bon Homme	Participating
REC-127*	581,474	4,775,076	Bon Homme	Participating
REC-128	581,468	4,774,997	Bon Homme	Participating
REC-129	576,816	4,779,814	Bon Homme	Non-participating
REC-130	567,502	4,781,060	Charles Mix	Non-participating
REC-131	568,850	4,781,446	Charles Mix	Non-participating
REC-132	570,408	4,783,811	Charles Mix	Non-participating
REC-133	570,806	4,783,497	Charles Mix	Non-participating
REC-134	570,845	4,782,153	Charles Mix	Non-participating
REC-135	573,665	4,780,153	Charles Mix	Non-participating
REC-136	579,049	4,772,150	Bon Homme	Non-participating
REC-137	579,104	4,772,978	Bon Homme	Non-participating
REC-138*	573,105	4,772,224	Bon Homme	Participating
REC-139	569,781	4,772,134	Charles Mix	Non-participating
REC-140	580,689	4,768,952	Bon Homme	Non-participating
REC-141	577,130	4,782,270	Hutchinson	Non-participating
REC-142	584,340	4,769,093	Bon Homme	Non-participating
REC-143	582,522	4,766,643	Bon Homme	Non-participating

<b>Receptor Name</b>	<b>Easting [m]</b>	<b>Northing [m]</b>	<b>County Name</b>	<b>Participating Status</b>
REC-144	582,964	4,764,514	Bon Homme	Non-participating
REC-145	568,186	4,765,929	Charles Mix	Non-participating
REC-146	576,221	4,771,527	Bon Homme	Participating
REC-147	575,778	4,770,361	Bon Homme	Participating
REC-148	568,806	4,770,128	Charles Mix	Non-participating
REC-149	567,763	4,773,526	Charles Mix	Non-participating

**Notes:**

[1] All coordinates presented in UTM NAD83 Zone 14N (meters)

[2] Coordinates provided by Developer in "RECEPTORS-OCCUPIED.KMZ" and through field investigation data provided 20180920

[3] Participating status provided by Developer in "Prevailing Winds - Homes on Leased Land" dated 20180516

[4] \* Indicates receptor that was analyzed with obstacles.

**APPENDIX C - ON-SITE FREQUENCY DISTRIBUTION**

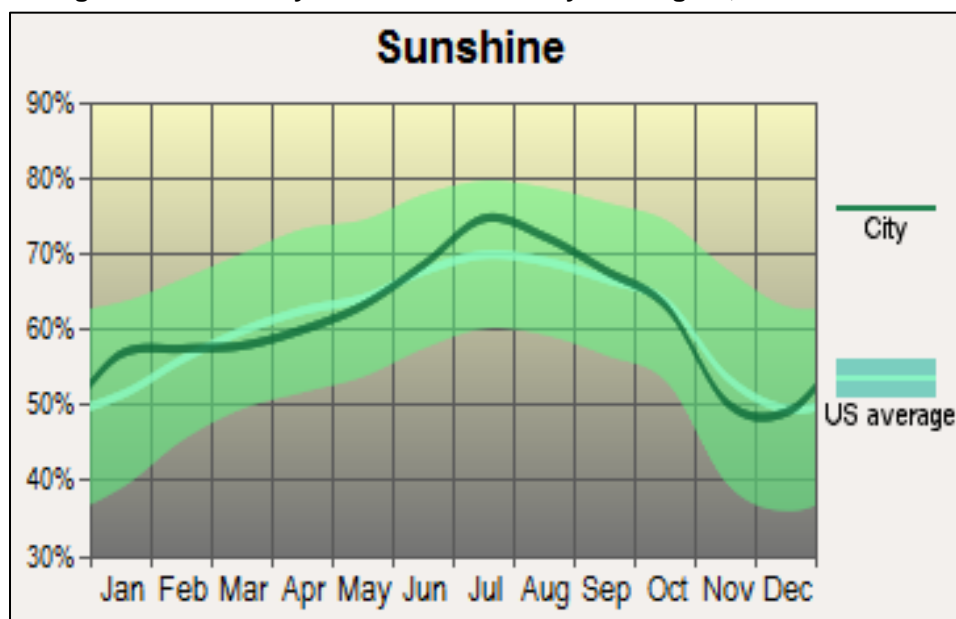
**Table C-1: Onsite Frequency Distribution, 111.5 magl**

Bin [m/s]	Wind Direction [degrees]											
	0	30	60	90	120	150	180	210	240	270	300	330
0	11.63	9.15	7.94	7.92	7.53	7.80	8.96	5.46	5.14	5.35	10.68	12.43
1	11.51	9.25	11.54	9.35	8.16	4.89	3.58	8.52	9.42	9.91	10.83	10.20
2	20.70	20.13	20.43	17.93	15.71	12.23	10.56	15.50	18.48	21.81	17.68	17.72
3	33.22	34.35	34.95	33.11	29.54	23.68	20.09	29.61	31.54	34.00	27.44	29.54
4	52.15	56.03	57.94	55.29	52.65	35.96	28.99	46.16	45.04	55.74	46.51	48.70
5	72.48	70.20	75.20	70.95	67.65	50.49	38.48	52.72	57.06	64.37	57.02	66.18
6	81.89	83.87	81.78	85.27	89.90	69.52	50.15	62.29	68.49	78.41	65.81	71.98
7	96.59	95.00	98.95	97.99	102.77	81.21	57.90	72.27	81.10	84.11	76.67	81.19
8	102.03	89.37	95.39	101.36	101.50	88.94	76.50	77.23	90.82	89.96	84.70	86.32
9	104.00	95.04	105.73	95.63	101.91	103.82	97.70	99.43	98.02	93.31	87.28	87.37
10	91.57	103.26	106.21	98.09	107.43	111.11	107.15	107.33	109.89	102.07	92.31	92.86
11	90.03	91.21	95.97	96.93	95.27	114.82	130.43	109.07	110.93	99.29	95.28	86.57
12	72.68	71.41	72.31	78.47	80.22	97.90	124.26	102.86	90.53	86.11	87.42	81.99
13	55.36	56.78	53.37	59.24	59.95	78.28	104.76	87.84	71.31	62.37	69.16	65.63
14	40.54	40.48	33.32	40.20	39.37	55.87	69.60	59.70	50.90	49.04	54.02	47.97
15	26.30	27.72	22.60	26.65	21.13	36.25	35.80	31.98	30.57	26.73	37.69	36.57
16	19.06	18.47	13.08	15.28	9.32	19.23	22.26	18.43	15.66	18.46	25.87	26.87
17	11.91	12.71	6.83	7.28	6.69	7.58	10.69	7.61	7.57	10.26	20.54	20.48
18	7.90	10.59	5.39	4.48	4.71	4.06	6.00	3.14	4.30	6.27	14.83	13.39
19	4.72	6.88	3.08	2.84	3.40	1.52	3.19	2.30	3.12	2.14	8.86	10.20
20	2.26	4.50	2.50	1.45	1.01	0.64	0.68	1.54	1.78	2.07	6.90	6.91
21	1.57	1.50	1.73	1.40	0.96	0.54	0.30	0.56	1.11	1.50	4.82	4.08
22	0.62	0.63	0.58	0.53	0.25	0.20	0.13	0.70	0.82	1.07	3.11	3.07
23	0.46	0.25	0.48	0.05	0.30	0.15	0.21	0.63	0.97	0.71	2.22	1.69
24	0.26	0.04	0.29	0.19	0.15	0.20	0.04	0.63	0.15	0.14	1.47	0.98
25	0.16	0.04	0.14	0.05	0.05	0.15	0.26	0.77	0.15	0.00	1.04	0.74
26	0.00	0.13	0.14	0.00	0.00	0.10	0.21	0.28	0.07	0.07	0.39	0.40
27	0.03	0.13	0.10	0.00	0.00	0.29	0.04	0.21	0.00	0.07	0.14	0.25
28	0.00	0.04	0.00	0.00	0.00	0.29	0.04	0.28	0.00	0.00	0.04	0.09
29	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.14	0.00	0.00	0.00	0.06
30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.21	0.15	0.00	0.00	0.00
31	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.00	0.00	0.00	0.00
32	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.00	0.00	0.00
33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
34	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
35	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<b>Sum</b>	<b>1012</b>	<b>1009</b>	<b>1008</b>	<b>1008</b>	<b>1008</b>	<b>1008</b>	<b>1009</b>	<b>1005</b>	<b>1005</b>	<b>1005</b>	<b>1011</b>	<b>1012</b>

**Notes:**

- [1] All data provided by Developer via "Prevailing Winds Site Average.windog"  
 [2] All data presented in milles for period from September 20, 2013 to September 13, 2018  
 [3] All data presented at 111.5 magl

**APPENDIX D - SUNSHINE PROBABILITY DATA**

**Figure D-1: Monthly Sunshine Probability for Wagner, South Dakota****Table D-1: Monthly Sunshine Probability for Wagner, South Dakota**

Month	Avg Sunshine Probability
January	58%
February	58%
March	59%
April	60%
May	63%
June	69%
July	74%
August	72%
September	68%
October	65%
November	50%
December	50%

**Notes:**[1] Data source: <http://www.city-data.com/city/Wagner-South-Dakota.html>

[2] Data location: Wagner, South Dakota

[3] Data in Table D-1 estimated from source data in Figure D-1

**APPENDIX E - POWER CURVE**



**Table E-1: GE 3.8-137 Power Curve Values**

<b>Wind Speed [m/s]</b>	<b>Power [kW]</b>
0.0	0
1.0	0
2.0	0
3.0	14
4.0	179
5.0	434
6.0	786
7.0	1269
8.0	1906
9.0	2648
10.0	3284
11.0	3776
12.0	3830
13.0	3830
14.0	3830
15.0	3830
16.0	3830
17.0	3830
18.0	3830
19.0	3830
20.0	3830
21.0	3830
22.0	3830
23.0	3830
24.0	3830
25.0	3830

**Notes:**[1] Power curve for air density of 1.16 kg/m<sup>3</sup> and site-specific TI band

[2] All data provided by Developer via "Site Specific Power Curve - PCD\_1206271\_PrevailingWind\_3.8-137\_EN\_r01"

**APPENDIX F - FLICKER RESULTS BY RECEPTOR**

**Table F-1: Flicker Duration by Receptor**

Receptor Name	Easting [m]	Northing [m]	County Name	Participating Status	Flicker Duration [hour/year]	Flicker Duration [max min/day]
REC-001	583,179	4,781,949	Hutchinson	Non-participating	0.00	0
REC-002	578,731	4,782,429	Hutchinson	Participating	0.00	0
REC-003	580,507	4,783,274	Hutchinson	Non-participating	0.00	0
REC-004	582,679	4,780,105	Hutchinson	Non-participating	5.67	27
REC-005	583,327	4,778,397	Bon Homme	Non-participating	0.00	0
REC-006	583,615	4,778,695	Bon Homme	Non-participating	0.00	0
REC-007	579,386	4,783,172	Hutchinson	Non-participating	0.00	0
REC-008*	579,365	4,780,123	Hutchinson	Non-participating	11.02	39
REC-009*	582,486	4,779,597	Bon Homme	Non-participating	9.22	38
REC-010	570,706	4,779,233	Charles Mix	Non-participating	0.00	0
REC-011	568,955	4,779,050	Charles Mix	Non-participating	0.00	0
REC-012	575,451	4,778,870	Bon Homme	Non-participating	0.00	0
REC-013	570,834	4,777,924	Charles Mix	Non-participating	0.00	0
REC-014*	578,568	4,777,265	Bon Homme	Non-participating	12.22	43
REC-015*	578,579	4,777,228	Bon Homme	Non-participating	12.83	44
REC-016	569,438	4,774,776	Charles Mix	Participating	4.80	27
REC-017*	568,000	4,773,684	Charles Mix	Non-participating	19.87	40
REC-018	575,894	4,773,069	Bon Homme	Participating	0.00	0
REC-019	568,870	4,772,838	Charles Mix	Participating	0.00	0
REC-020	568,171	4,772,373	Charles Mix	Non-participating	0.00	0
REC-021	574,123	4,771,642	Bon Homme	Participating	0.00	0
REC-022	574,118	4,771,913	Bon Homme	Non-participating	0.00	0
REC-023	567,115	4,771,132	Charles Mix	Non-participating	0.00	0
REC-024*	569,456	4,770,886	Charles Mix	Non-participating	6.20	31
REC-025	582,410	4,770,691	Bon Homme	Participating	0.00	0
REC-026	582,206	4,770,538	Bon Homme	Non-participating	0.00	0
REC-027	569,451	4,770,123	Charles Mix	Non-participating	0.00	0
REC-028	578,916	4,770,107	Bon Homme	Participating	0.00	0
REC-029	567,890	4,769,897	Charles Mix	Non-participating	0.00	0
REC-030	574,058	4,769,738	Bon Homme	Non-participating	3.57	25
REC-031*	571,038	4,769,100	Charles Mix	Non-participating	6.43	31
REC-032*	579,595	4,768,434	Bon Homme	Participating	9.67	45
REC-033	574,388	4,768,112	Bon Homme	Non-participating	0.00	0
REC-034*	575,857	4,767,969	Bon Homme	Non-participating	0.00	0
REC-035	568,988	4,768,088	Charles Mix	Non-participating	0.00	0
REC-036	574,140	4,767,903	Bon Homme	Non-participating	0.00	0
REC-037*	580,535	4,767,956	Bon Homme	Participating	0.00	0
REC-038	569,571	4,767,694	Charles Mix	Non-participating	0.00	0
REC-039*	575,754	4,767,512	Bon Homme	Non-participating	0.00	0
REC-040*	575,854	4,767,409	Bon Homme	Non-participating	7.42	34
REC-041*	577,366	4,767,429	Bon Homme	Participating	22.70	55
REC-042*	580,535	4,768,650	Bon Homme	Non-participating	28.00	53
REC-043	582,314	4,767,105	Bon Homme	Non-participating	0.00	0
REC-044	577,582	4,766,535	Bon Homme	Participating	0.00	0

Receptor Name	Easting [m]	Northing [m]	County Name	Participating Status	Flicker Duration [hour/year]	Flicker Duration [max min/day]
REC-045*	580,460	4,766,528	Bon Homme	Participating	18.48	45
REC-046*	570,892	4,766,384	Charles Mix	Participating	46.25	76
REC-047	576,072	4,766,099	Bon Homme	Non-participating	0.00	0
REC-048	575,888	4,765,484	Bon Homme	Non-participating	0.00	0
REC-049	579,136	4,765,004	Bon Homme	Non-participating	4.85	27
REC-050	575,594	4,764,878	Bon Homme	Participating	0.00	0
REC-051*	577,015	4,764,806	Bon Homme	Participating	8.20	32
REC-052	571,035	4,764,976	Charles Mix	Non-participating	0.00	0
REC-053	575,752	4,763,554	Bon Homme	Non-participating	0.00	0
REC-054	579,261	4,763,509	Bon Homme	Non-participating	0.00	0
REC-055	575,738	4,763,383	Bon Homme	Non-participating	0.00	0
REC-056	578,784	4,763,423	Bon Homme	Non-participating	0.00	0
REC-057	575,729	4,763,021	Bon Homme	Non-participating	0.00	0
REC-058	574,690	4,762,906	Bon Homme	Non-participating	0.00	0
REC-059	574,609	4,762,765	Bon Homme	Non-participating	0.00	0
REC-060	575,719	4,763,759	Bon Homme	Non-participating	0.00	0
REC-061	566,590	4,774,005	Charles Mix	Non-participating	0.00	0
REC-062	566,795	4,771,446	Charles Mix	Non-participating	0.00	0
REC-063	567,576	4,773,523	Charles Mix	Non-participating	5.02	27
REC-064	568,170	4,775,222	Charles Mix	Non-participating	0.00	0
REC-065	568,402	4,770,548	Charles Mix	Non-participating	0.00	0
REC-066	569,475	4,776,605	Charles Mix	Participating	0.00	0
REC-067	569,782	4,765,374	Charles Mix	Non-participating	0.00	0
REC-068	570,301	4,776,152	Charles Mix	Non-participating	3.13	24
REC-069	570,321	4,776,086	Charles Mix	Non-participating	3.20	24
REC-070*	570,931	4,767,169	Charles Mix	Non-participating	8.80	36
REC-071	571,247	4,765,598	Charles Mix	Non-participating	11.72	25
REC-072	571,848	4,767,001	Charles Mix	Participating	0.00	0
REC-073	572,712	4,764,371	Charles Mix	Non-participating	0.00	0
REC-074	572,760	4,768,610	Bon Homme	Non-participating	0.00	0
REC-075*	572,875	4,775,184	Charles Mix	Participating	20.17	42
REC-076*	573,024	4,775,138	Charles Mix	Non-participating	33.90	51
REC-077	573,104	4,767,559	Bon Homme	Non-participating	0.00	0
REC-078	572,690	4,764,270	Charles Mix	Non-participating	0.00	0
REC-079*	572,840	4,766,532	Charles Mix	Participating	0.00	0
REC-080	574,527	4,771,635	Bon Homme	Participating	0.00	0
REC-081	574,606	4,772,084	Bon Homme	Participating	0.00	0
REC-082*	575,265	4,775,117	Bon Homme	Participating	8.75	31
REC-083	575,384	4,771,696	Bon Homme	Participating	0.00	0
REC-084	575,460	4,773,772	Bon Homme	Participating	4.85	29
REC-085*	576,210	4,770,611	Bon Homme	Participating	0.00	0
REC-086	576,538	4,765,598	Bon Homme	Participating	0.00	0
REC-087	576,971	4,770,447	Bon Homme	Participating	0.00	0
REC-088	577,660	4,765,661	Bon Homme	Participating	5.57	28
REC-089*	577,747	4,768,860	Bon Homme	Participating	24.83	42

Receptor Name	Easting [m]	Northing [m]	County Name	Participating Status	Flicker Duration [hour/year]	Flicker Duration [max min/day]
REC-090	577,878	4,764,079	Bon Homme	Non-participating	0.00	0
REC-091	577,916	4,763,844	Bon Homme	Non-participating	0.00	0
REC-092	578,532	4,767,119	Bon Homme	Participating	3.78	24
REC-093*	578,576	4,778,619	Bon Homme	Participating	20.83	37
REC-094*	578,515	4,776,677	Bon Homme	Participating	12.23	38
REC-095	578,804	4,764,275	Bon Homme	Non-participating	0.00	0
REC-096*	578,828	4,768,793	Bon Homme	Non-participating	22.47	54
REC-097	578,943	4,770,455	Bon Homme	Non-participating	0.00	0
REC-098	579,475	4,767,289	Bon Homme	Non-participating	0.00	0
REC-099	579,721	4,762,442	Bon Homme	Participating	0.00	0
REC-100	580,720	4,765,706	Bon Homme	Non-participating	0.00	0
REC-101	580,992	4,762,541	Bon Homme	Non-participating	0.00	0
REC-102	581,560	4,763,175	Bon Homme	Non-participating	0.00	0
REC-103	581,721	4,767,420	Bon Homme	Participating	0.00	0
REC-104	581,794	4,770,381	Bon Homme	Non-participating	0.00	0
REC-105*	581,891	4,769,063	Bon Homme	Non-participating	0.00	0
REC-106	581,883	4,766,985	Bon Homme	Participating	0.00	0
REC-107	582,090	4,770,568	Bon Homme	Non-participating	0.00	0
REC-108	582,148	4,764,102	Bon Homme	Participating	0.00	0
REC-109	582,610	4,767,583	Bon Homme	Non-participating	0.00	0
REC-110	583,963	4,770,430	Bon Homme	Non-participating	0.00	0
REC-111	582,578	4,767,332	Bon Homme	Non-participating	0.00	0
REC-112*	570,034	4,777,429	Charles Mix	Non-participating	5.37	31
REC-113*	580,226	4,778,670	Bon Homme	Participating	5.92	31
REC-114*	580,644	4,779,066	Bon Homme	Participating	32.80	46
REC-115	580,813	4,776,798	Bon Homme	Participating	1.73	17
REC-116*	581,676	4,775,654	Bon Homme	Participating	0.00	0
REC-117	579,368	4,775,404	Bon Homme	Participating	0.00	0
REC-118	580,095	4,784,337	Hutchinson	Non-participating	0.00	0
REC-119	581,868	4,783,246	Hutchinson	Non-participating	0.00	0
REC-120	582,411	4,781,467	Hutchinson	Non-participating	0.00	0
REC-121	582,256	4,783,055	Hutchinson	Non-participating	0.00	0
REC-122	582,261	4,777,793	Bon Homme	Participating	0.00	0
REC-123	581,461	4,785,646	Hutchinson	Non-participating	0.00	0
REC-124	577,505	4,781,336	Hutchinson	Non-participating	0.00	0
REC-125	580,996	4,773,976	Bon Homme	Non-participating	0.00	0
REC-126	580,916	4,774,830	Bon Homme	Participating	0.00	0
REC-127*	581,474	4,775,076	Bon Homme	Participating	0.00	0
REC-128	581,468	4,774,997	Bon Homme	Participating	0.00	0
REC-129	576,816	4,779,814	Bon Homme	Non-participating	0.00	0
REC-130	567,502	4,781,060	Charles Mix	Non-participating	0.00	0
REC-131	568,850	4,781,446	Charles Mix	Non-participating	0.00	0
REC-132	570,408	4,783,811	Charles Mix	Non-participating	0.00	0
REC-133	570,806	4,783,497	Charles Mix	Non-participating	0.00	0
REC-134	570,845	4,782,153	Charles Mix	Non-participating	0.00	0

Receptor Name	Easting [m]	Northing [m]	County Name	Participating Status	Flicker Duration [hour/year]	Flicker Duration [max min/day]
REC-135	573,665	4,780,153	Charles Mix	Non-participating	0.00	0
REC-136	579,049	4,772,150	Bon Homme	Non-participating	0.00	0
REC-137	579,104	4,772,978	Bon Homme	Non-participating	0.00	0
REC-138*	573,105	4,772,224	Bon Homme	Participating	0.00	0
REC-139	569,781	4,772,134	Charles Mix	Non-participating	6.15	26
REC-140	580,689	4,768,952	Bon Homme	Non-participating	5.27	29
REC-141	577,130	4,782,270	Hutchinson	Non-participating	0.00	0
REC-142	584,340	4,769,093	Bon Homme	Non-participating	0.00	0
REC-143	582,522	4,766,643	Bon Homme	Non-participating	0.00	0
REC-144	582,964	4,764,514	Bon Homme	Non-participating	0.00	0
REC-145	568,186	4,765,929	Charles Mix	Non-participating	0.00	0
REC-146	576,221	4,771,527	Bon Homme	Participating	0.00	0
REC-147	575,778	4,770,361	Bon Homme	Participating	15.03	43
REC-148	568,806	4,770,128	Charles Mix	Non-participating	0.00	0
REC-149	567,763	4,773,526	Charles Mix	Non-participating	7.35	31

**Notes:**

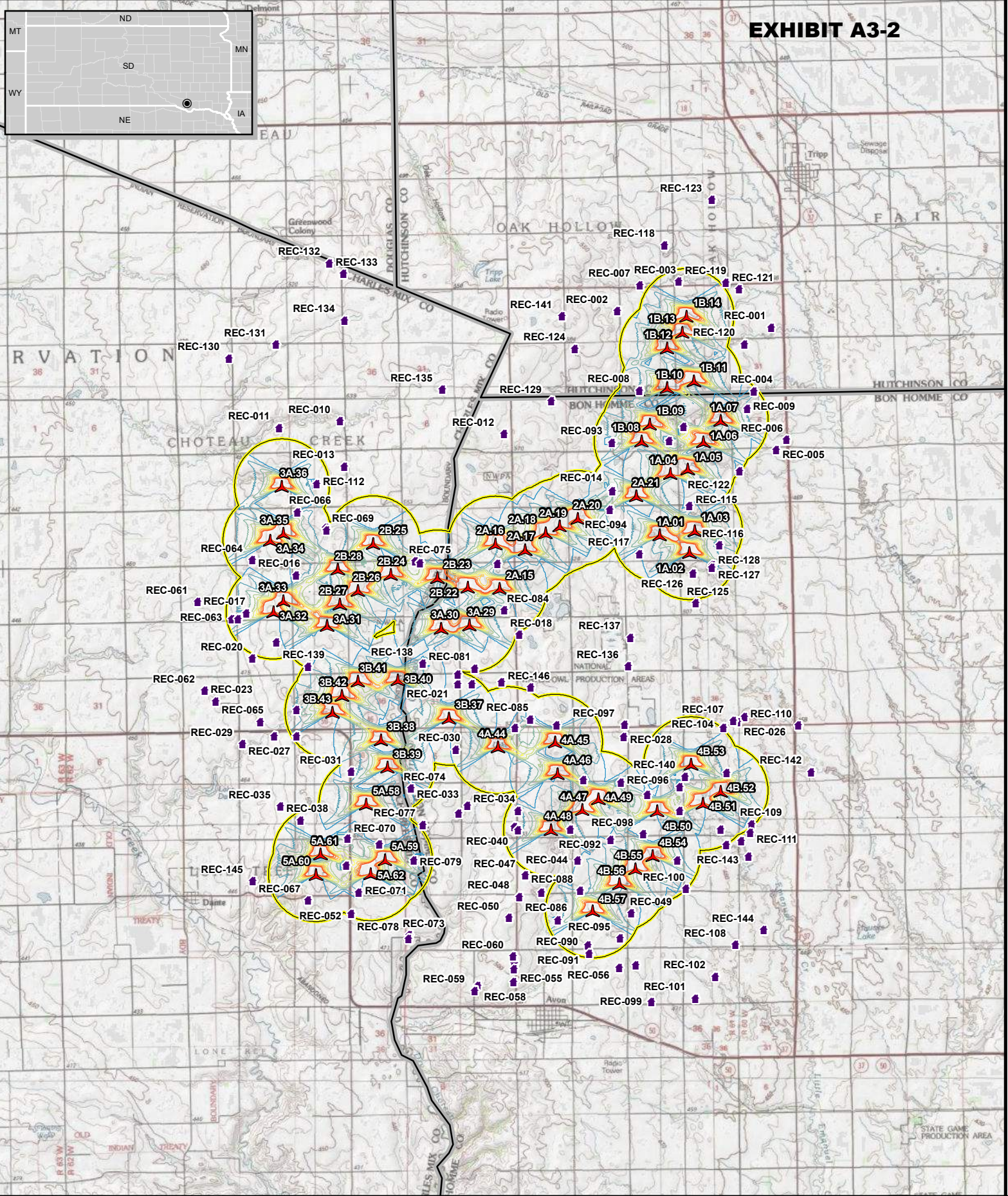
[1] All coordinates presented in UTM NAD83 Zone 14N (meters)

[2] All results based on turbine layout in Table B-1

[3] \* Indicates receptor that was analyzed with obstacles.

**APPENDIX G - SHADOW FLICKER DURATION MAP**





<b>LEGEND</b> County Boundary Wind Turbine Receptor Wind Turbine Buffer (1370m)		<b>REFERENCE</b> 0 1.5 3 MILES 0 1.5 3 KILOMETERS		<b>PREVAILING WIND PARK</b> <b>Shadow Flicker Duration [Hr/Yr] - GE 3.8-137 Layout</b> <b>LOCATION:</b> Charles Mix/Bonne Homme/Hutchinson Cty, SD <b>CLIENT:</b> Prevailing Wind Park, LLC <b>PROJ. NO.:</b> 105644 <b>CREATED:</b> 10/03/2018		<b>Page 40 of 67</b> 
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**APPENDIX H - SHADOW FLICKER CALENDAR**

Project:  
sPower Shadow Flicker

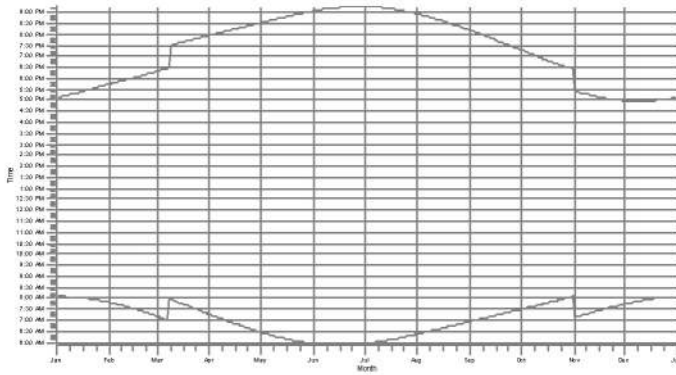
Description:  
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Calculated:  
10/3/2018 3:53 PM/3.0.654

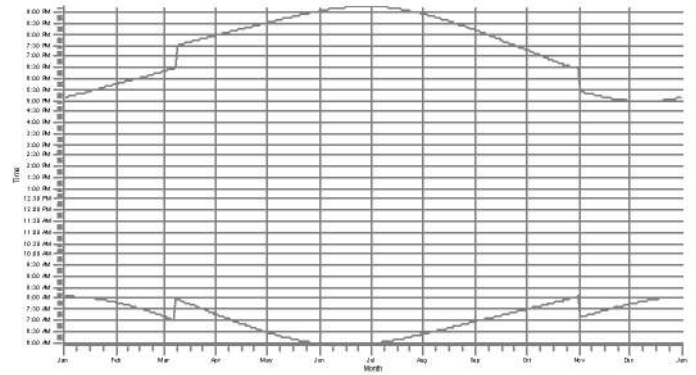
## SHADOW - Calendar, graphical

Calculation: Results.v6.62xGE3.8\_wObstacles\_noMap

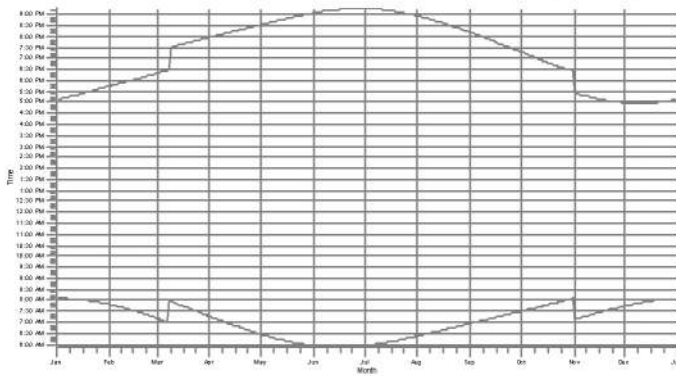
REC-001: Shadow Receptor: 1.0 × 1.0 Azimuth: 0.0° Slope: 0.0° (1)



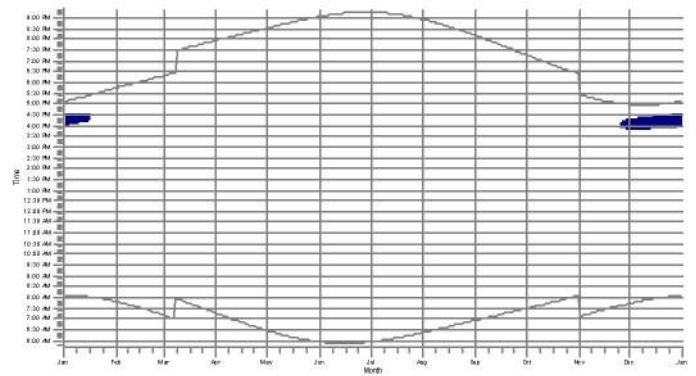
REC-002: Shadow Receptor: 1.0 × 1.0 Azimuth: 0.0° Slope: 0.0° (2)



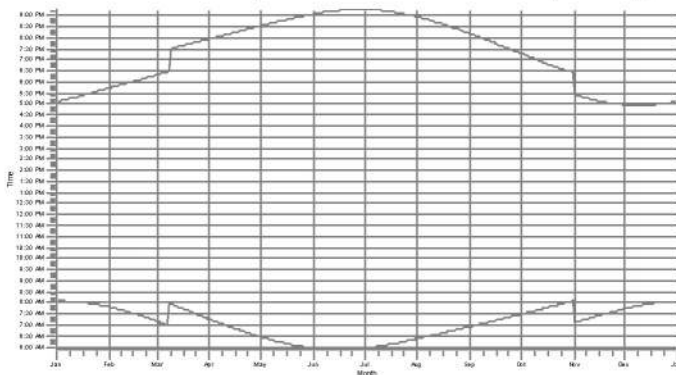
REC-003: Shadow Receptor: 1.0 × 1.0 Azimuth: 0.0° Slope: 0.0° (3)



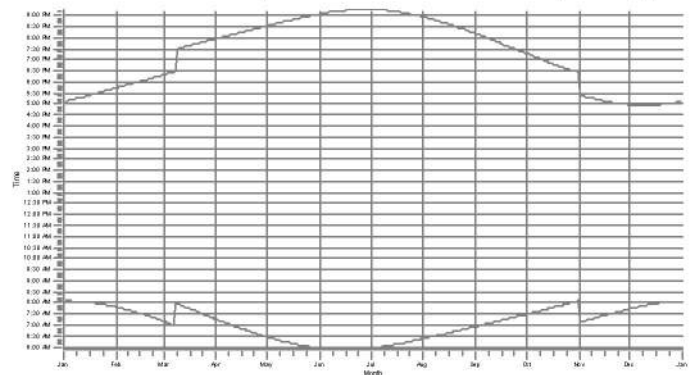
REC-004: Shadow Receptor: 1.0 × 1.0 Azimuth: 0.0° Slope: 0.0° (4)



REC-005: Shadow Receptor: 1.0 × 1.0 Azimuth: 0.0° Slope: 0.0° (5)



REC-006: Shadow Receptor: 1.0 × 1.0 Azimuth: 0.0° Slope: 0.0° (6)



WTGs  
1A.07: GE WIND ENERGY GE 3.8-137 3830 137.0 ICH hub: 111.5 m (TOT: 180.0 m) (295)

Project:  
sPower Shadow Flicker

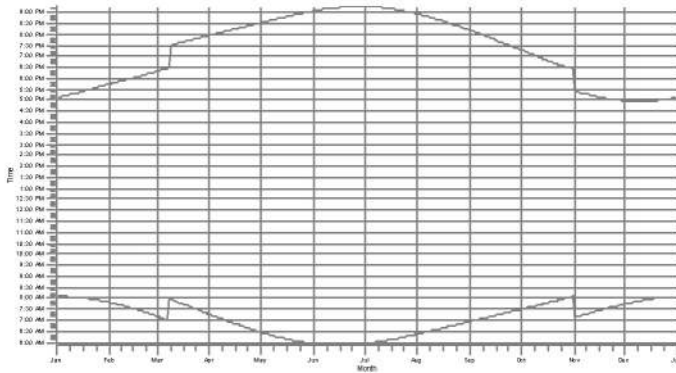
Description:  
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Calculated:  
10/3/2018 3:53 PM/3.0.654

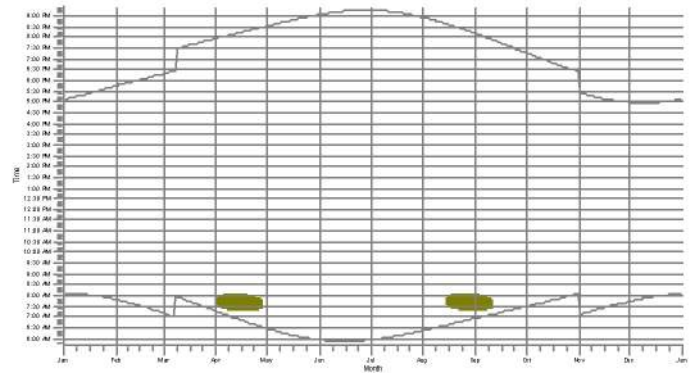
## SHADOW - Calendar, graphical

Calculation: Results.v6.62xGE3.8\_wObstacles\_noMap

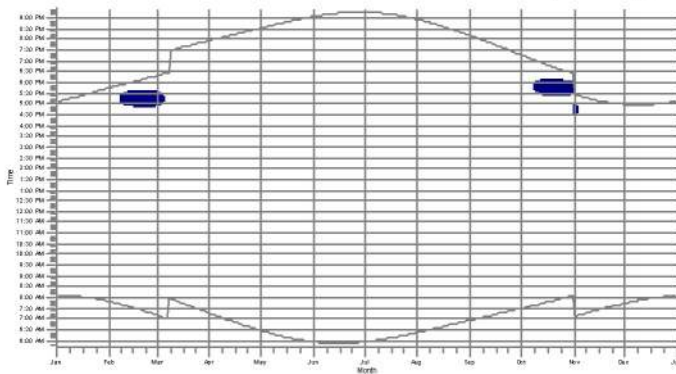
REC-007: Shadow Receptor: 1.0 × 1.0 Azimuth: 0.0° Slope: 0.0° (7)



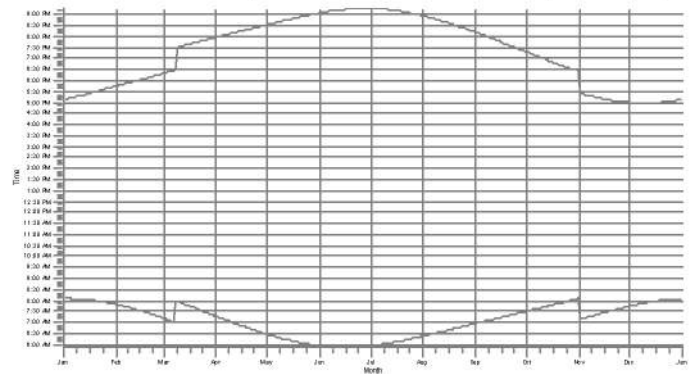
REC-008: Shadow Receptor: 1.0 × 1.0 Azimuth: 0.0° Slope: 0.0° (8)



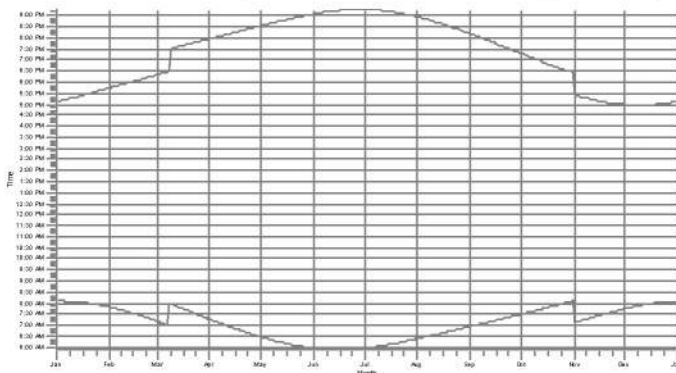
REC-009: Shadow Receptor: 1.0 × 1.0 Azimuth: 0.0° Slope: 0.0° (9)



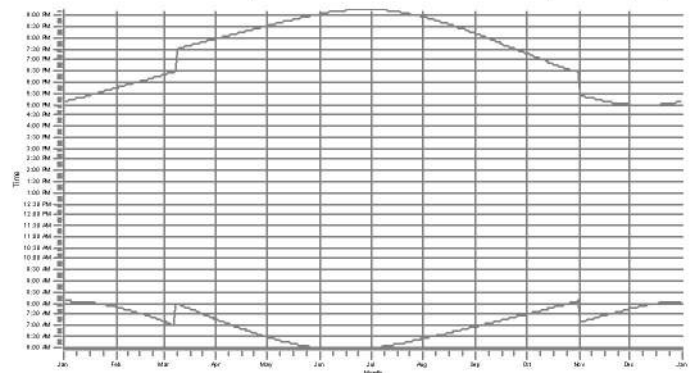
REC-010: Shadow Receptor: 1.0 × 1.0 Azimuth: 0.0° Slope: 0.0° (10)



REC-011: Shadow Receptor: 1.0 × 1.0 Azimuth: 0.0° Slope: 0.0° (11)



REC-012: Shadow Receptor: 1.0 × 1.0 Azimuth: 0.0° Slope: 0.0° (12)



WTGs

1A.07: GE WIND ENERGY GE 3.6-137 3830 137.0 IOW hub: 111.5 m (TOT: 180.0 m) (295) 1B.10: GE WIND ENERGY GE 3.6-137 3830 137.0 IOW hub: 111.5 m (TOT: 180.0 m) (298)

Project:  
sPower Shadow Flicker

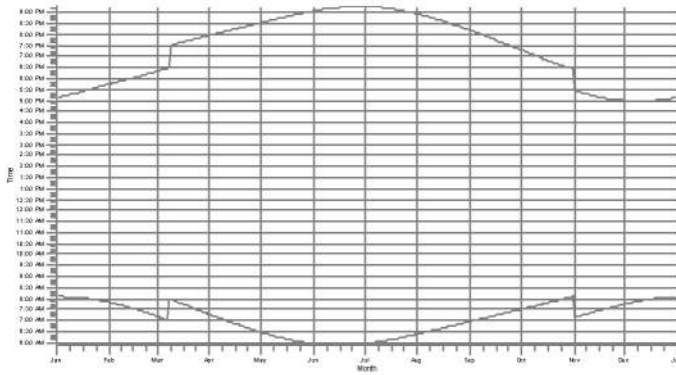
Description:  
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Calculated:  
10/3/2018 3:53 PM/3.0.654

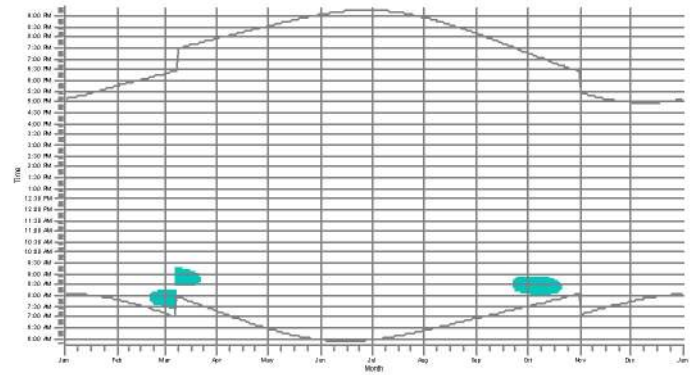
## SHADOW - Calendar, graphical

Calculation: Results.v6.62xGE3.8\_wObstacles\_noMap

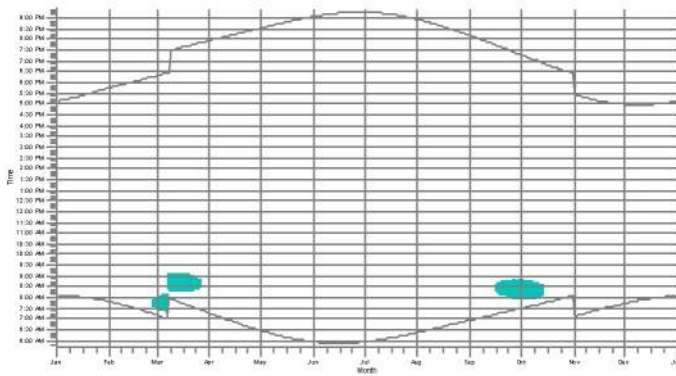
REC-013: Shadow Receptor: 1.0 × 1.0 Azimuth: 0.0° Slope: 0.0° (13)



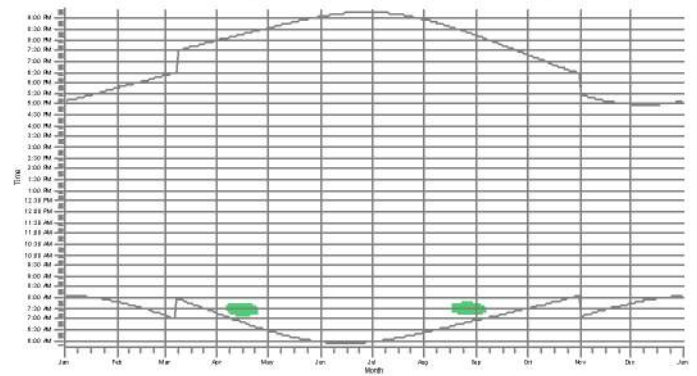
REC-014: Shadow Receptor: 1.0 × 1.0 Azimuth: 0.0° Slope: 0.0° (14)



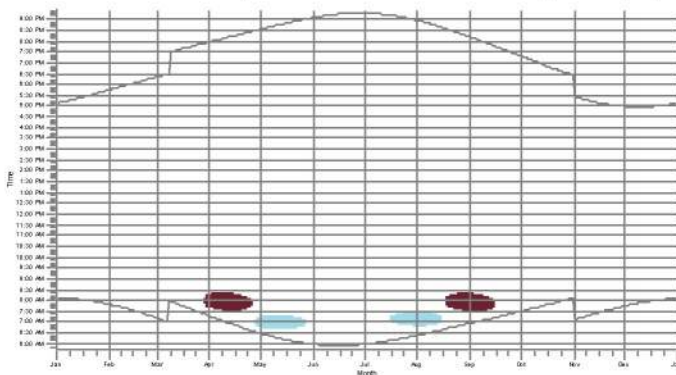
REC-015: Shadow Receptor: 1.0 × 1.0 Azimuth: 0.0° Slope: 0.0° (15)



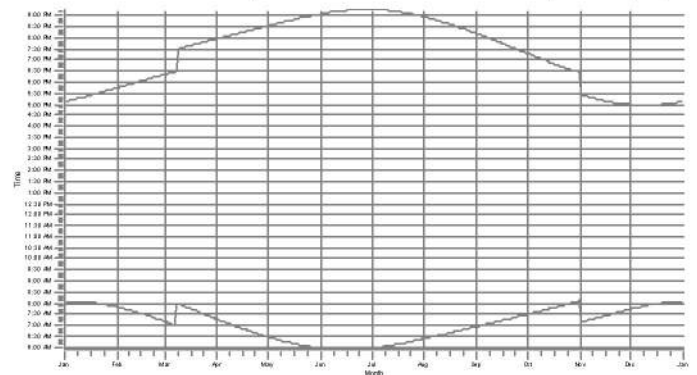
REC-016: Shadow Receptor: 1.0 × 1.0 Azimuth: 0.0° Slope: 0.0° (16)



REC-017: Shadow Receptor: 1.0 × 1.0 Azimuth: 0.0° Slope: 0.0° (17)



REC-018: Shadow Receptor: 1.0 × 1.0 Azimuth: 0.0° Slope: 0.0° (18)



WTGs

2A.21: GE WIND ENERGY GE 3.8-137 3830 137.0 IOI hub: 111.5 m (TOT: 180.0 m) (209) 2B.28: GE WIND ENERGY GE 3.8-137 3830 137.0 IOI hub: 111.5 m (TOT: 180.0 m) (216) 3A.32: GE WIND ENERGY GE 3.8-137 3830 137.0 IOI hub: 111.5 m (TOT: 180.0 m) (220) 3A.33: GE WIND ENERGY GE 3.8-137 3830 137.0 IOI hub: 111.5 m (TOT: 180.0 m) (221)



Project:  
sPower Shadow Flicker

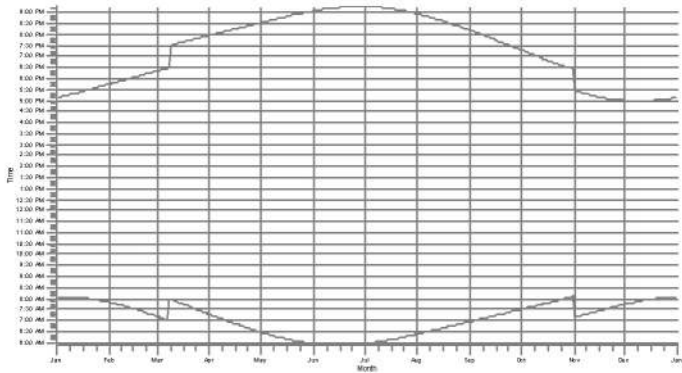
Description:  
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Calculated:  
10/3/2018 3:53 PM/3.0.654

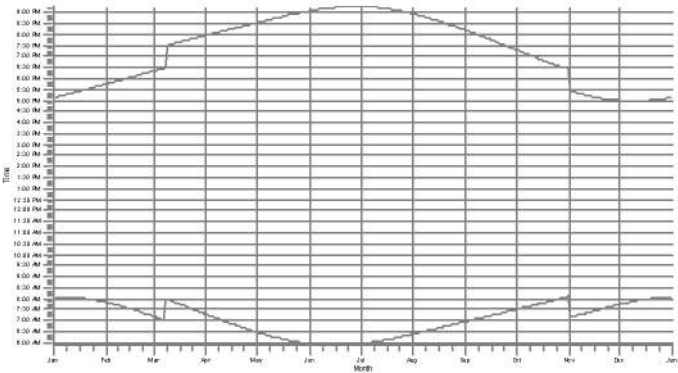
SHADOW - Calendar, graphical

Calculation: Results.v6.62xGE3.8\_wObstacles\_noMap

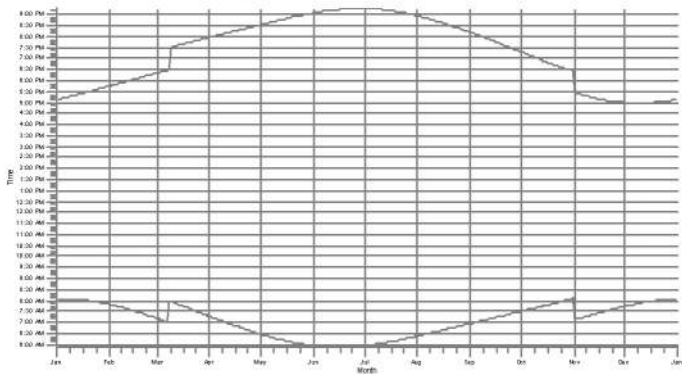
REC-019: Shadow Receptor: 1.0 × 1.0 Azimuth: 0.0° Slope: 0.0° (19)



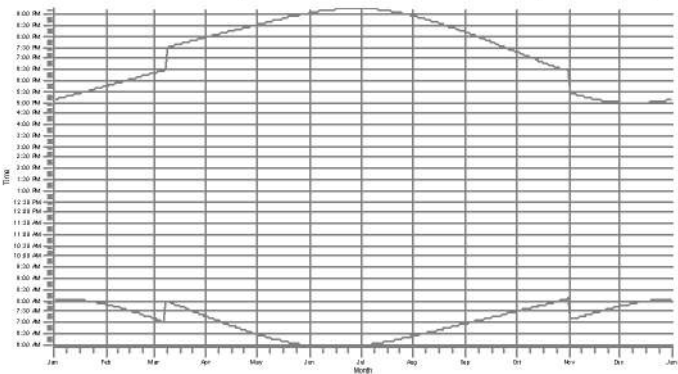
REC-020: Shadow Receptor: 1.0 × 1.0 Azimuth: 0.0° Slope: 0.0° (20)



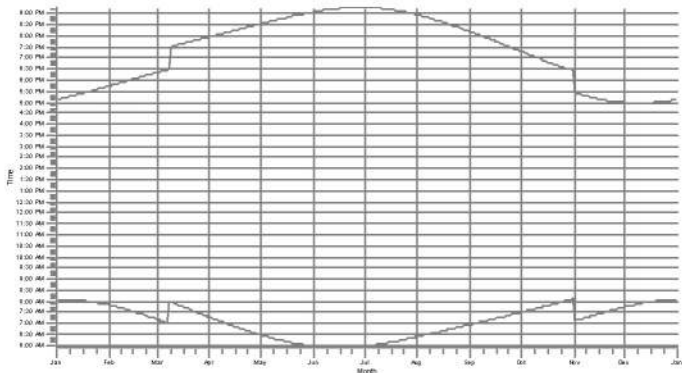
REC-021: Shadow Receptor: 1.0 × 1.0 Azimuth: 0.0° Slope: 0.0° (21)



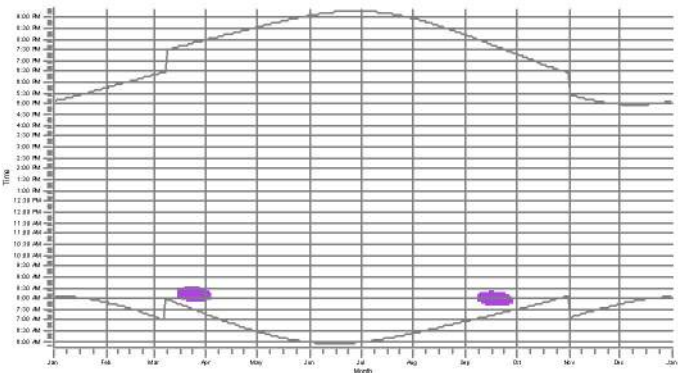
REC-022: Shadow Receptor: 1.0 × 1.0 Azimuth: 0.0° Slope: 0.0° (22)



REC-023: Shadow Receptor: 1.0 × 1.0 Azimuth: 0.0° Slope: 0.0° (23)



REC-024: Shadow Receptor: 1.0 × 1.0 Azimuth: 0.0° Slope: 0.0° (24)



WTGs  
38.43 GE WIND ENERGY GE 3.8-137 3830 137.0 IOW hub: 111.5 m (TOT: 180.0 m) (331)

Project:  
sPower Shadow Flicker

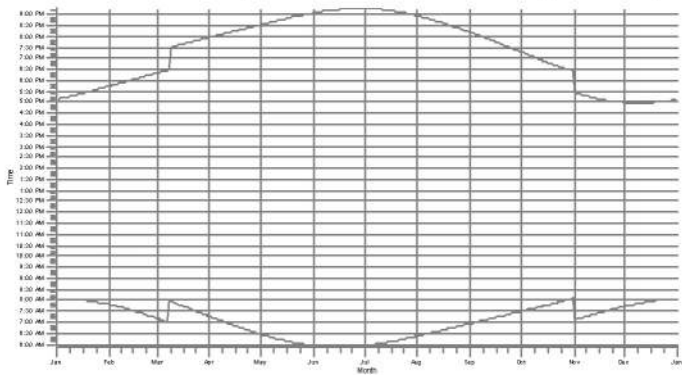
Description:  
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Calculated:  
10/3/2018 3:53 PM/3.0.654

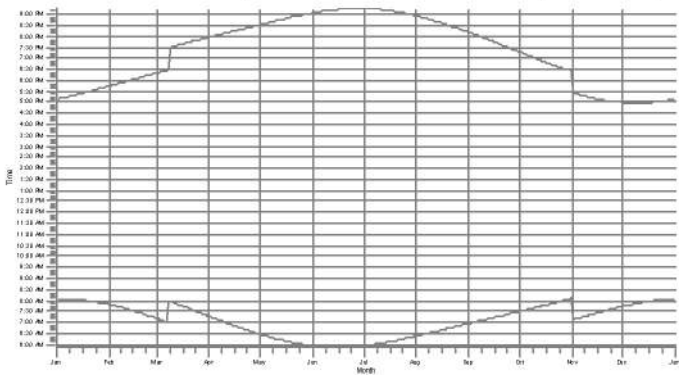
SHADOW - Calendar, graphical

Calculation: Results.v6.62xGE3.8\_wObstacles\_noMap

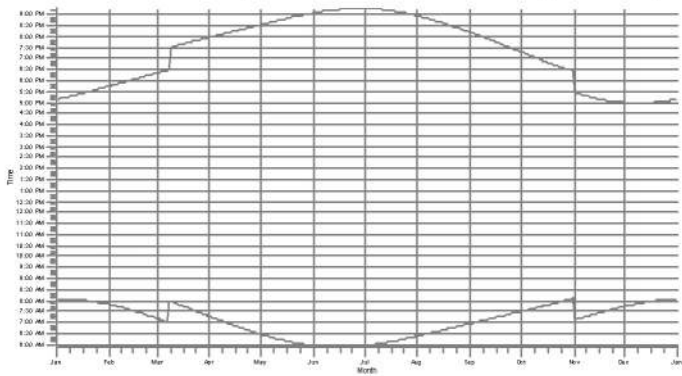
REC-025: Shadow Receptor: 1.0 × 1.0 Azimuth: 0.0° Slope: 0.0° (25)



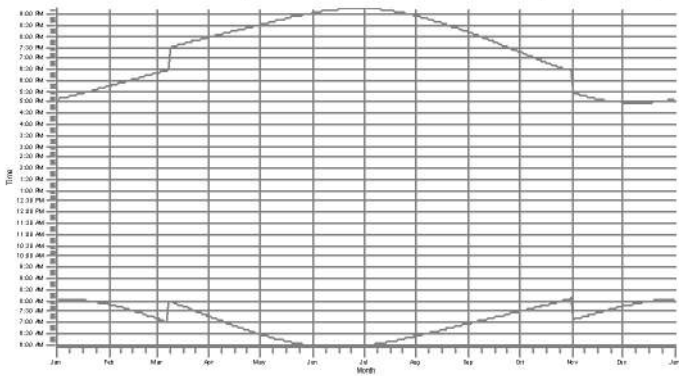
REC-026: Shadow Receptor: 1.0 × 1.0 Azimuth: 0.0° Slope: 0.0° (26)



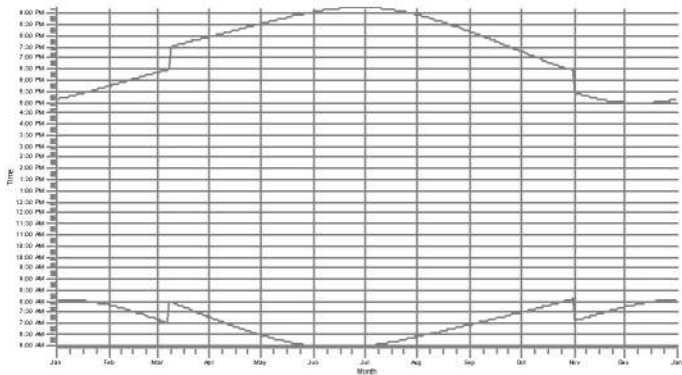
REC-027: Shadow Receptor: 1.0 × 1.0 Azimuth: 0.0° Slope: 0.0° (27)



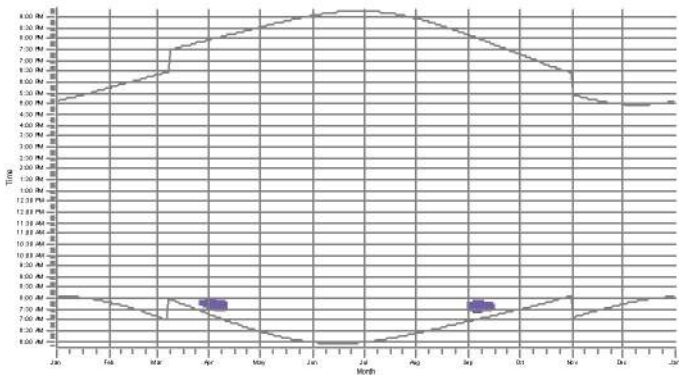
REC-028: Shadow Receptor: 1.0 × 1.0 Azimuth: 0.0° Slope: 0.0° (28)



REC-029: Shadow Receptor: 1.0 × 1.0 Azimuth: 0.0° Slope: 0.0° (29)



REC-030: Shadow Receptor: 1.0 × 1.0 Azimuth: 0.0° Slope: 0.0° (30)



WTGS  
4A.44: GE WIND ENERGY GE 3.8-137 3830 137.0 ICH hub: 111.5 m (TOT: 180.0 m) (332)

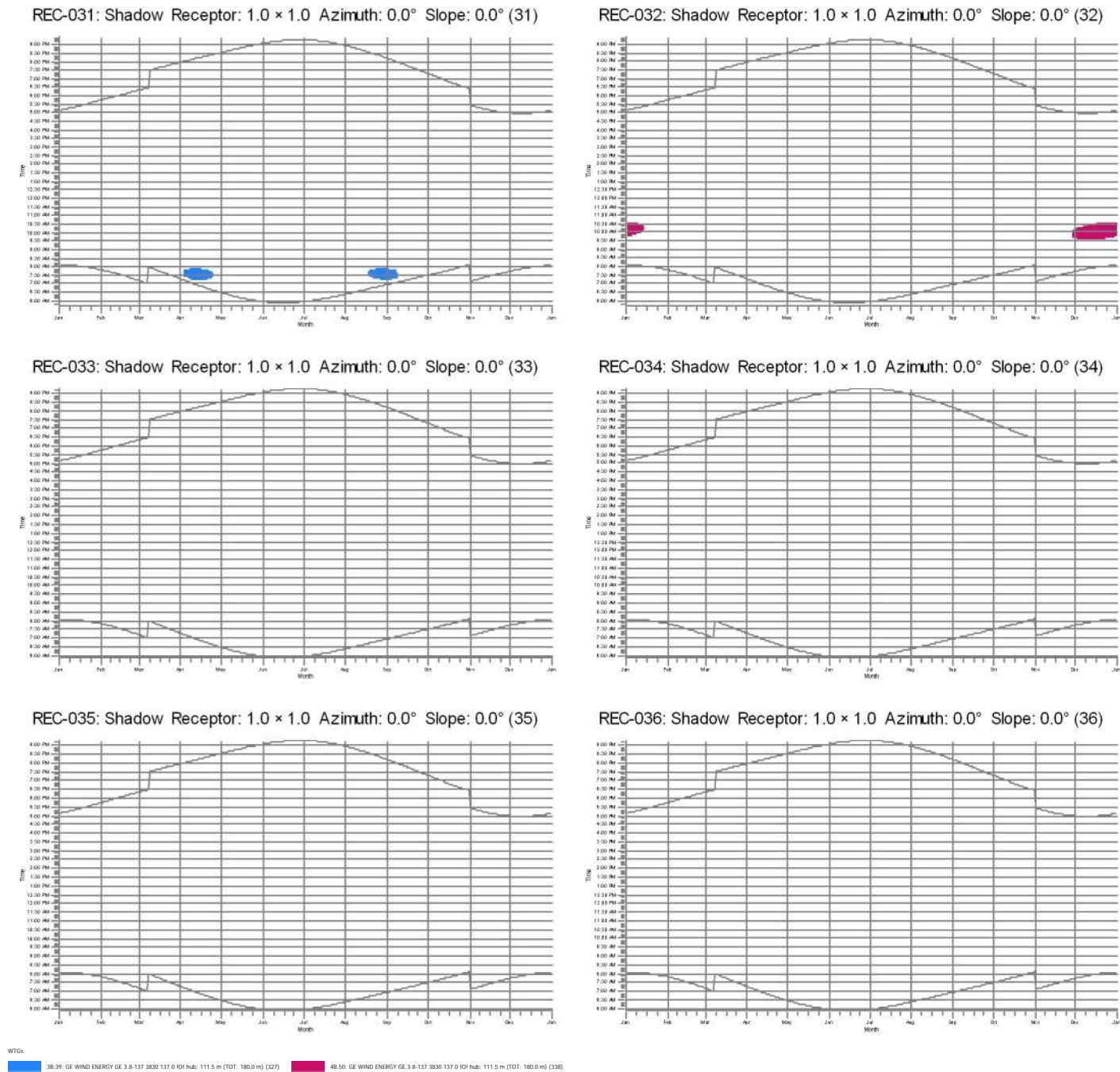
Project:  
sPower Shadow Flicker

Description:  
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10/3/2018 3:53 PM/3.0.654

SHADOW - Calendar, graphical

Calculation: Results.v6.62xGE3.8\_wObstacles\_noMap





Project:  
sPower Shadow Flicker

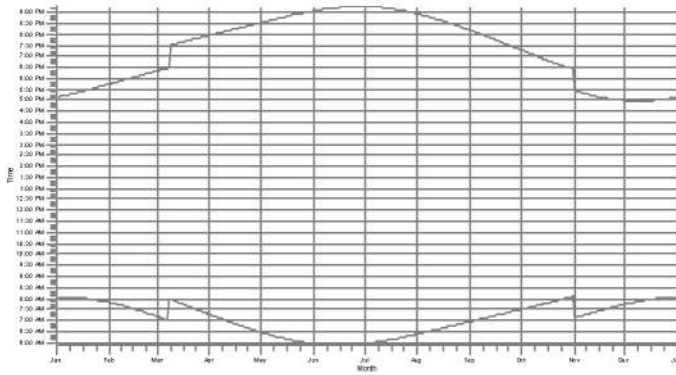
Description:  
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Calculated:  
10/3/2018 3:53 PM/3.0.654

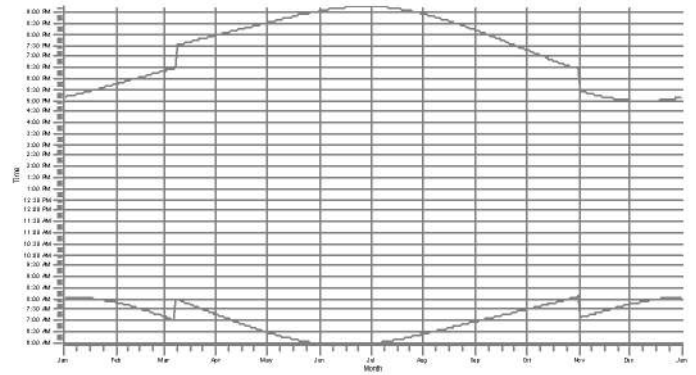
## SHADOW - Calendar, graphical

Calculation: Results.v6.62xGE3.8\_wObstacles\_noMap

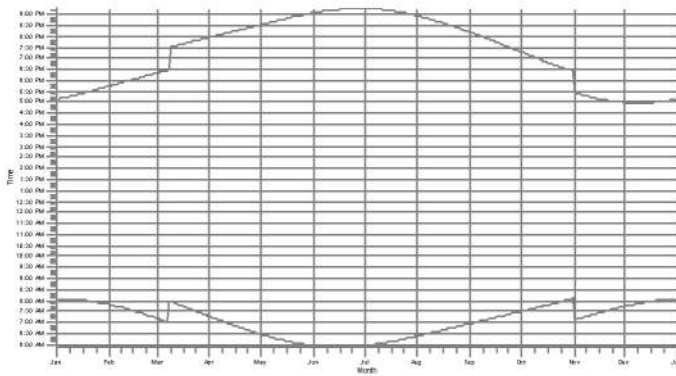
REC-037: Shadow Receptor: 1.0 × 1.0 Azimuth: 0.0° Slope: 0.0° (37)



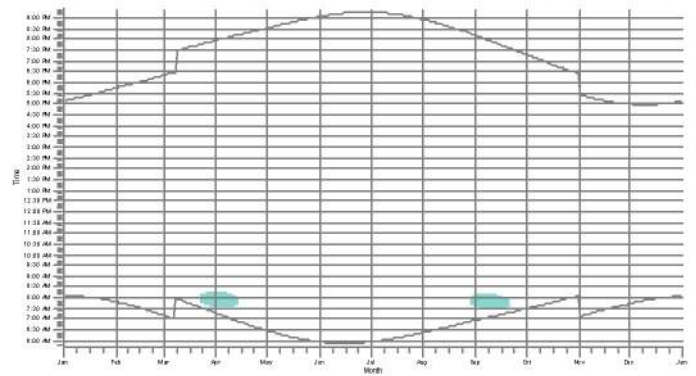
REC-038: Shadow Receptor: 1.0 × 1.0 Azimuth: 0.0° Slope: 0.0° (38)



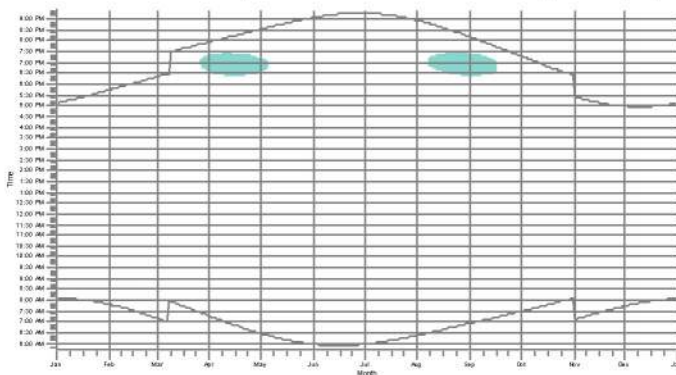
REC-039: Shadow Receptor: 1.0 × 1.0 Azimuth: 0.0° Slope: 0.0° (39)



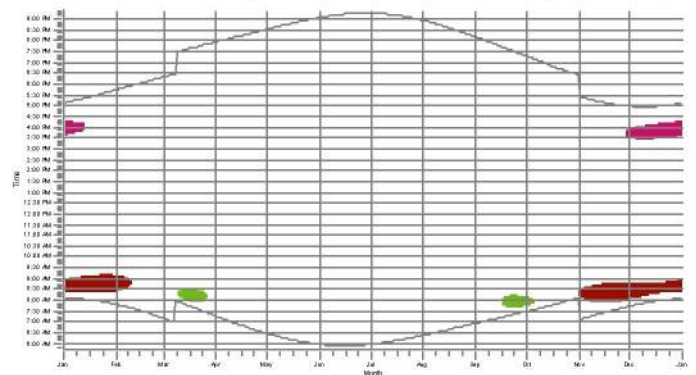
REC-040: Shadow Receptor: 1.0 × 1.0 Azimuth: 0.0° Slope: 0.0° (40)



REC-041: Shadow Receptor: 1.0 × 1.0 Azimuth: 0.0° Slope: 0.0° (41)



REC-042: Shadow Receptor: 1.0 × 1.0 Azimuth: 0.0° Slope: 0.0° (42)



WTGs

44.48: GE WIND ENERGY GE 3.8-137 3830 137.0 I/OI hub: 111.5 m (TOT: 180.0 m) (336) 48.50: GE WIND ENERGY GE 3.8-137 3830 137.0 I/OI hub: 111.5 m (TOT: 180.0 m) (338) 48.51: GE WIND ENERGY GE 3.8-137 3830 137.0 I/OI hub: 111.5 m (TOT: 180.0 m) (339) 48.52: GE WIND ENERGY GE 3.8-137 3830 137.0 I/OI hub: 111.5 m (TOT: 180.0 m) (340)



# EXHIBIT A3-2

Project:  
sPower Shadow Flicker

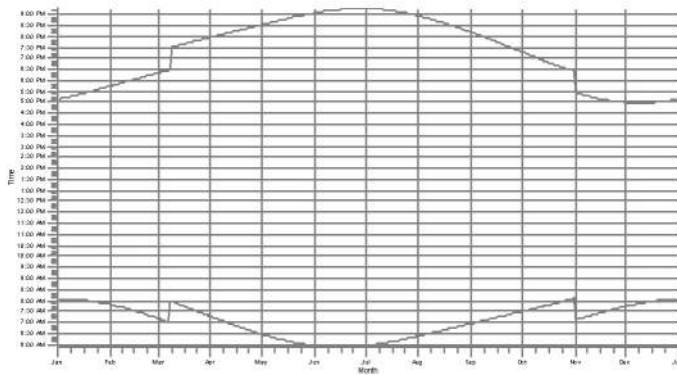
Description:  
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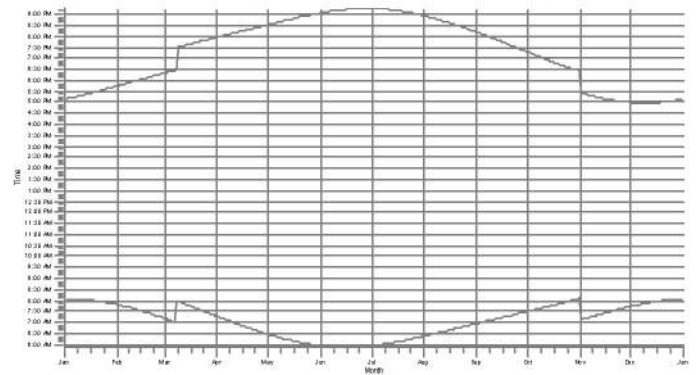
## SHADOW - Calendar, graphical

Calculation: Results.v6.62xGE3.8\_wObstacles\_noMap

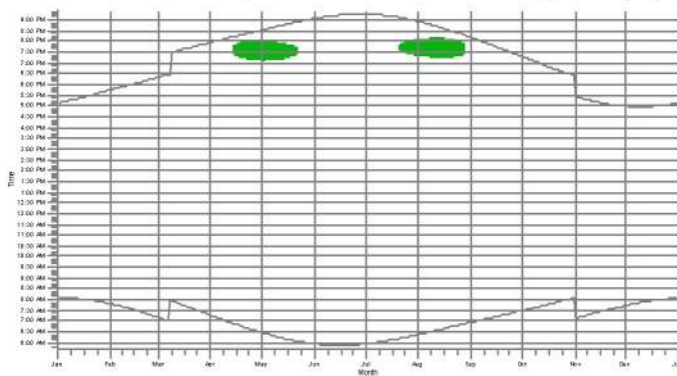
REC-043: Shadow Receptor: 1.0 × 1.0 Azimuth: 0.0° Slope: 0.0° (43)



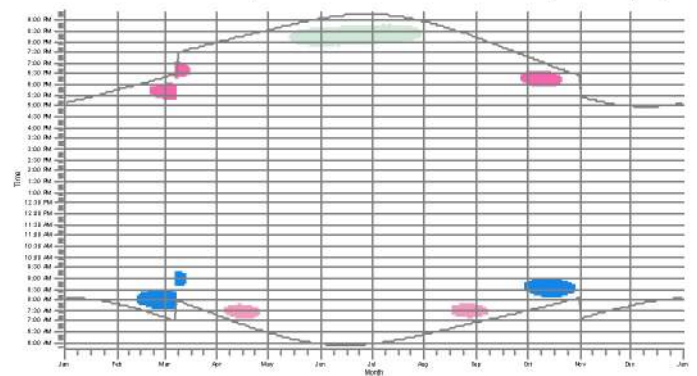
REC-044: Shadow Receptor: 1.0 × 1.0 Azimuth: 0.0° Slope: 0.0° (44)



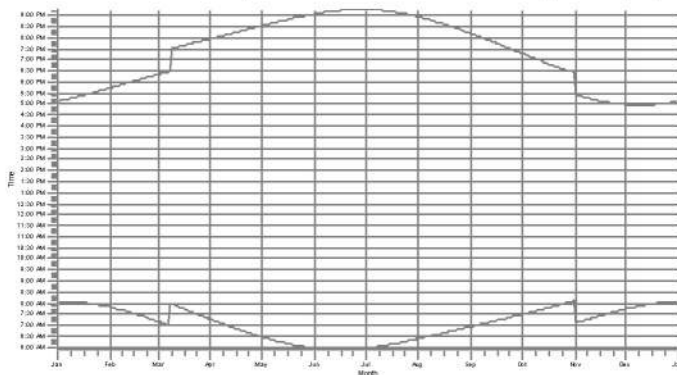
REC-045: Shadow Receptor: 1.0 × 1.0 Azimuth: 0.0° Slope: 0.0° (45)



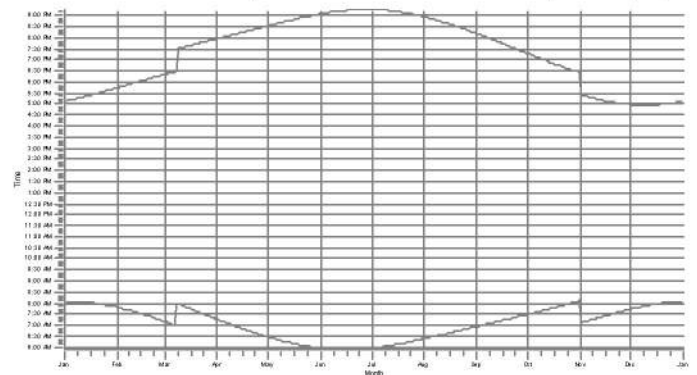
REC-046: Shadow Receptor: 1.0 × 1.0 Azimuth: 0.0° Slope: 0.0° (46)



REC-047: Shadow Receptor: 1.0 × 1.0 Azimuth: 0.0° Slope: 0.0° (47)



REC-048: Shadow Receptor: 1.0 × 1.0 Azimuth: 0.0° Slope: 0.0° (48)



WTGS

48.54: GE WIND ENERGY GE 3.8-127 3830 137.0 I/OI hub: 111.5 m (TOT: 180.0 m) (342) SA.60: GE WIND ENERGY GE 3.8-127 3830 137.0 I/OI hub: 111.5 m (TOT: 180.0 m) (348)  
SA.59: GE WIND ENERGY GE 3.8-127 3830 137.0 I/OI hub: 111.5 m (TOT: 180.0 m) (347) SA.61: GE WIND ENERGY GE 3.8-127 3830 137.0 I/OI hub: 111.5 m (TOT: 180.0 m) (349)  
SA.62: GE WIND ENERGY GE 3.8-127 3830 137.0 I/OI hub: 111.5 m (TOT: 180.0 m) (350)

# EXHIBIT A3-2

Project:

sPower Shadow Flicker

Description:

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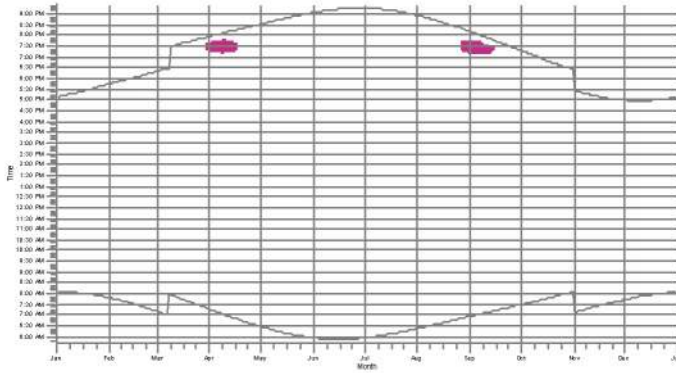
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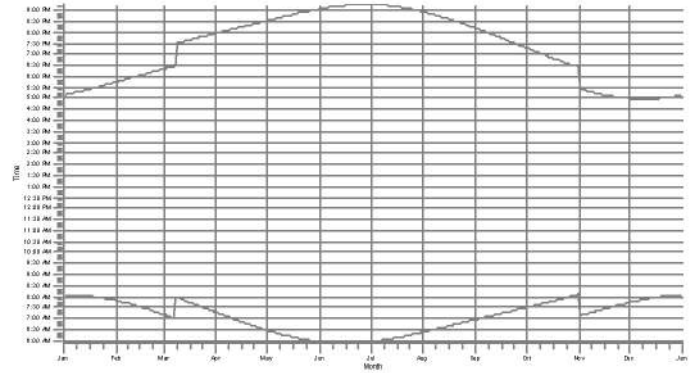
## SHADOW - Calendar, graphical

Calculation: Results.v6.62xGE3.8\_wObstacles\_noMap

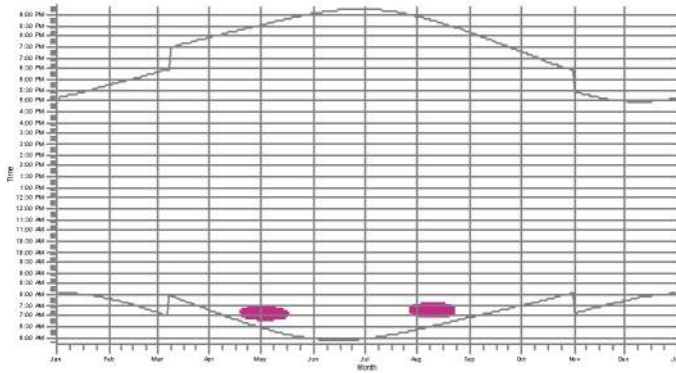
REC-049: Shadow Receptor: 1.0 × 1.0 Azimuth: 0.0° Slope: 0.0° (49)



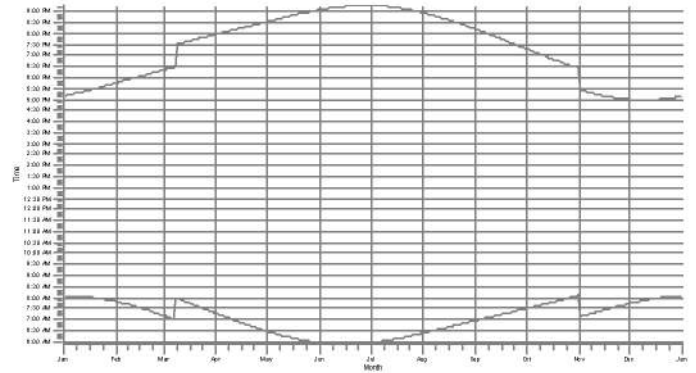
REC-050: Shadow Receptor: 1.0 × 1.0 Azimuth: 0.0° Slope: 0.0° (50)



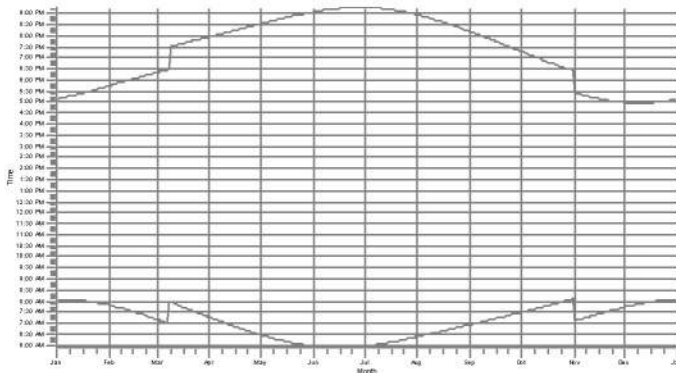
REC-051: Shadow Receptor: 1.0 × 1.0 Azimuth: 0.0° Slope: 0.0° (51)



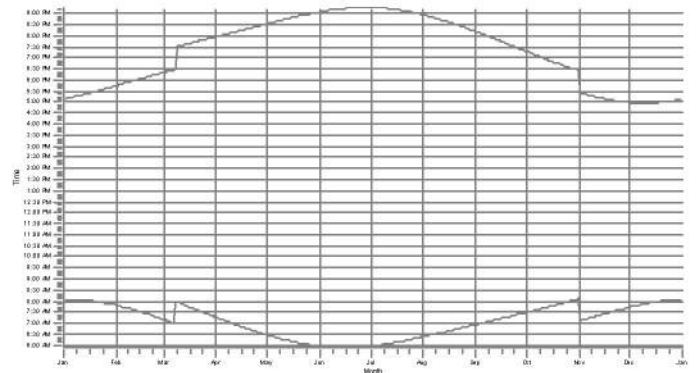
REC-052: Shadow Receptor: 1.0 × 1.0 Azimuth: 0.0° Slope: 0.0° (52)



REC-053: Shadow Receptor: 1.0 × 1.0 Azimuth: 0.0° Slope: 0.0° (53)



REC-054: Shadow Receptor: 1.0 × 1.0 Azimuth: 0.0° Slope: 0.0° (54)



WTGs

48.57 GE WIND ENERGY GE 3.8-137 3830 137.0 IOW hub: 111.5 m (TOT: 180.0 m) (345)

Project:  
sPower Shadow Flicker

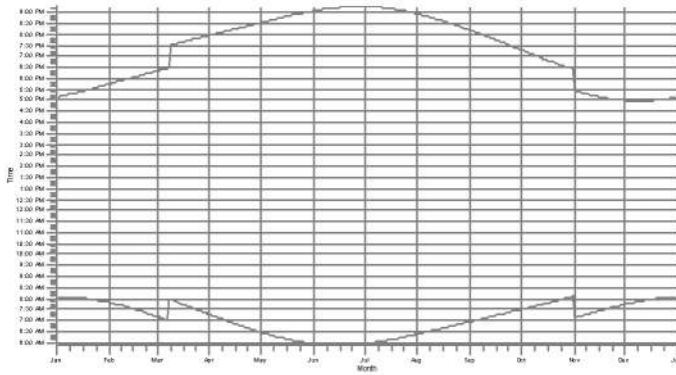
Description:  
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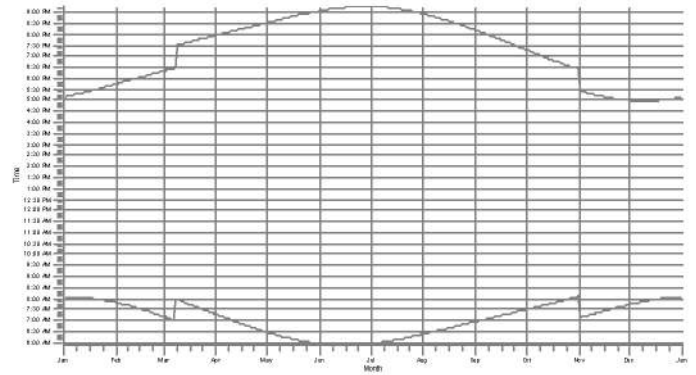
## SHADOW - Calendar, graphical

Calculation: Results.v6.62xGE3.8\_wObstacles\_noMap

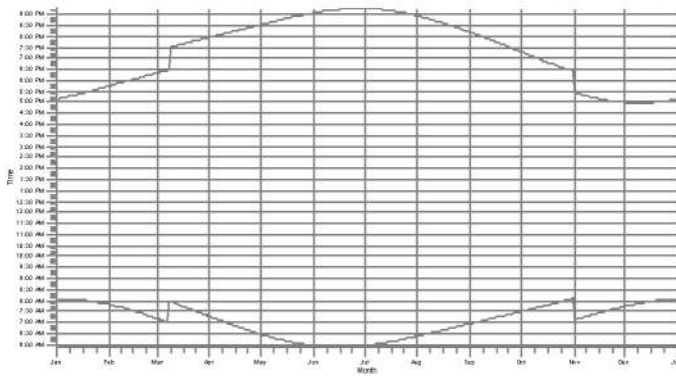
REC-055: Shadow Receptor: 1.0 × 1.0 Azimuth: 0.0° Slope: 0.0° (55)



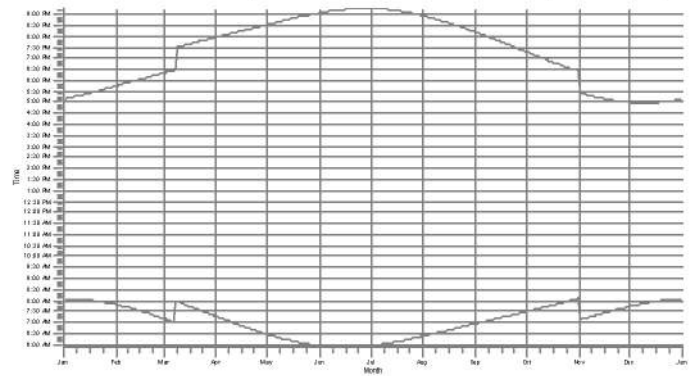
REC-056: Shadow Receptor: 1.0 × 1.0 Azimuth: 0.0° Slope: 0.0° (56)



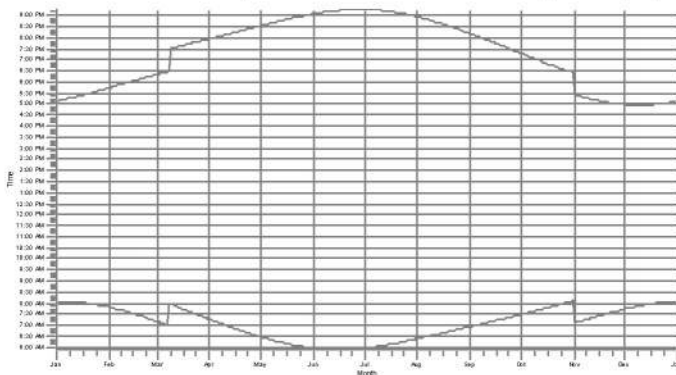
REC-057: Shadow Receptor: 1.0 × 1.0 Azimuth: 0.0° Slope: 0.0° (57)



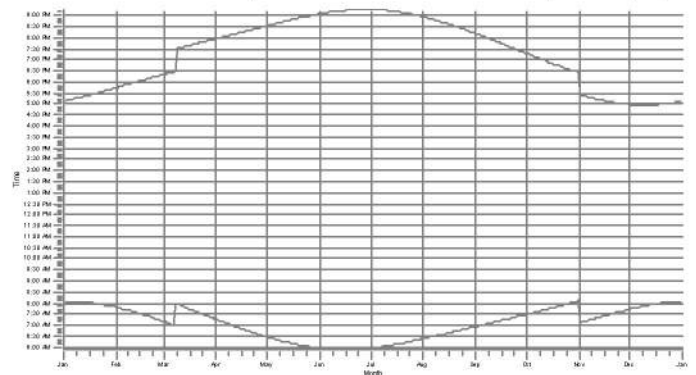
REC-058: Shadow Receptor: 1.0 × 1.0 Azimuth: 0.0° Slope: 0.0° (58)



REC-059: Shadow Receptor: 1.0 × 1.0 Azimuth: 0.0° Slope: 0.0° (59)



REC-060: Shadow Receptor: 1.0 × 1.0 Azimuth: 0.0° Slope: 0.0° (60)



WTGS



Project:  
sPower Shadow Flicker

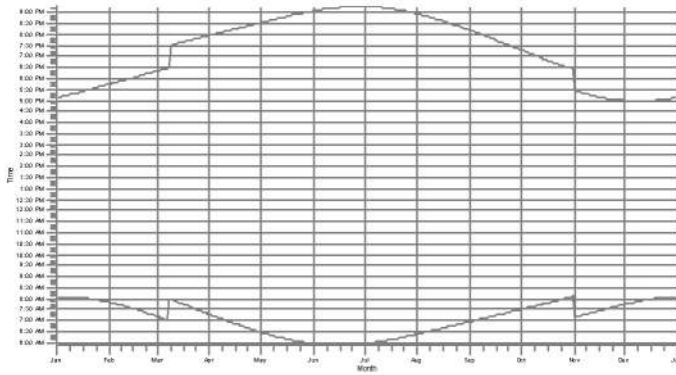
Description:  
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Calculated:  
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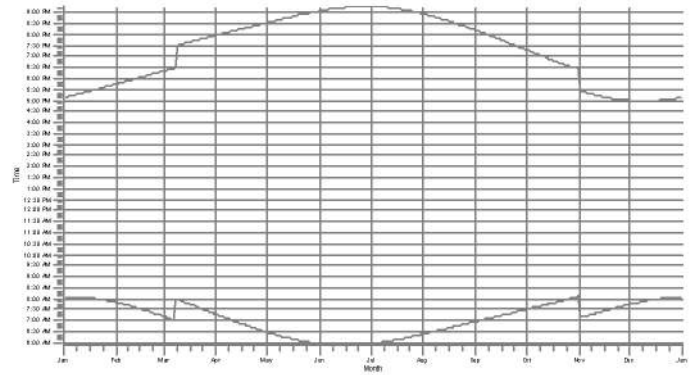
## SHADOW - Calendar, graphical

Calculation: Results.v6.62xGE3.8\_wObstacles\_noMap

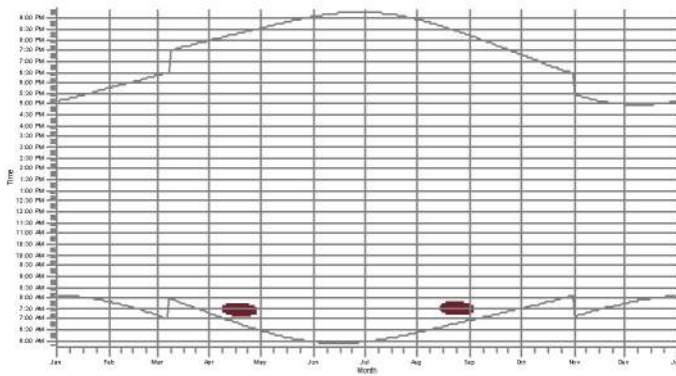
REC-061: Shadow Receptor: 1.0 × 1.0 Azimuth: 0.0° Slope: 0.0° (61)



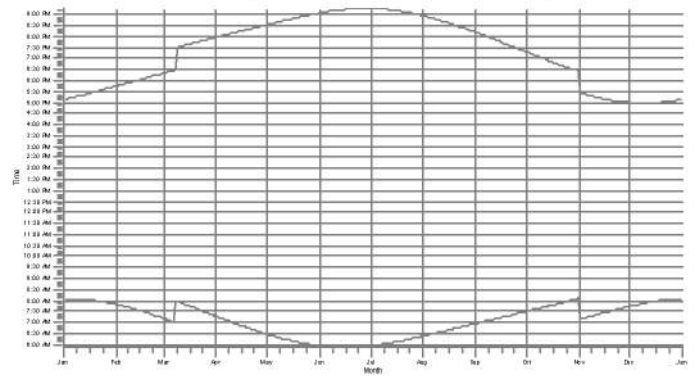
REC-062: Shadow Receptor: 1.0 × 1.0 Azimuth: 0.0° Slope: 0.0° (62)



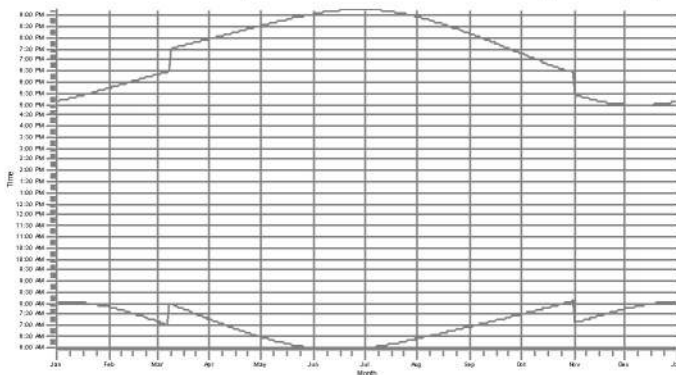
REC-063: Shadow Receptor: 1.0 × 1.0 Azimuth: 0.0° Slope: 0.0° (63)



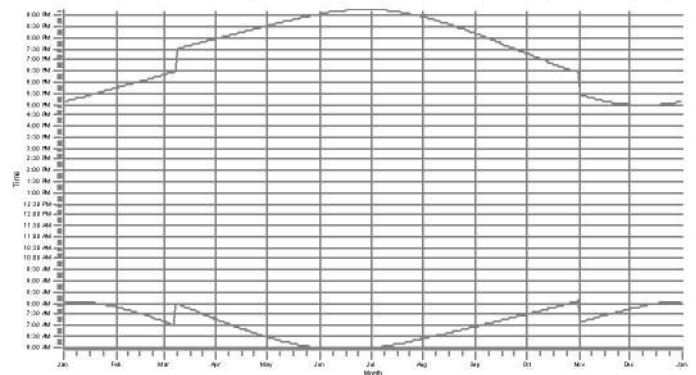
REC-064: Shadow Receptor: 1.0 × 1.0 Azimuth: 0.0° Slope: 0.0° (64)



REC-065: Shadow Receptor: 1.0 × 1.0 Azimuth: 0.0° Slope: 0.0° (65)



REC-066: Shadow Receptor: 1.0 × 1.0 Azimuth: 0.0° Slope: 0.0° (66)



WTGs  
3A.32 GE WIND ENERGY GE 3.8-137 3830 137.0 IOW hub: 111.5 m (TOT: 180.0 m) (220)

Project:  
sPower Shadow Flicker

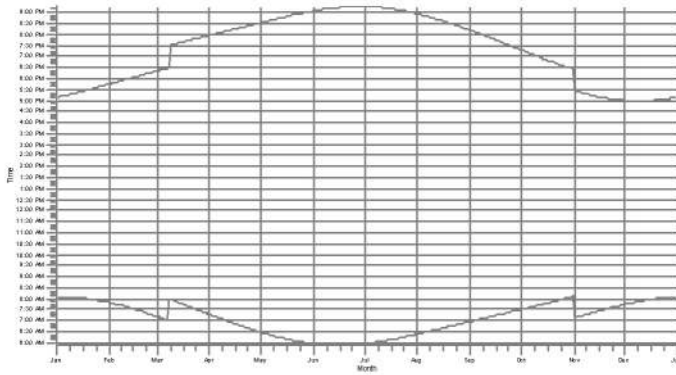
Description:  
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10/3/2018 3:53 PM/3.0.654

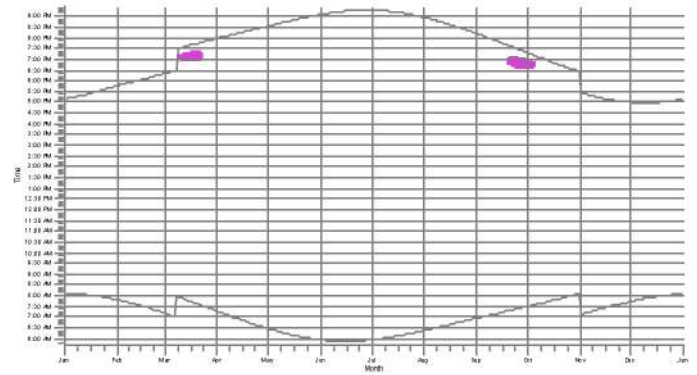
## SHADOW - Calendar, graphical

Calculation: Results.v6.62xGE3.8\_wObstacles\_noMap

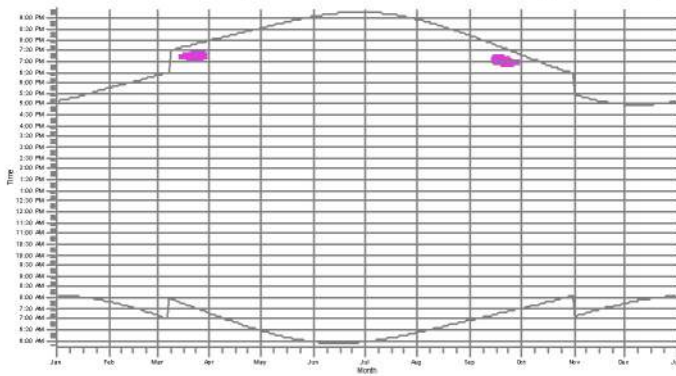
REC-067: Shadow Receptor: 1.0 × 1.0 Azimuth: 0.0° Slope: 0.0° (67)



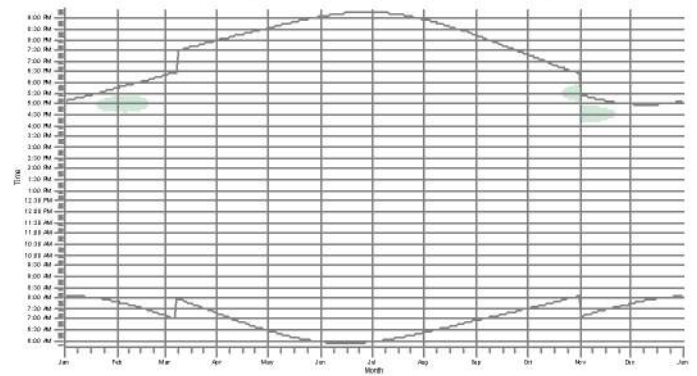
REC-068: Shadow Receptor: 1.0 × 1.0 Azimuth: 0.0° Slope: 0.0° (68)



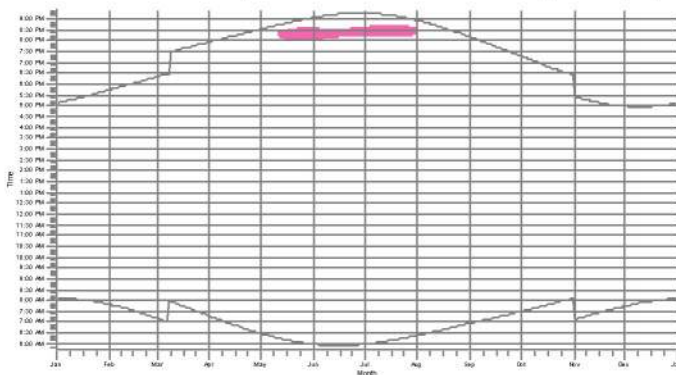
REC-069: Shadow Receptor: 1.0 × 1.0 Azimuth: 0.0° Slope: 0.0° (69)



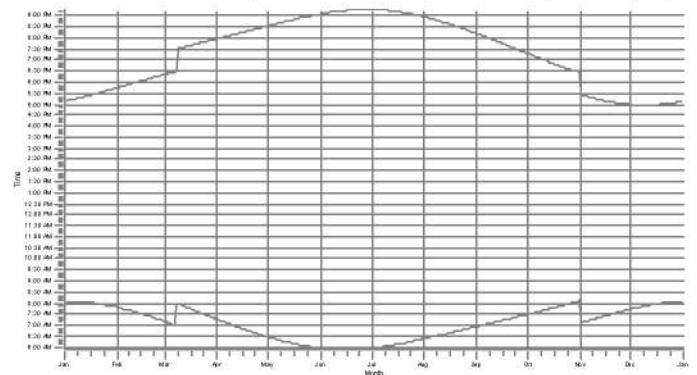
REC-070: Shadow Receptor: 1.0 × 1.0 Azimuth: 0.0° Slope: 0.0° (70)



REC-071: Shadow Receptor: 1.0 × 1.0 Azimuth: 0.0° Slope: 0.0° (71)



REC-072: Shadow Receptor: 1.0 × 1.0 Azimuth: 0.0° Slope: 0.0° (72)



WTGs

SA.35: GE WIND ENERGY GE 3.8-137 3830 137.0 I/OI hub: 111.5 m (TOT: 180.0 m) (223)

SA.60: GE WIND ENERGY GE 3.8-137 3830 137.0 I/OI hub: 111.5 m (TOT: 180.0 m) (348)

SA.61: GE WIND ENERGY GE 3.8-137 3830 137.0 I/OI hub: 111.5 m (TOT: 180.0 m) (349)

Project:  
sPower Shadow Flicker

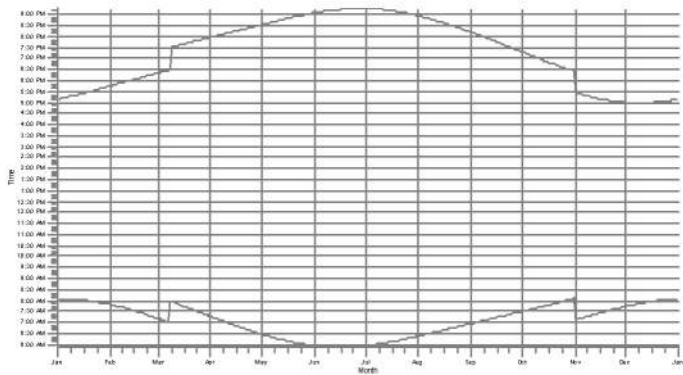
Description:  
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10/3/2018 3:53 PM/3.0.654

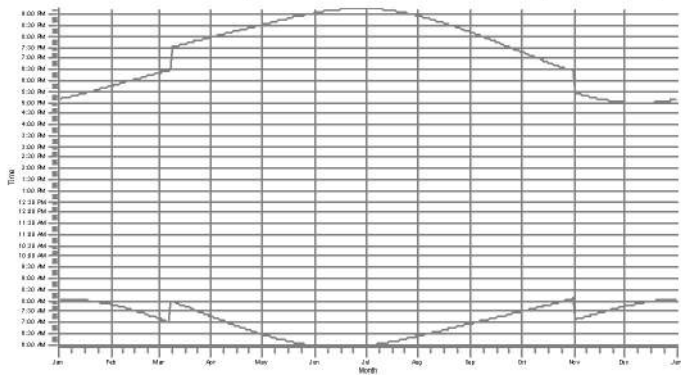
SHADOW - Calendar, graphical

Calculation: Results.v6.62xGE3.8\_wObstacles\_noMap

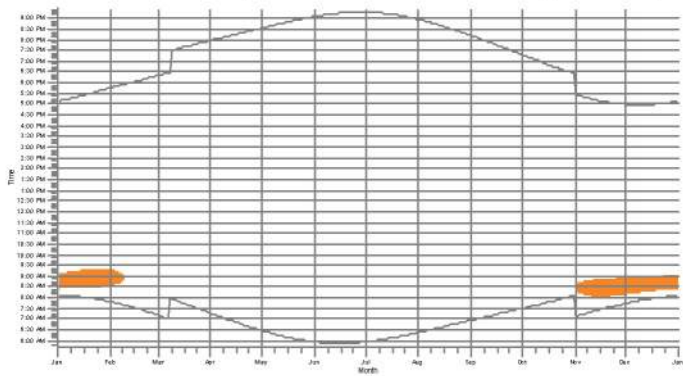
REC-073: Shadow Receptor: 1.0 × 1.0 Azimuth: 0.0° Slope: 0.0° (73)



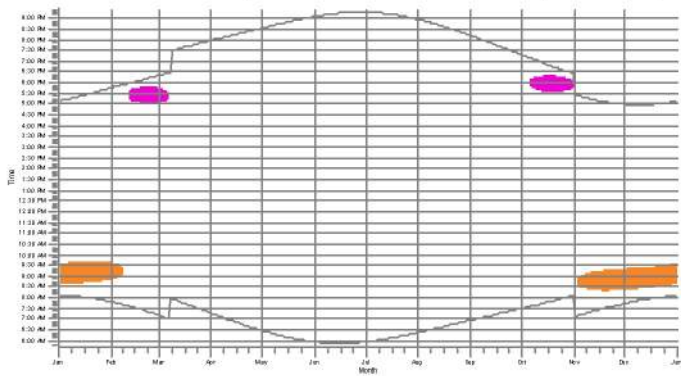
REC-074: Shadow Receptor: 1.0 × 1.0 Azimuth: 0.0° Slope: 0.0° (74)



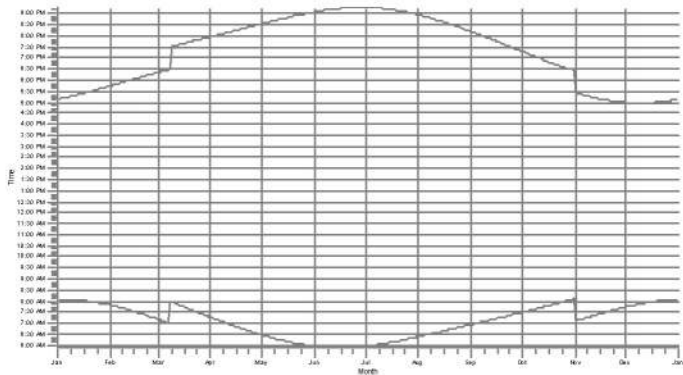
REC-075: Shadow Receptor: 1.0 × 1.0 Azimuth: 0.0° Slope: 0.0° (75)



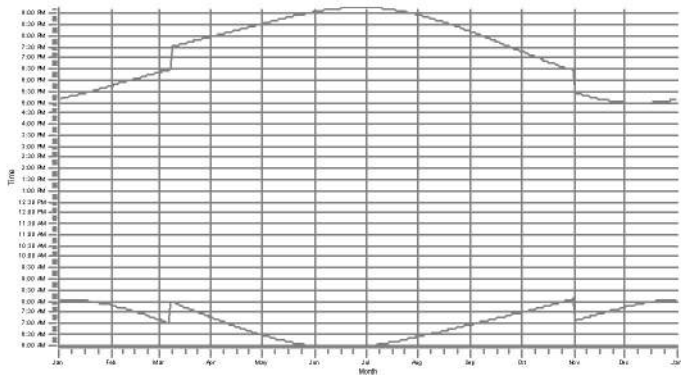
REC-076: Shadow Receptor: 1.0 × 1.0 Azimuth: 0.0° Slope: 0.0° (76)



REC-077: Shadow Receptor: 1.0 × 1.0 Azimuth: 0.0° Slope: 0.0° (77)



REC-078: Shadow Receptor: 1.0 × 1.0 Azimuth: 0.0° Slope: 0.0° (78)



WTGs  
28.23: GE WIND ENERGY GE 3.6-137 3830 137.0 IOW hub: 111.5 m (TOT: 180.0 m) (311)  
28.24: GE WIND ENERGY GE 3.6-137 3830 137.0 IOW hub: 111.5 m (TOT: 180.0 m) (312)



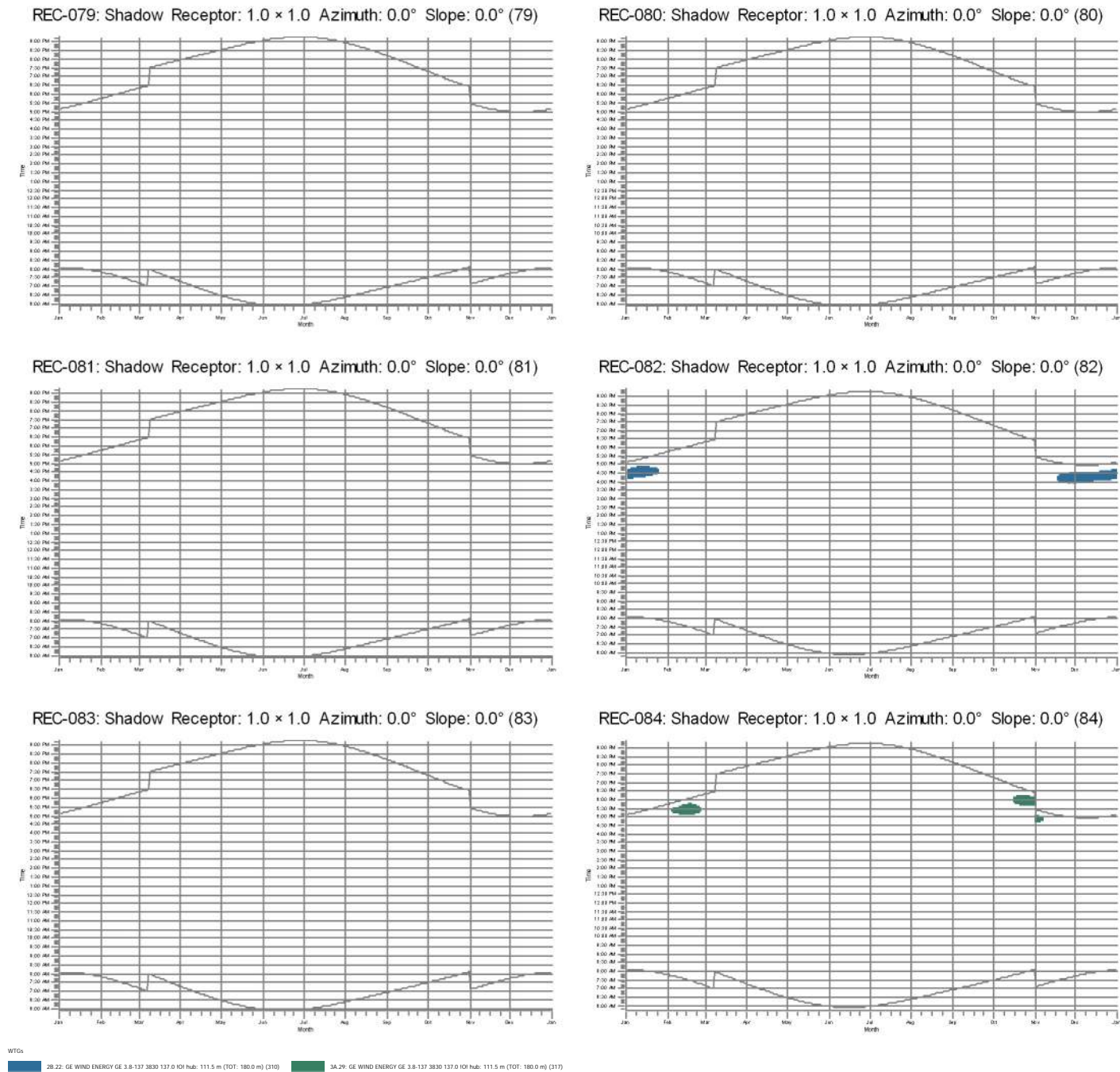
Project:  
sPower Shadow Flicker

Description:  
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10/3/2018 3:53 PM/3.0.654

SHADOW - Calendar, graphical

Calculation: Results.v6.62xGE3.8\_wObstacles\_noMap



Project:  
sPower Shadow Flicker

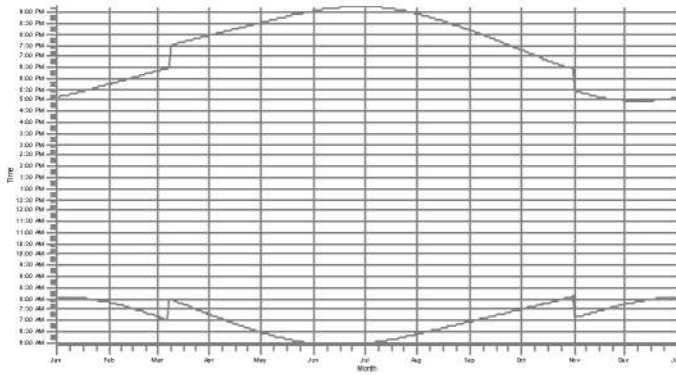
Description:  
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10/3/2018 3:53 PM/3.0.654

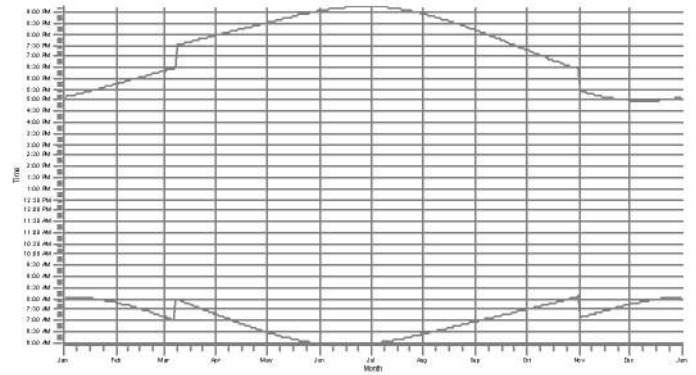
## SHADOW - Calendar, graphical

Calculation: Results.v6.62xGE3.8\_wObstacles\_noMap

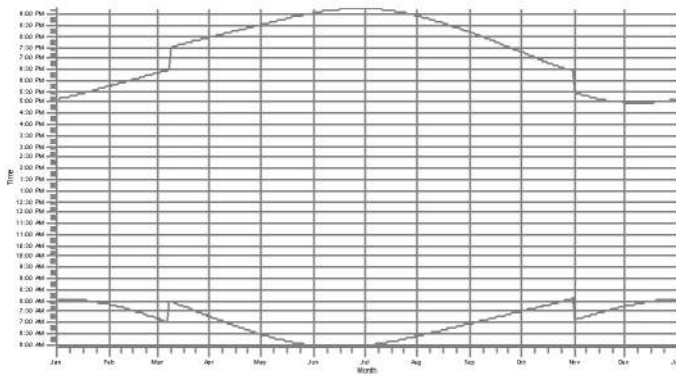
REC-085: Shadow Receptor: 1.0 × 1.0 Azimuth: 0.0° Slope: 0.0° (85)



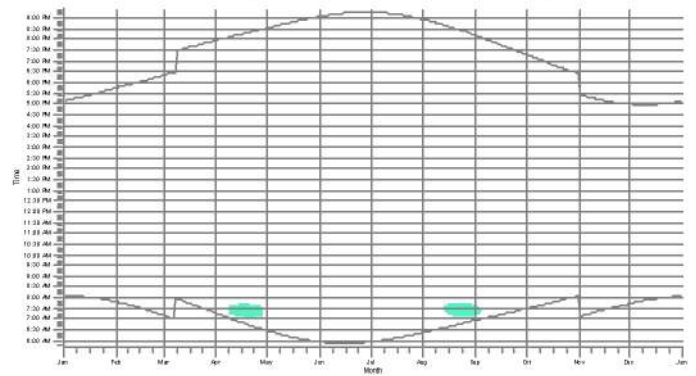
REC-086: Shadow Receptor: 1.0 × 1.0 Azimuth: 0.0° Slope: 0.0° (86)



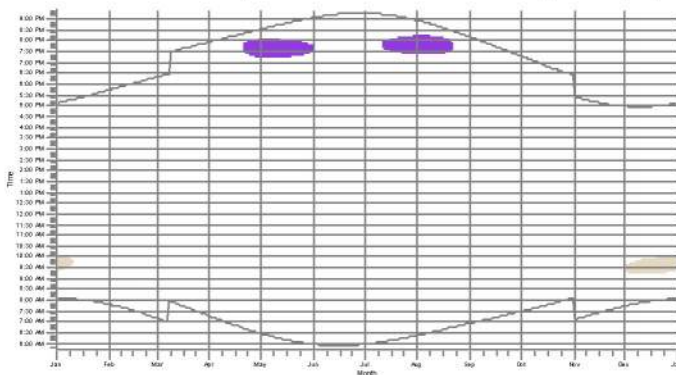
REC-087: Shadow Receptor: 1.0 × 1.0 Azimuth: 0.0° Slope: 0.0° (87)



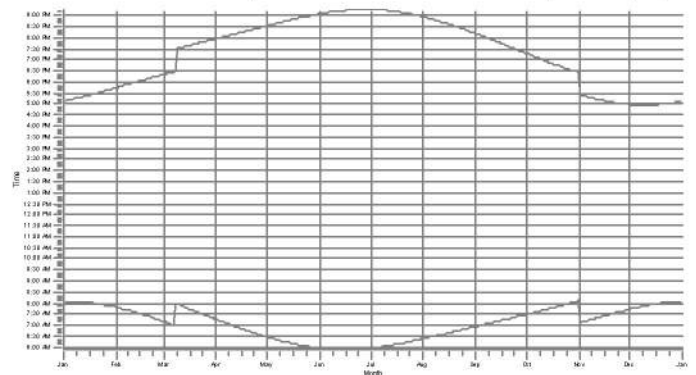
REC-088: Shadow Receptor: 1.0 × 1.0 Azimuth: 0.0° Slope: 0.0° (88)



REC-089: Shadow Receptor: 1.0 × 1.0 Azimuth: 0.0° Slope: 0.0° (89)



REC-090: Shadow Receptor: 1.0 × 1.0 Azimuth: 0.0° Slope: 0.0° (90)



WTGS

44.46: GE WIND ENERGY GE 3.8-137 3830 137.0 I/OI hub: 111.5 m (TOT: 180.0 m) (334) 44.49: GE WIND ENERGY GE 3.8-137 3830 137.0 I/OI hub: 111.5 m (TOT: 180.0 m) (337) 48.56: GE WIND ENERGY GE 3.8-137 3830 137.0 I/OI hub: 111.5 m (TOT: 180.0 m) (344)



Project:  
sPower Shadow Flicker

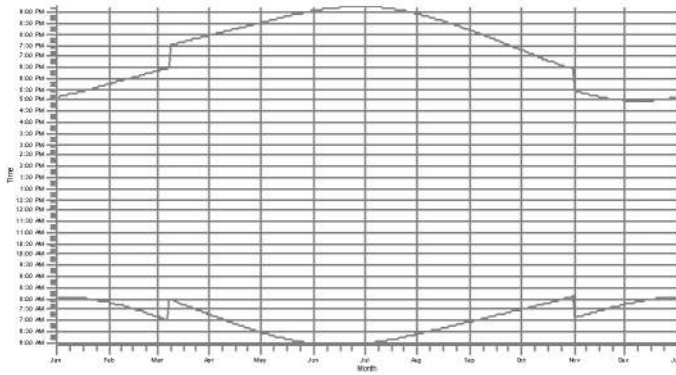
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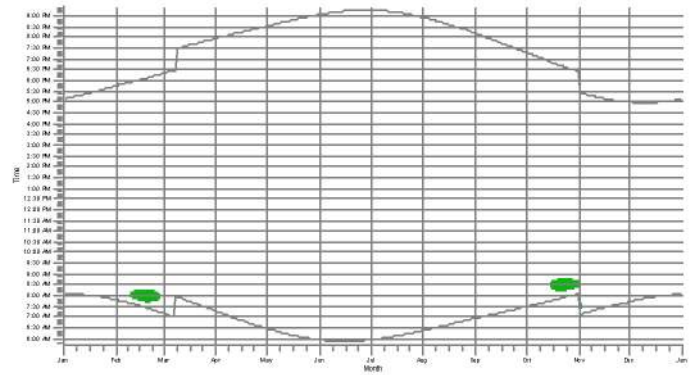
## SHADOW - Calendar, graphical

Calculation: Results.v6.62xGE3.8\_wObstacles\_noMap

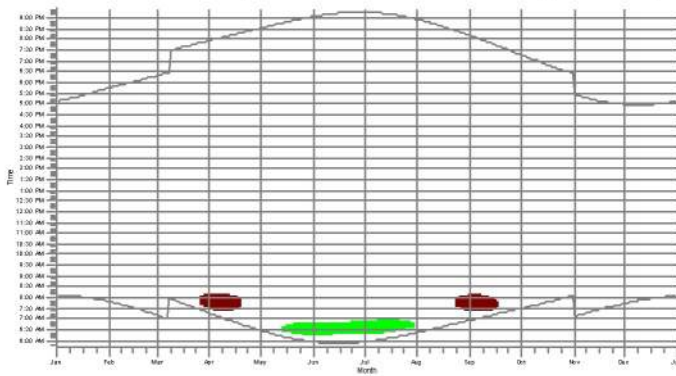
REC-091: Shadow Receptor: 1.0 × 1.0 Azimuth: 0.0° Slope: 0.0° (91)



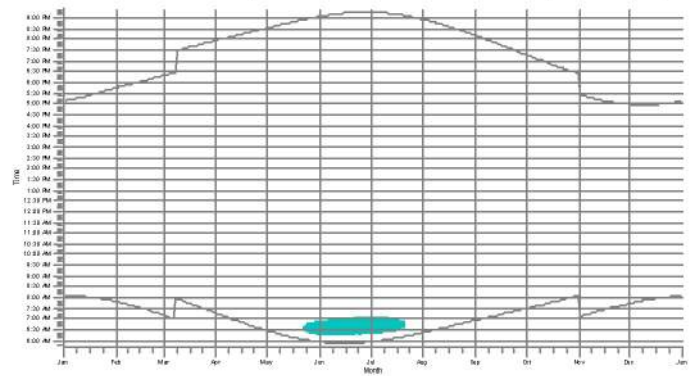
REC-092: Shadow Receptor: 1.0 × 1.0 Azimuth: 0.0° Slope: 0.0° (92)



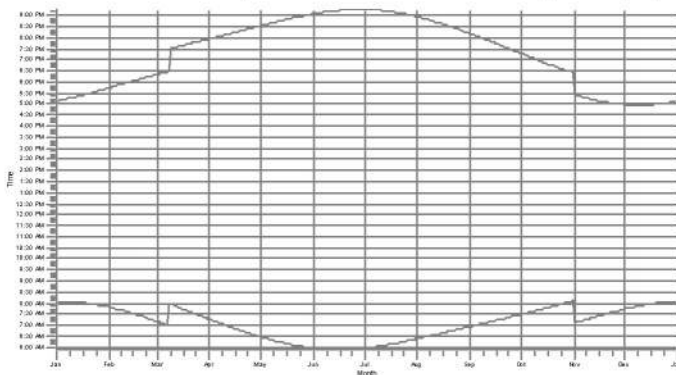
REC-093: Shadow Receptor: 1.0 × 1.0 Azimuth: 0.0° Slope: 0.0° (93)



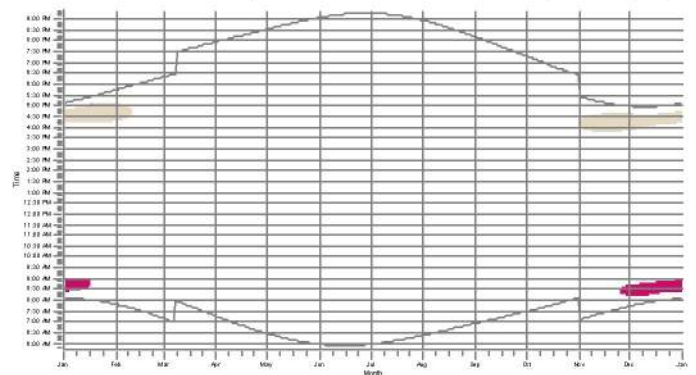
REC-094: Shadow Receptor: 1.0 × 1.0 Azimuth: 0.0° Slope: 0.0° (94)



REC-095: Shadow Receptor: 1.0 × 1.0 Azimuth: 0.0° Slope: 0.0° (95)



REC-096: Shadow Receptor: 1.0 × 1.0 Azimuth: 0.0° Slope: 0.0° (96)



WTGS  
 18.08: GE WIND ENERGY GE 3.8-137 3830 137.0 IOI hub: 111.5 m (TOT: 180.0 m) (296)  
 18.09: GE WIND ENERGY GE 3.8-137 3830 137.0 IOI hub: 111.5 m (TOT: 180.0 m) (297)  
 2A.21: GE WIND ENERGY GE 3.8-137 3830 137.0 IOI hub: 111.5 m (TOT: 180.0 m) (309)  
 4A.47: GE WIND ENERGY GE 3.8-137 3830 137.0 IOI hub: 111.5 m (TOT: 180.0 m) (335)  
 4A.49: GE WIND ENERGY GE 3.8-137 3830 137.0 IOI hub: 111.5 m (TOT: 180.0 m) (337)  
 4B.50: GE WIND ENERGY GE 3.8-137 3830 137.0 IOI hub: 111.5 m (TOT: 180.0 m) (338)  
 4B.54: GE WIND ENERGY GE 3.8-137 3830 137.0 IOI hub: 111.5 m (TOT: 180.0 m) (342)

Project:  
sPower Shadow Flicker

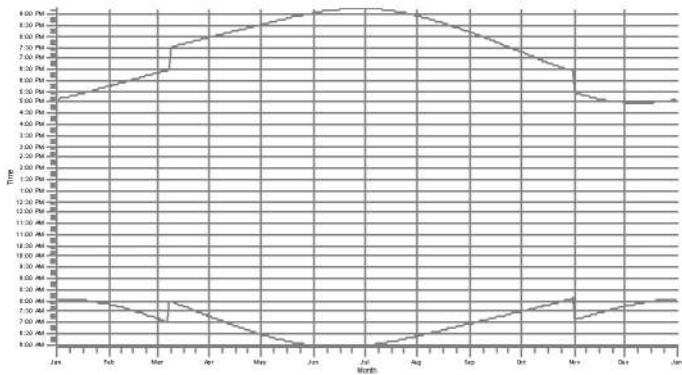
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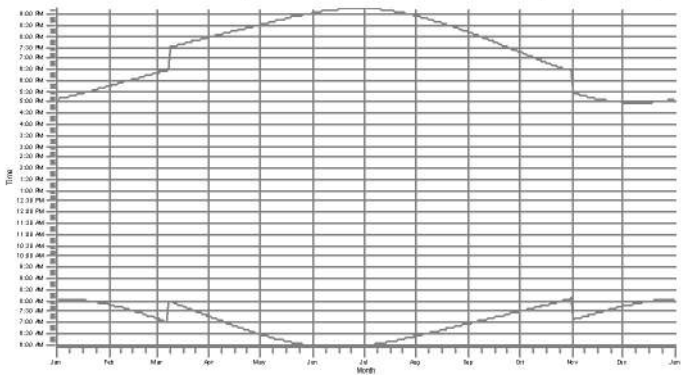
SHADOW - Calendar, graphical

Calculation: Results.v6.62xGE3.8\_wObstacles\_noMap

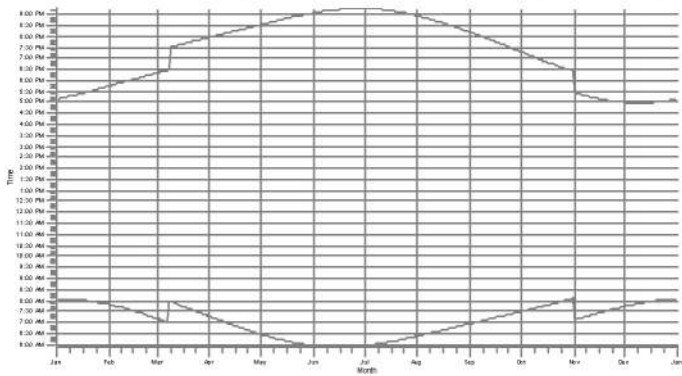
REC-097: Shadow Receptor: 1.0 × 1.0 Azimuth: 0.0° Slope: 0.0° (97)



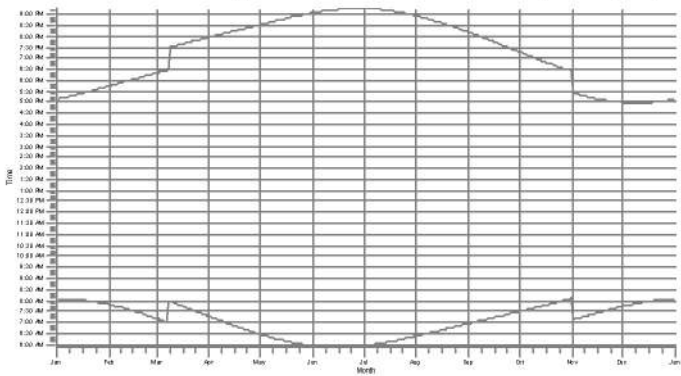
REC-098: Shadow Receptor: 1.0 × 1.0 Azimuth: 0.0° Slope: 0.0° (98)



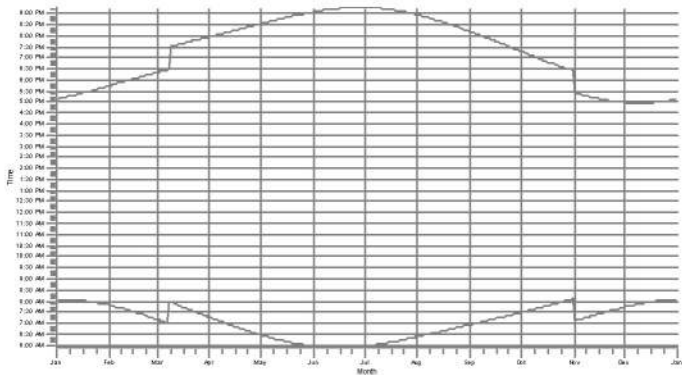
REC-099: Shadow Receptor: 1.0 × 1.0 Azimuth: 0.0° Slope: 0.0° (99)



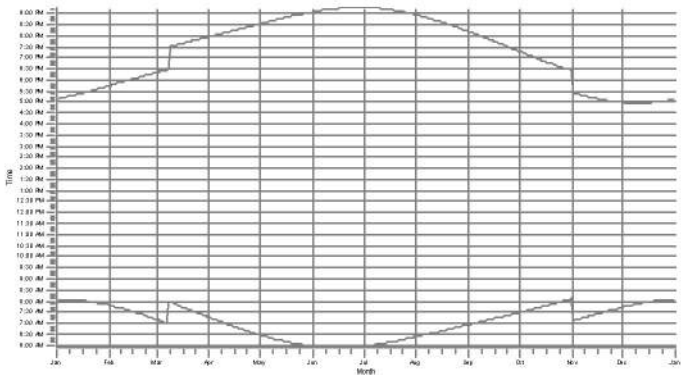
REC-100: Shadow Receptor: 1.0 × 1.0 Azimuth: 0.0° Slope: 0.0° (100)



REC-101: Shadow Receptor: 1.0 × 1.0 Azimuth: 0.0° Slope: 0.0° (101)



REC-102: Shadow Receptor: 1.0 × 1.0 Azimuth: 0.0° Slope: 0.0° (102)



WTGS

Project:  
sPower Shadow Flicker

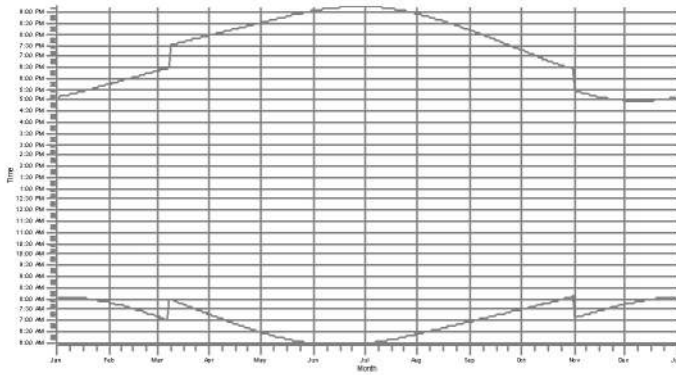
Description:  
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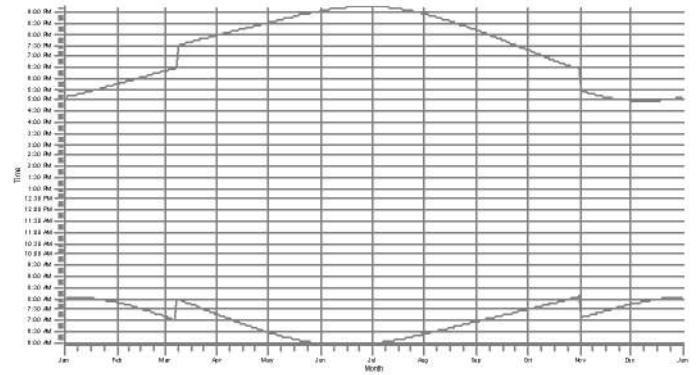
## SHADOW - Calendar, graphical

Calculation: Results.v6.62xGE3.8\_wObstacles\_noMap

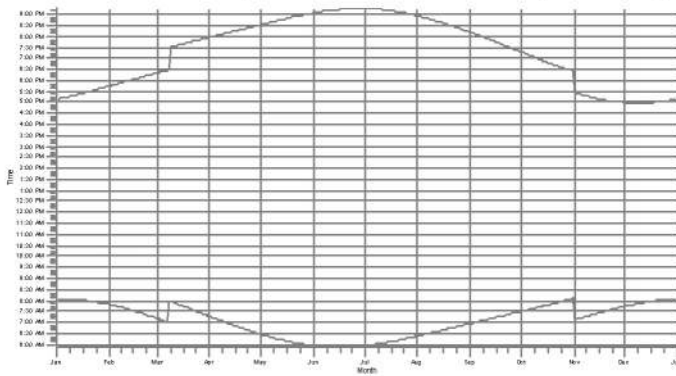
REC-103: Shadow Receptor: 1.0 × 1.0 Azimuth: 0.0° Slope: 0.0° (103)



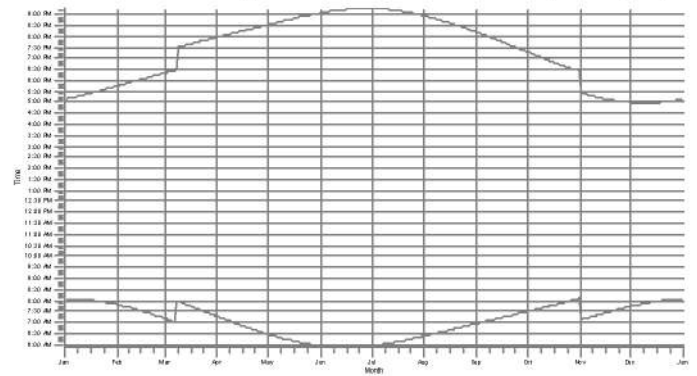
REC-104: Shadow Receptor: 1.0 × 1.0 Azimuth: 0.0° Slope: 0.0° (104)



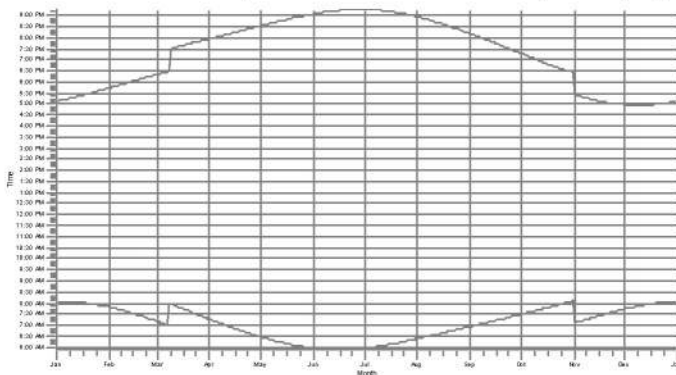
REC-105: Shadow Receptor: 1.0 × 1.0 Azimuth: 0.0° Slope: 0.0° (105)



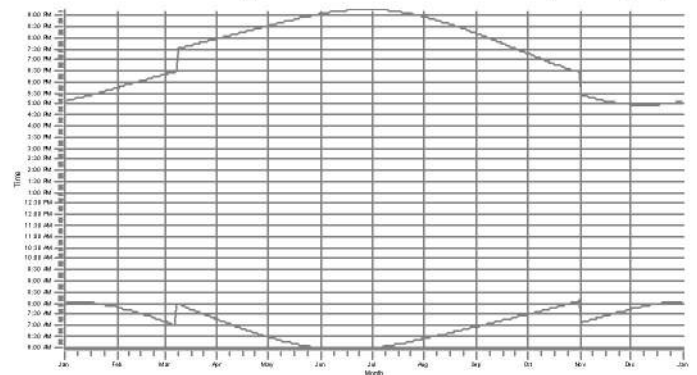
REC-106: Shadow Receptor: 1.0 × 1.0 Azimuth: 0.0° Slope: 0.0° (106)



REC-107: Shadow Receptor: 1.0 × 1.0 Azimuth: 0.0° Slope: 0.0° (107)



REC-108: Shadow Receptor: 1.0 × 1.0 Azimuth: 0.0° Slope: 0.0° (108)



WTGS



Project:  
sPower Shadow Flicker

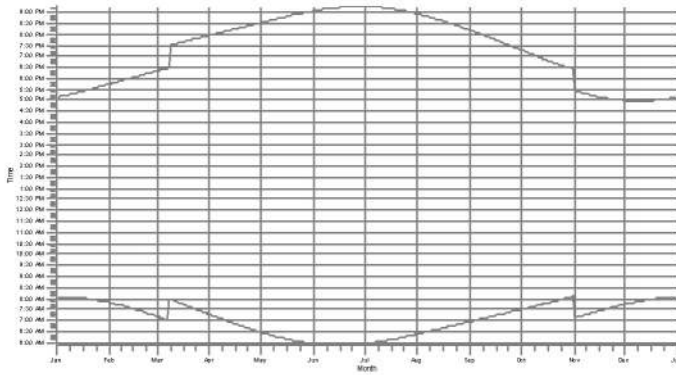
Description:  
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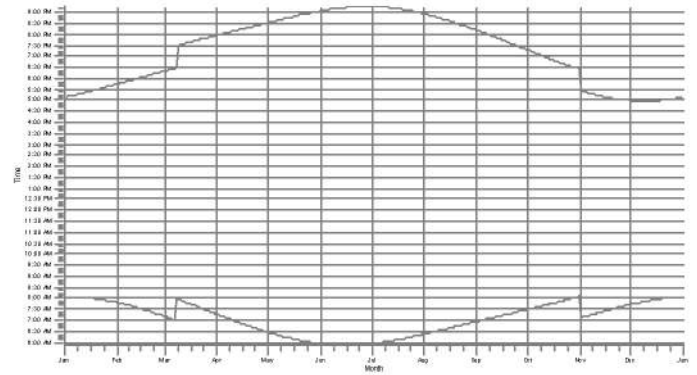
## SHADOW - Calendar, graphical

Calculation: Results.v6.62xGE3.8\_wObstacles\_noMap

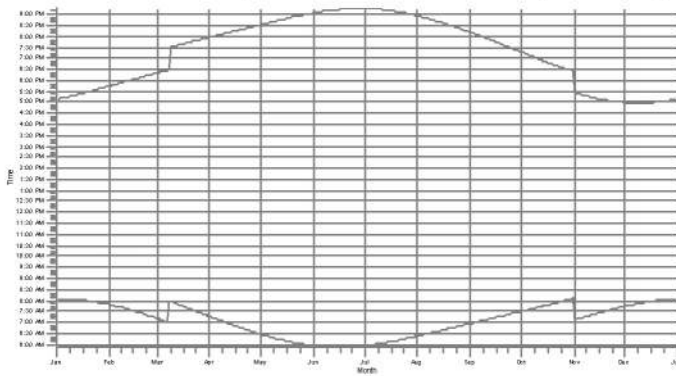
REC-109: Shadow Receptor: 1.0 × 1.0 Azimuth: 0.0° Slope: 0.0° (109)



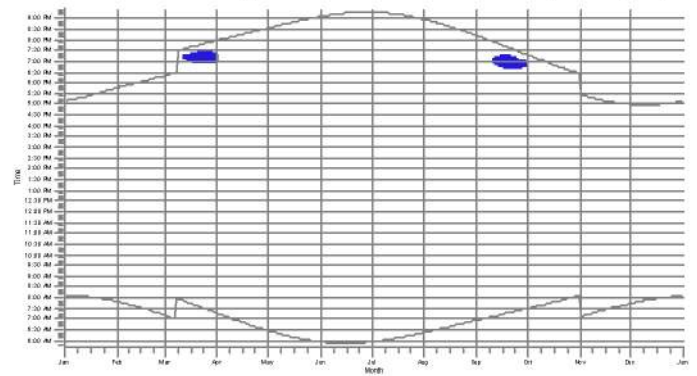
REC-110: Shadow Receptor: 1.0 × 1.0 Azimuth: 0.0° Slope: 0.0° (110)



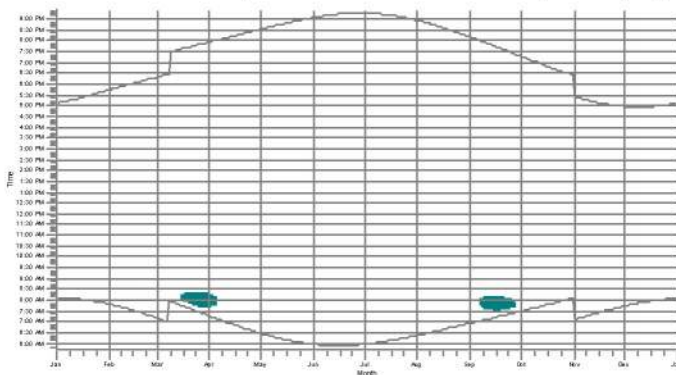
REC-111: Shadow Receptor: 1.0 × 1.0 Azimuth: 0.0° Slope: 0.0° (111)



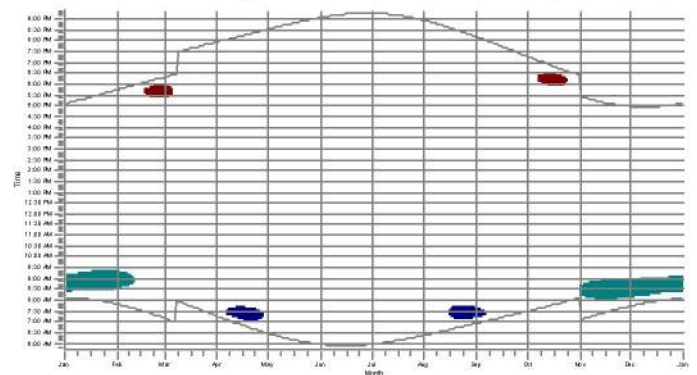
REC-112: Shadow Receptor: 1.0 × 1.0 Azimuth: 0.0° Slope: 0.0° (112)



REC-113: Shadow Receptor: 1.0 × 1.0 Azimuth: 0.0° Slope: 0.0° (113)



REC-114: Shadow Receptor: 1.0 × 1.0 Azimuth: 0.0° Slope: 0.0° (114)



WTGS

1A.06: GE WIND ENERGY GE 3.8-137 3830 137.0 I/OI hub: 111.5 m (TOT: 180.0 m) (294) 1A.07: GE WIND ENERGY GE 3.8-137 3830 137.0 I/OI hub: 111.5 m (TOT: 180.0 m) (295) 1B.08: GE WIND ENERGY GE 3.8-137 3830 137.0 I/OI hub: 111.5 m (TOT: 180.0 m) (296) 1A.34: GE WIND ENERGY GE 3.8-137 3830 137.0 I/OI hub: 111.5 m (TOT: 180.0 m) (224)

Project:  
sPower Shadow Flicker

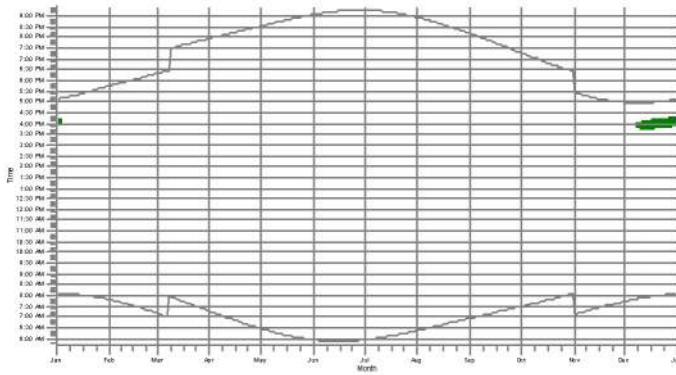
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10/3/2018 3:53 PM/3.0.654

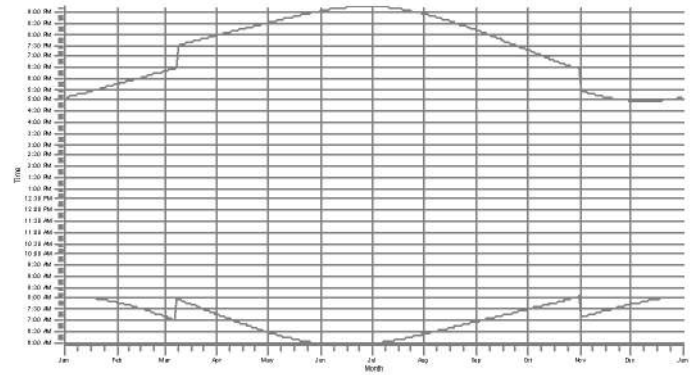
## SHADOW - Calendar, graphical

Calculation: Results.v6.62xGE3.8\_wObstacles\_noMap

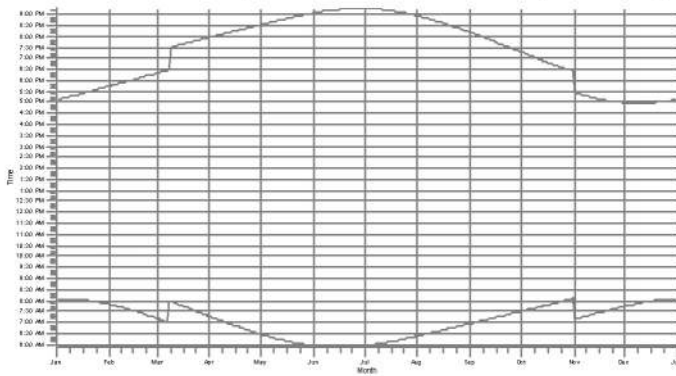
REC-115: Shadow Receptor: 1.0 × 1.0 Azimuth: 0.0° Slope: 0.0° (115)



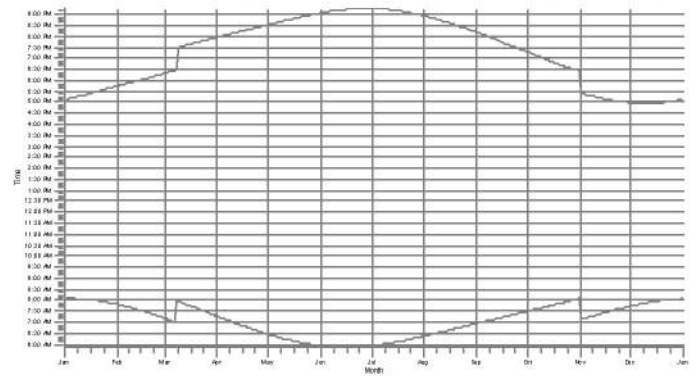
REC-116: Shadow Receptor: 1.0 × 1.0 Azimuth: 0.0° Slope: 0.0° (116)



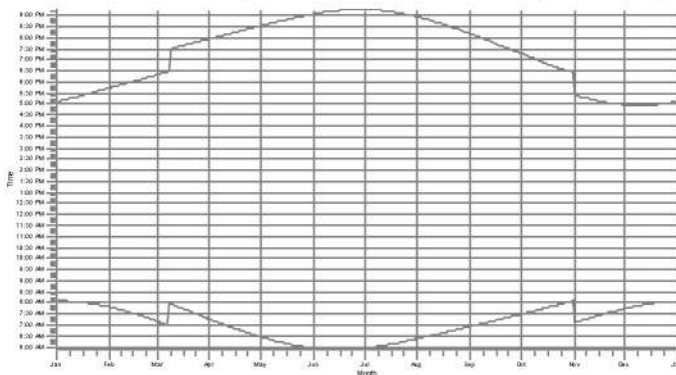
REC-117: Shadow Receptor: 1.0 × 1.0 Azimuth: 0.0° Slope: 0.0° (117)



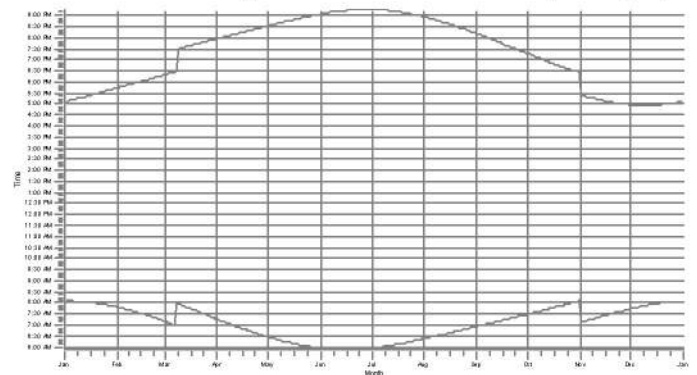
REC-118: Shadow Receptor: 1.0 × 1.0 Azimuth: 0.0° Slope: 0.0° (118)



REC-119: Shadow Receptor: 1.0 × 1.0 Azimuth: 0.0° Slope: 0.0° (119)



REC-120: Shadow Receptor: 1.0 × 1.0 Azimuth: 0.0° Slope: 0.0° (120)



WTGs  
1A.01: GE WIND ENERGY GE 3.8-137 3830 137.0 IOW hub: 111.5 m (TOT: 180.0 m) (289)

Project:  
sPower Shadow Flicker

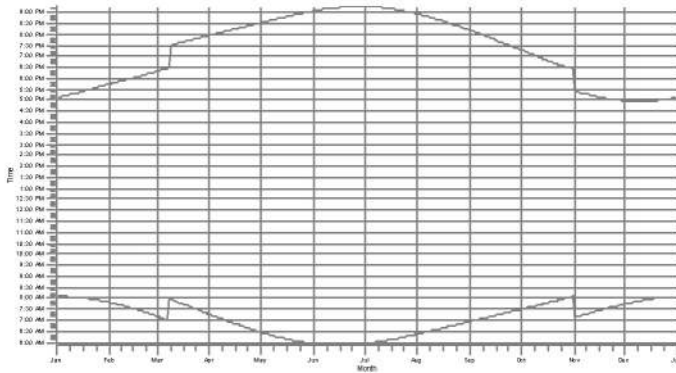
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10/3/2018 3:53 PM/3.0.654

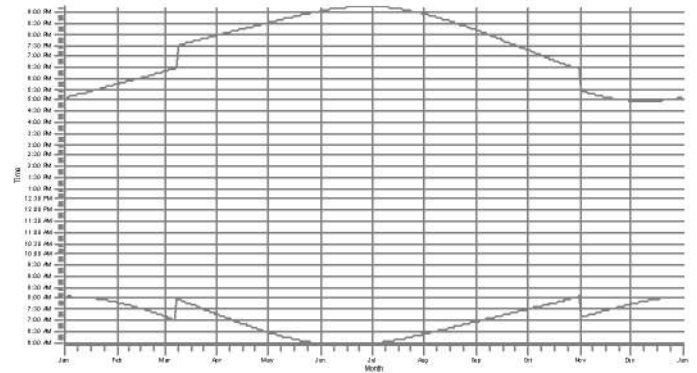
## SHADOW - Calendar, graphical

Calculation: Results.v6.62xGE3.8\_wObstacles\_noMap

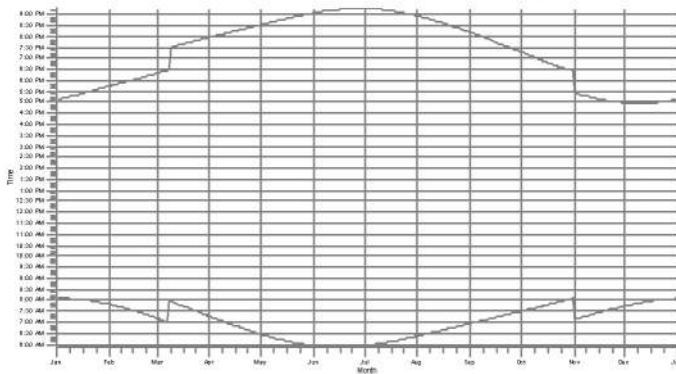
REC-121: Shadow Receptor: 1.0 × 1.0 Azimuth: 0.0° Slope: 0.0° (121)



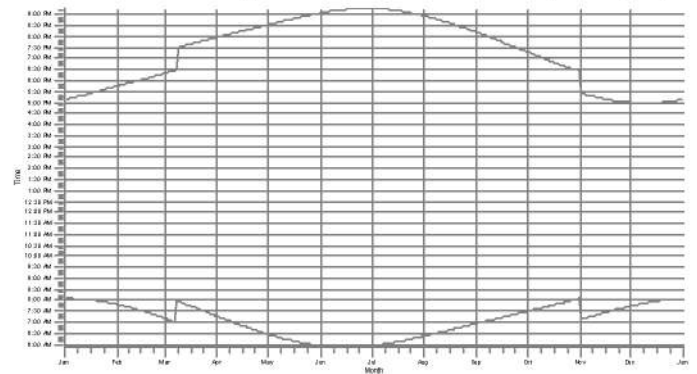
REC-122: Shadow Receptor: 1.0 × 1.0 Azimuth: 0.0° Slope: 0.0° (122)



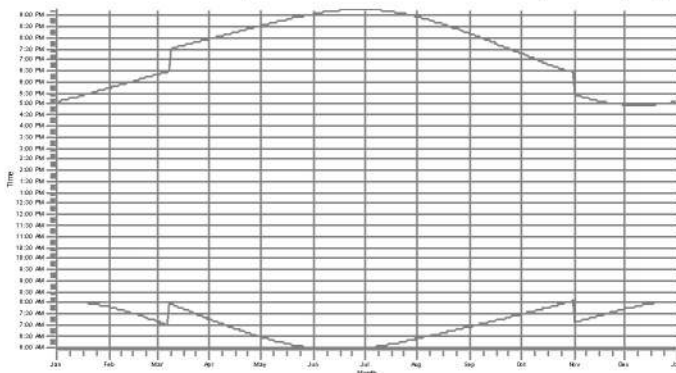
REC-123: Shadow Receptor: 1.0 × 1.0 Azimuth: 0.0° Slope: 0.0° (123)



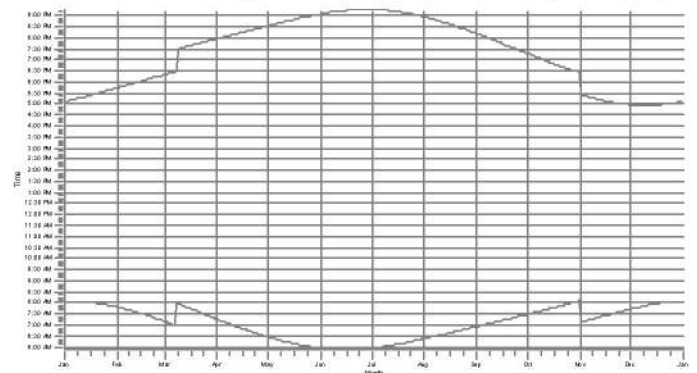
REC-124: Shadow Receptor: 1.0 × 1.0 Azimuth: 0.0° Slope: 0.0° (124)



REC-125: Shadow Receptor: 1.0 × 1.0 Azimuth: 0.0° Slope: 0.0° (125)



REC-126: Shadow Receptor: 1.0 × 1.0 Azimuth: 0.0° Slope: 0.0° (126)



WTGS



Project:  
sPower Shadow Flicker

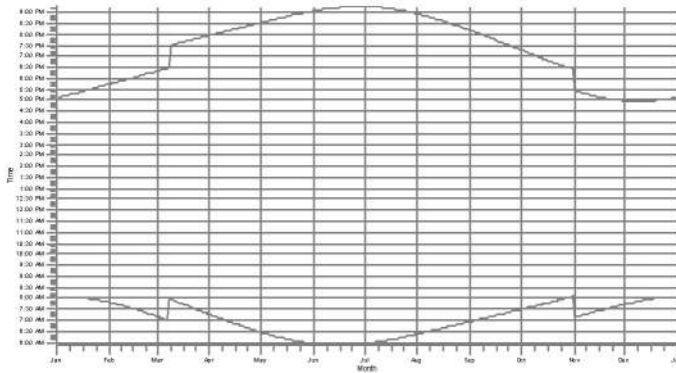
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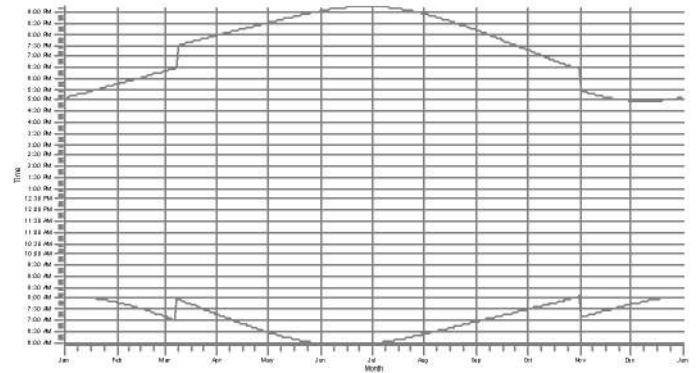
## SHADOW - Calendar, graphical

Calculation: Results.v6.62xGE3.8\_wObstacles\_noMap

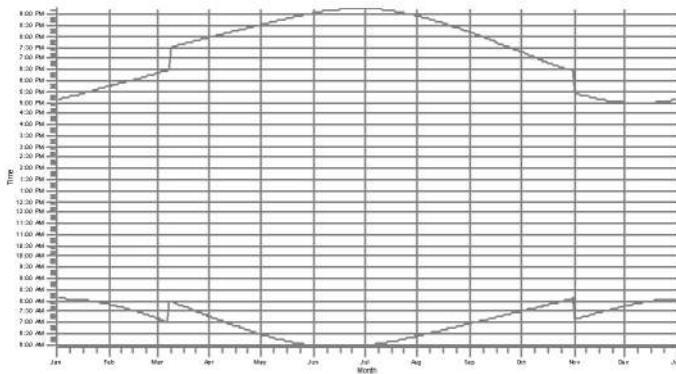
REC-127: Shadow Receptor: 1.0 × 1.0 Azimuth: 0.0° Slope: 0.0° (127)



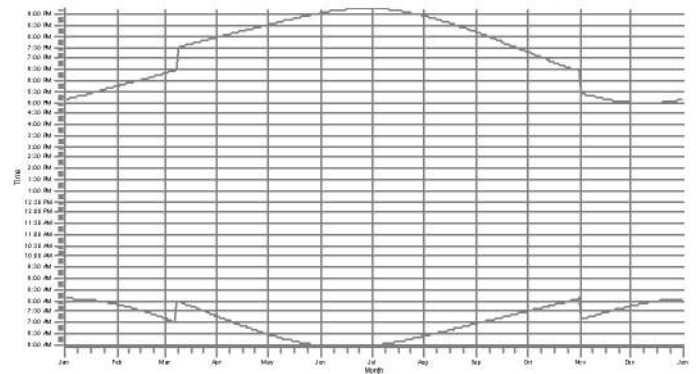
REC-128: Shadow Receptor: 1.0 × 1.0 Azimuth: 0.0° Slope: 0.0° (128)



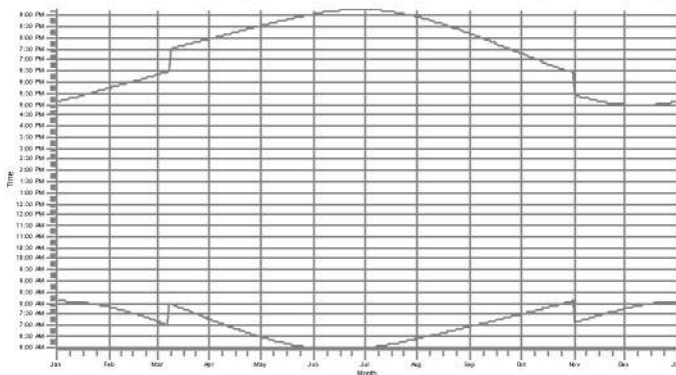
REC-129: Shadow Receptor: 1.0 × 1.0 Azimuth: 0.0° Slope: 0.0° (129)



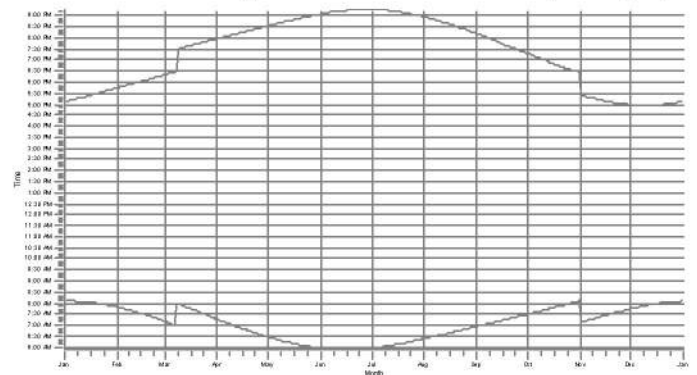
REC-130: Shadow Receptor: 1.0 × 1.0 Azimuth: 0.0° Slope: 0.0° (130)



REC-131: Shadow Receptor: 1.0 × 1.0 Azimuth: 0.0° Slope: 0.0° (131)



REC-132: Shadow Receptor: 1.0 × 1.0 Azimuth: 0.0° Slope: 0.0° (132)



WTGS

Project:  
sPower Shadow Flicker

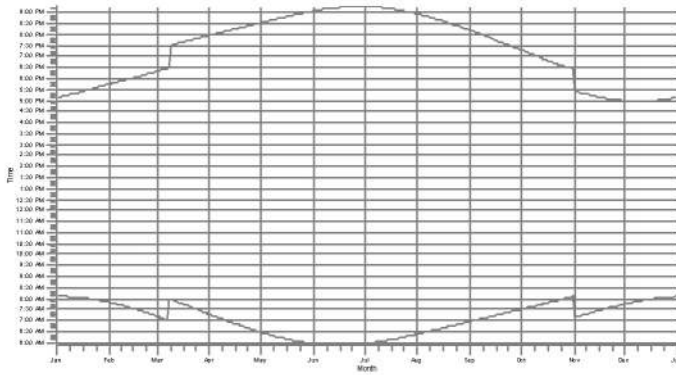
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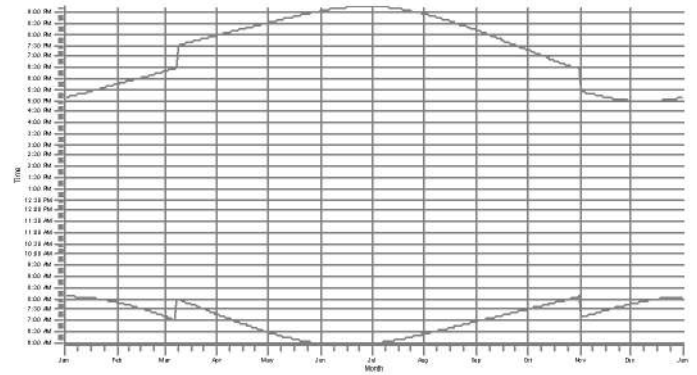
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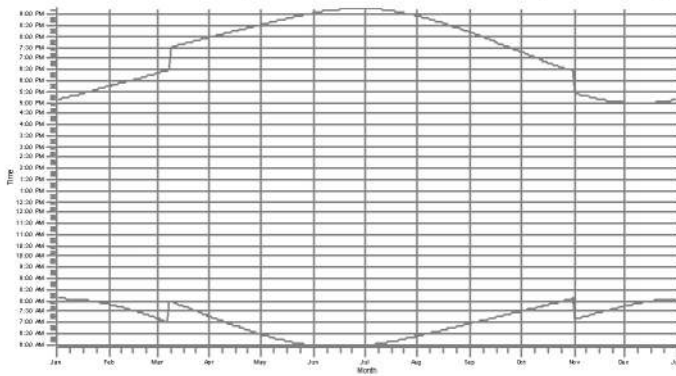
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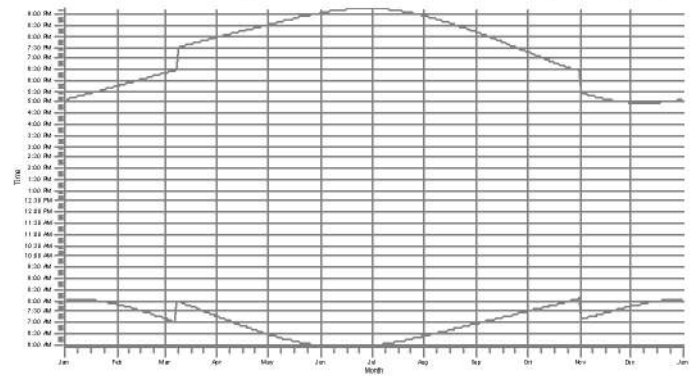
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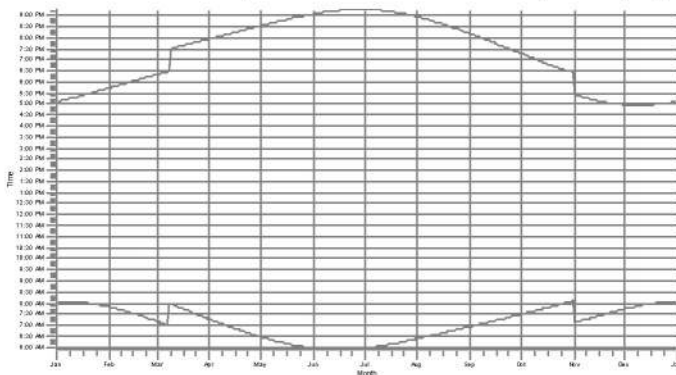
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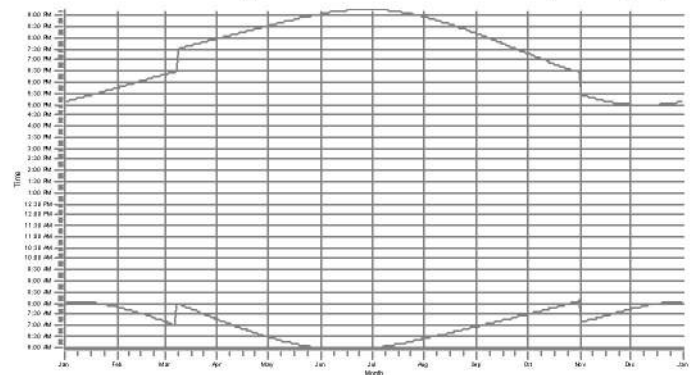
REC-136: Shadow Receptor: 1.0 × 1.0 Azimuth: 0.0° Slope: 0.0° (136)



REC-137: Shadow Receptor: 1.0 × 1.0 Azimuth: 0.0° Slope: 0.0° (137)



REC-138: Shadow Receptor: 1.0 × 1.0 Azimuth: 0.0° Slope: 0.0° (138)



WTGS



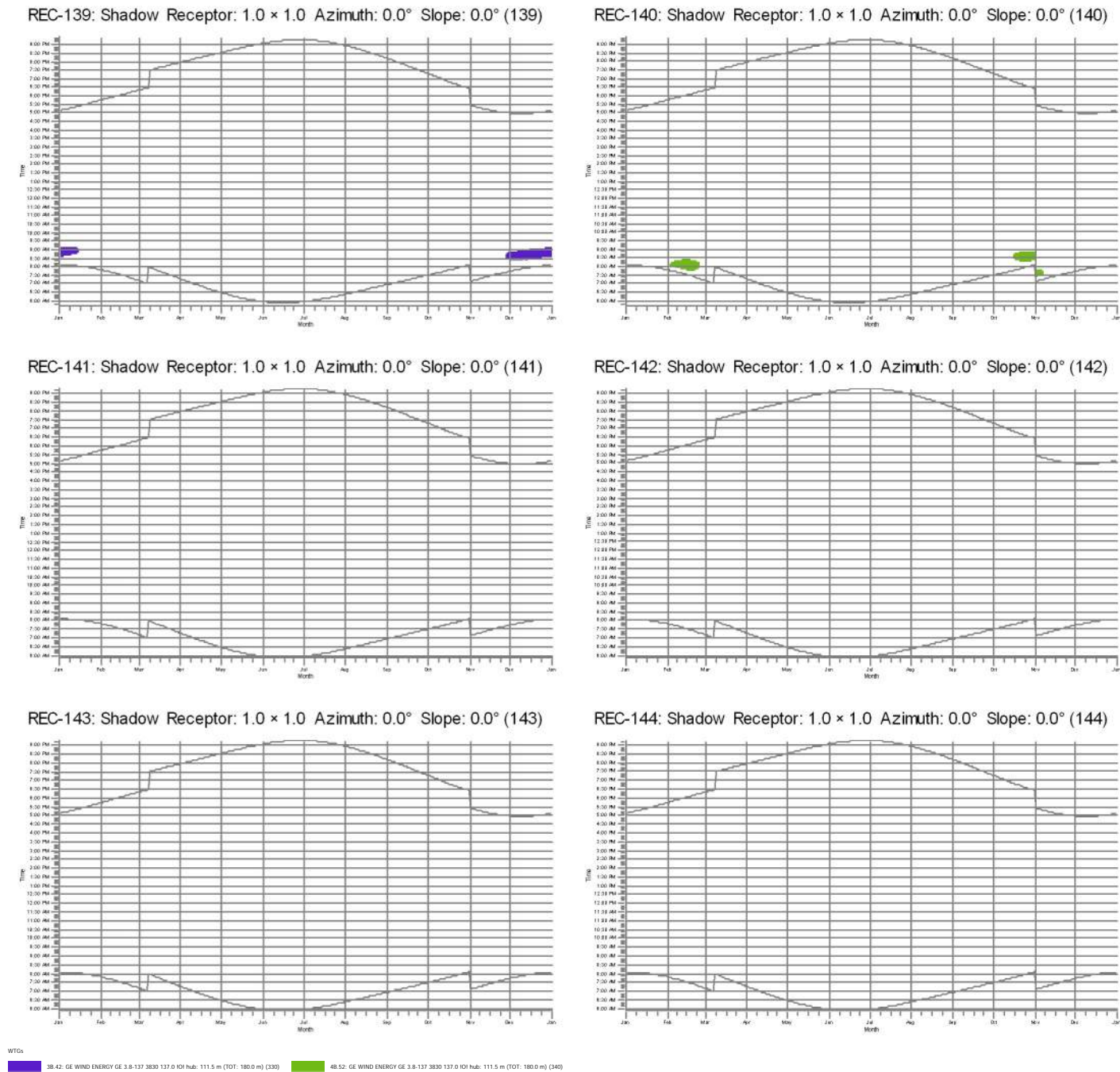
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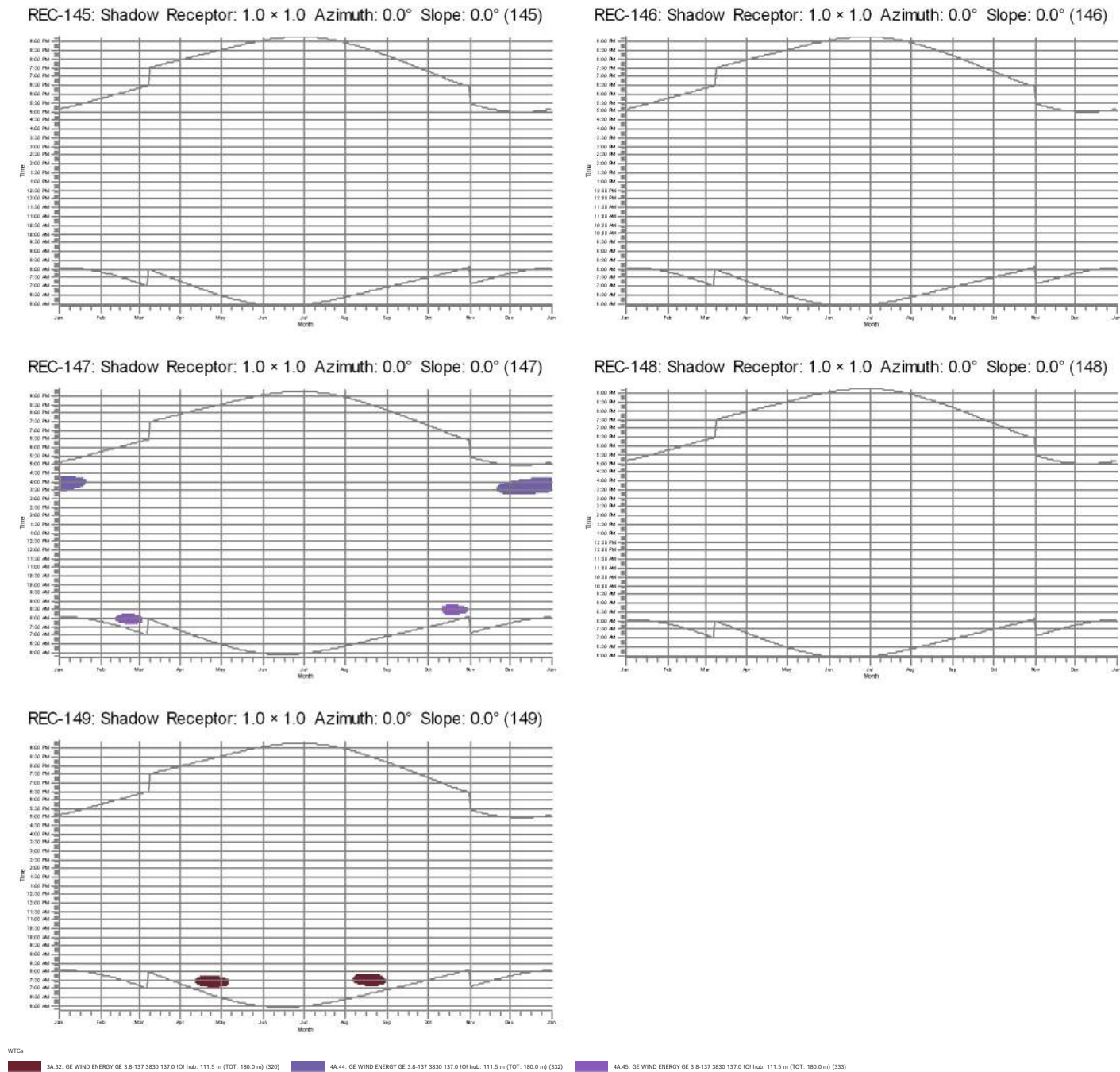
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# Sound Study



## Prevailing Wind Park

### Prevailing Wind Park, LLC

Prevailing Wind Park  
Project No. 105644

Revision 6  
10/05/2018

# **Sound Study**

prepared for

**Prevailing Wind Park, LLC  
Prevailing Wind Park  
Bon Homme/Charles Mix/Hutchinson Counties, SD**

**Project No. 105644**

**Revision 6  
10/05/2018**

prepared by

**Burns & McDonnell Engineering Company, Inc.  
Kansas City, Missouri**

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**TABLE OF CONTENTS**

	<u><b>Page No.</b></u>
<b>1.0 EXECUTIVE SUMMARY .....</b>	<b>1-1</b>
<b>2.0 ACOUSTICAL TERMINOLOGY .....</b>	<b>2-1</b>
<b>3.0 REGULATIONS.....</b>	<b>3-1</b>
<b>4.0 AMBIENT SOUND SURVEY .....</b>	<b>4-1</b>
<b>5.0 SOUND MODELING .....</b>	<b>5-1</b>
5.1 Wind Turbine and Transformer Sound Characteristics.....	5-1
5.2 Model Inputs and Settings .....	5-2
5.2.1 Project Layout .....	5-2
5.2.2 Terrain and Vegetation.....	5-2
5.2.3 Sound Propagation and Directivity .....	5-2
5.2.4 Atmospheric Conditions .....	5-3
5.2.5 Sound Emission Data .....	5-3
5.3 Acoustical Modeling Results .....	5-4
<b>6.0 CONCLUSION.....</b>	<b>6-1</b>
 <b>APPENDIX A - AMBIENT MEASUREMENT DATA</b>	
<b>APPENDIX B - SITE LAYOUT AND RECEIVER LOCATIONS</b>	
<b>APPENDIX C - MODELING RESULTS</b>	
<b>APPENDIX D - SOUND LEVEL CONTOURS</b>	



**LIST OF TABLES****Page No.**

Table 2-1: Typical Sound Pressure Levels Associated with Common Noise Sources.....	2-2
Table 4-1: Ambient Measurements Data.....	4-3
Table 5-1: Wind Turbine Sound Power Levels.....	5-3

**LIST OF FIGURES****Page No.**

Figure 4-1: Measurement Point Locations .....	4-2
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**LIST OF ABBREVIATIONS**

<b><u>Abbreviation</u></b>	<b><u>Term/Phrase/Name</u></b>
ANSI	American National Standards Institute
Burns & McDonnell	Burns & McDonnell Engineering Company, Inc.
CadnaA	Computer Aided Design for Noise Abatement
dB	Decibel
dBA	A-weighted decibels
DEM	Digital Elevation Model
Developer	Prevailing Wind Park, LLC
GE	General Electric
Hz	Hertz
IEC	International Electrotechnical Commission
ISO	International Organization for Standardization
L <sub>90</sub>	the sound level exceeded 90 percent of the time period
L <sub>eq</sub>	equivalent-continuous sound level
LWES	Large Wind Energy System
L <sub>x</sub>	exceedance sound level
MP	measurement point
Project	Prevailing Wind Park
The Act	The Noise Control Act of 1972
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey
WES	Wind Energy System

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**REVISION HISTORY**

<b>Rev</b>	<b>Issue Date</b>	<b>Release Notes</b>
0	03-Apr-2018	Original release
1	09-Apr-2018	Revised wind turbine layout, incorporated client comments
2	11-Apr-2018	Added REC-138
3	16-Apr-2018	Revised wind turbine layout
4	27-Apr-2018	Revised wind turbine layout
5	14-May-2018	Incorporated client comments
6	05-Oct-2018	Revised layout, added new receptors, updated hub height, removed Vestas turbine option

## **1.0 EXECUTIVE SUMMARY**

Prevailing Wind Park, LLC (Developer) is proposing to construct the Prevailing Wind Park near Avon, South Dakota, in Bon Homme, Hutchinson, and Charles Mix Counties (Project). The Project will consist of 60 to 62 wind turbines with a maximum nameplate capacity of up to 219.6 megawatts (MW), although output at the point of interconnection will be limited to a maximum of 200 MW. A total of 62 wind turbine sites were analyzed for the General Electric (GE) 3.8-137 turbine model. This sound assessment was completed to determine if the Project can operate in compliance with the applicable sound regulations.

Burns & McDonnell Engineering Company, Inc. (Burns & McDonnell) conducted an ambient sound survey and sound modeling study for the proposed Project. There were several objectives in this study, which included:

- Identification of any applicable county, city, state, or federal noise ordinances and other applicable sound guidelines;
- Measure ambient sound levels at noise-sensitive receivers;
- Estimation of the operational sound levels from the hypothetical Project layout using the three-dimensional sound modeling program Computer Aided Noise Abatement (CadnaA); and
- Determination if the wind farm can operate in compliance with the identified applicable regulatory standards.

There are no federal or state noise regulations that apply to this Project. Therefore, only local regulations would apply. Bon Homme County has adopted a zoning ordinance that pertains to large wind energy systems (LWES). The ordinance limits “noise levels produced by the LWES to 45 dBA, average A-weighted sound pressure at the perimeter of occupied residences existing at the time the permit application is filed, unless a signed waiver or easement is obtained from the owner of the residence.” Charles Mix County is zoned at the township level and, because no turbines are sited in organized townships, there are no zoning requirements for the Project within Charles Mix County. Hutchinson County has no numeric noise ordinance. Therefore, the Bon Homme County ordinance sound level limit was used as the design goal for all areas of the Project.

The wind turbines were modeled using manufacturer-specified sound power levels. Sound pressure levels were predicted at all identified receivers within and surrounding the Project area. There are no expected exceedances of the identified regulations due to operation of any of the proposed wind turbine locations of the Project.



## **2.0 ACOUSTICAL TERMINOLOGY**

The term “sound level” is often used to describe two different sound characteristics: sound power and sound pressure. Every source that produces sound has a sound power level. The sound power level is the acoustical energy emitted by a sound source and is an absolute number that is not affected by the surrounding environment. The acoustical energy produced by a source propagates through media as pressure fluctuations. These pressure fluctuations, also called sound pressure, are what human ears hear and microphones measure.

Sound is physically characterized by amplitude and frequency. The amplitude of sound is measured in decibels (dB) as the logarithmic ratio of a sound pressure to a reference sound pressure (20 microPascals). The reference sound pressure corresponds to the typical threshold of human hearing. To the average listener, a 3-dB change in a continuous broadband sound is generally considered “just barely perceptible”; a 5-dB change is generally considered “clearly noticeable”; and a 10-dB change is generally considered a doubling (or halving, if the sound is decreasing) of the apparent loudness.

Sound waves can occur at many different wavelengths, also known as the frequency. Frequency is measured in hertz (Hz) and is the number of wave cycles per second that occur. The typical human ear can hear frequencies ranging from approximately 20 to 20,000 Hz. Normally, the human ear is most sensitive to sounds in the middle frequencies (1,000 to 8,000 Hz) and is less sensitive to sounds in the lower and higher frequencies. As such, the A-weighting scale was developed to simulate the frequency response of the human ear to sounds at typical environmental levels. The A-weighting scale emphasizes sounds in the middle frequencies and de-emphasizes sounds in the low and high frequencies. Any sound level to which the A-weighting scale has been applied is expressed in A-weighted decibels, or dBA. For reference, the A-weighted sound pressure level and subjective loudness associated with some common sound sources are listed in Table 2-1.

**Table 2-1: Typical Sound Pressure Levels Associated with Common Noise Sources**

Sound Pressure Level (dBA) <sup>a</sup>	Subjective Evaluation	Environment	
		Outdoor	Indoor
140	Deafening	Jet aircraft at 75 feet	--
130	Threshold of pain	Jet aircraft during takeoff at a distance of 300 feet	--
120	Threshold of feeling	Elevated train	Hard rock band
110		Jet flyover at 1,000 feet	Inside propeller plane
100	Very loud	Power mower, motorcycle at 25 feet, auto horn at 10 feet, crowd noise at football game	--
90	--	Propeller plane flyover at 1,000 feet, noisy urban street	Full symphony or band, food blender, noisy factory
80	Moderately loud	Diesel truck (40 mph) <sup>a</sup> at 50 feet	Inside auto at high speed, garbage disposal
70	Loud	B-757 cabin during flight	Close conversation, vacuum cleaner
60	Moderate	Air-conditioner condenser at 15 feet, near highway traffic	General office
50	Quiet	--	Private office
40	--	Farm field with light breeze, birdcalls	Soft stereo music in residence
30	Very quiet	Quiet residential neighborhood	Bedroom, average residence (without TV and stereo)
20	--	Rustling leaves	Quiet theater, whisper
10	Just audible	--	Human breathing
0	Threshold of hearing	--	--

Source: Adapted from *Architectural Acoustics*, M. David Egan, 1988 and *Architectural Graphic Standards*, Ramsey and Sleeper, 1994.

(a) dBA = A-weighted decibels; mph = miles per hour

Sound metrics have been developed to quantify fluctuating environmental sound levels. These metrics include the exceedance sound level. The exceedance sound level,  $L_x$ , is the sound level exceeded during “x” percent of the sampling period and is also referred to as a statistical sound level.  $L_{90}$  levels are presented throughout this study. The  $L_{90}$  is a common  $L_x$  value and represents the sound level with minimal influence from short-term, loud transient sound sources. The  $L_{90}$  represents the sound level exceeded for 90 percent of the time period during which sound levels are measured. The  $L_{90}$  value is regarded as the most accurate tool for measuring relatively constant background noise and for minimizing the influence of isolated spikes in sound levels (i.e., barking dog, door slamming).

### **3.0 REGULATIONS**

Federal, state, and county regulations were reviewed to determine the applicable overall sound level limits for the Project.

The Noise Control Act of 1972 (the Act) (U.S.C. 4901) mandated a national policy “to promote an environment for all Americans free from noise that jeopardizes their health or welfare, to establish a means for effective coordination of Federal research activities in noise control, to authorize the establishment of Federal noise emission standards for products distributed in commerce, and to provide information to the public respecting the noise emission and noise reduction characteristics of such products.”

As required by the Act, the EPA established criteria for protecting the public health and wellbeing. However, these criteria do not constitute enforceable federal regulations or standards. The EPA has since delegated regulatory authority to local entities. Therefore, there are no federal noise regulations that apply to this Project.

Bon Homme County has adopted a zoning ordinance that pertains to large wind energy systems. The ordinance limits “noise levels produced by the LWES to 45 dBA, average A-weighted sound pressure at the perimeter of occupied residences existing at the time the permit application is filed, unless a signed waiver or easement is obtained from the owner of the residence.” Charles Mix County is zoned at the township level and, because no turbines are sited in organized townships, there are no zoning requirements for the Project within Charles Mix County. Hutchinson County has no numeric noise ordinance. Therefore, the design criteria for the Project is 45 dBA at occupied receptors, unless a signed waiver or easement is obtained from the owner of the residence.

## **4.0 AMBIENT SOUND SURVEY**

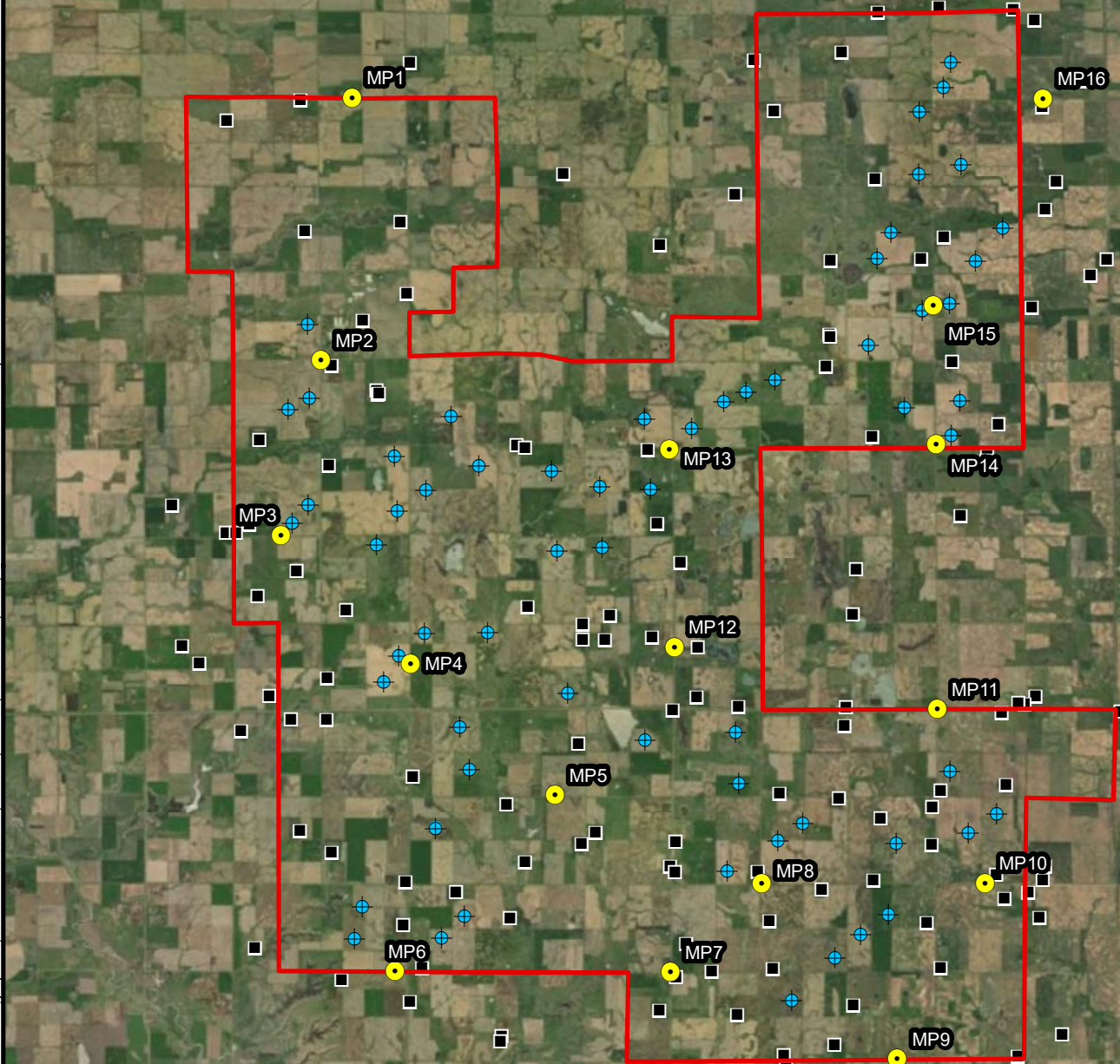
Burns & McDonnell personnel conducted an ambient sound survey of surrounding Project areas on March 12 and 13, 2018.

Measurements were taken using American National Standards Institute (ANSI) S1.4 type 1 sound level meters (Larson David Model 831). The sound level meters were calibrated at the beginning and end of each set of measurements. None of the calibration level changes exceeded  $\pm 0.5$  dB. Windscreens were used at all times on the microphone, and the meters were mounted on tripods. Certificates of calibration for the equipment used are available upon request. The microphones were located approximately 5 feet above ground level with the microphones directed towards the closest proposed wind turbine location and angled per the manufacturer's recommendation. All measurements were taken when meteorological conditions were favorable for conducting ambient sound measurements, per ANSI standards (low wind, moderate temperatures, humidity, and no precipitation).

Ambient far-field measurements were made at 16 locations, labeled measurement point (MP) MP1 through MP16, as shown in Figure 4-1. The measurement points were selected because they were accessible and representative of existing ambient sound levels in the vicinity of noise-sensitive receivers.

The far-field sound level measurements were 5 minutes in duration, and measured values were logged by the sound meter at each measurement point. The sound levels varied at each measurement point due to the extraneous sounds that occurred during the respective measurement. The overall A-weighted  $L_{eq}$  and  $L_{90}$  sound levels collected during the ambient far-field measurements are shown below in Table 4-1. Sound levels measured were in the range of 21.5 dBA to 45.0 dBA  $L_{90}$ .





- Measurement Point
- ⊕ Turbine Location
- Occupied Residence
- Project Area

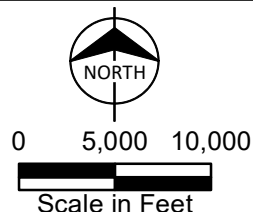


Figure 4-1  
Prevailing Wind Park  
Measurement Point Locations  
**Page 14 of 34**

**Table 4-1: Ambient Measurements Data**

Measurement Location	Sound Pressure Level (dBA)					
	Ambient (5:00 PM on 03/12/18)		Ambient (12:00 AM on 03/13/18)		Ambient (10:00 AM on 03/13/18)	
	L <sub>eq</sub>	L <sub>90</sub>	L <sub>eq</sub>	L <sub>90</sub>	L <sub>eq</sub>	L <sub>90</sub>
MP1	34.6	26.0	40.4	30.0	35.2	25.1
MP2	36.5	29.6	35.7	28.6	39.0	30.2
MP3	37.7	29.2	32.6	22.3	41.0	28.0
MP4	39.6	29.1	33.7	24.3	35.0	28.9
MP5	36.9	28.0	34.6	22.6	35.4	25.4
MP6	47.9	33.4	34.7	26.3	40.0	31.8
MP7	38.3	31.0	30.2	24.0	42.6	37.7
MP8	34.8	28.4	28.6	22.7	47.7	27.9
MP9	35.7	27.0	35.3	29.5	33.2	24.4
MP10	37.4	30.6	39.4	35.2	35.0	27.1
MP11	62.7	45.0	35.6	31.6	69.1	28.1
MP12	39.5	32.6	37.1	21.5	40.6	29.4
MP13	36.3	27.1	38.9	32.1	59.5	28.4
MP14	35.7	28.8	34.1	27.4	35.1	28.9
MP15	33.8	28.4	35.7	28.7	35.0	29.3
MP16	49.8	36.9	39.0	29.8	35.0	28.8

Extraneous sounds during the measurement periods included high speed traffic, birds, wind noise, and farm equipment. The measured sound levels and noise sources are presented in Appendix A.



## **5.0 SOUND MODELING**

### **5.1 Wind Turbine and Transformer Sound Characteristics**

The sound commonly associated with a wind turbine is described as a rhythmic “whoosh” caused by aerodynamic processes. This sound is created as air flow interacts with the surface of rotor blades. As air flows over the rotor blade, turbulent eddies form in the surface boundary layer and wake of the blade. These eddies are where most of the “whooshing” sound is formed. Additional sound is generated from vortex shedding produced by the tip of the rotor blade. Air flowing past the rotor tip creates alternating low-pressure vortices on the downstream side of the tip, causing sound generation to occur. Older wind turbines, built with rotors which operate downwind of the tower (downwind turbines), often have higher aerodynamic impulse sound levels. This is caused by the interaction between the aerodynamic lift created on the rotor blades and the turbulent wake vortices produced by the tower. Modern wind turbine rotors are mostly built to operate upwind of the tower (upwind turbines). Upwind wind turbines are not impacted by wake vortices generated by the tower and, therefore, overall sound levels can be as much as 10 dBA less. The rhythmic fluctuations of the overall sound level are less perceivable the farther one gets from the turbine. Additionally, multiple turbines operating at the same time will create the whooshing sound at different times. These non-synchronized sounds will blend together to create a more constant sound to an observer at most distances from the turbines. Another phenomenon that reduces perceivable noise from turbines is the wind itself. Higher wind speed produces noise in itself that tends to mask (or drown out) the sounds created by wind turbines.

Advancement in wind turbine technology has reduced pure tonal emissions of modern wind turbines. Manufacturers have reduced distinct tonal sounds by reshaping turbine blades and adjusting the angle at which air contacts the blade. Pitching technology allows the angle of the blade to adjust when the maximum rotational speed is achieved, which allows the turbine to maintain a constant rotational velocity. Therefore, sound emission levels remain constant as the velocity remains the same.

Wind turbines can create noise in other ways as well. Wind turbines have a nacelle where the mechanical portions of the turbine are housed. The current generation of wind turbines uses multiple techniques to reduce the noise from this portion of the turbine: vibration isolating mounts, special gears, and acoustic insulation. In general, all moving parts and the housing of the current generation wind turbines have been designed to minimize the noise they generate.

## **5.2 Model Inputs and Settings**

Predicted sound levels were modeled using industry-accepted sound modeling software. The program used to model the turbines was the CadnaA, Version 2018, published by DataKustik, Ltd., Munich, Germany. The CadnaA program is a scaled, three-dimensional program that accounts for air absorption, terrain, ground absorption, and ground reflection for each piece of noise-emitting equipment and predicts downwind sound pressure levels. The model calculates sound propagation based on International Organization for Standardization (ISO) 9613-2:1996, General Method of Calculation. ISO 9613, and therefore CadnaA, assesses the sound pressure levels based on the Octave Band Center Frequency range from 31.5 to 8,000 Hz. Compliance with the regulations for all turbines operating should equate to compliance for any combination of the turbines operating.

### **5.2.1 Project Layout**

Prevailing Wind's hypothetical layout contains 62 wind turbine sites, including alternatives. Predictive modeling was conducted to determine the impacts at the occupied residences shown in the Project layout figure included in Appendix B.

### **5.2.2 Terrain and Vegetation**

Terrain and attenuation from ground absorption can have a significant impact on sound transmission. U.S. Geological Survey (USGS) Digital Elevation Model (DEM) contours were imported into the model to account for topographic variations around the Project. The contours were overlaid onto high resolution, digital orthoimagery obtained from the U.S. Department of Agriculture (USDA). The terrain around the proposed Project is mostly rural with few minor changes in elevation. The land is primarily used for agricultural purposes. As such, vegetation is mostly low-lying with some small areas of trees. Therefore, vegetation was excluded from the analysis to maintain conservativeness in the model. Ground attenuation is expected to be fairly high, due to the "soft ground" of the surrounding areas; however, a conservative value was used in the model.

### **5.2.3 Sound Propagation and Directivity**

CadnaA calculates downwind sound propagation using ISO 9613 standards, which use omnidirectional downwind sound propagation and worst-case directivity factors. In other words, the model assumes that each turbine propagates its maximum sound level in all directions at all times. While this may seem to over-predict upwind sound levels, this approach has been validated by field measurements. Under most normal circumstances, wind turbine noise is not significantly directional, but tends to radiate uniformly in all directions.

### 5.2.4 Atmospheric Conditions

Atmospheric conditions were based on program defaults. Layers in the atmosphere often form where temperature increases with height (temperature inversions). Sound waves can reflect off of the temperature inversion layer and return to the surface of the earth. This process can increase sound levels at the surface, especially if the height of the inversion begins near the surface of the earth. Temperature inversions tend to occur mainly at night when winds are light or calm, usually when wind turbines are not operating. CadnaA calculates the downwind sound in a manner which is favorable for propagation (worst-case scenario) by assuming a well-developed moderate ground-based temperature inversion such as can occur at night. Therefore, predicted sound level results tend to be higher than would actually occur.

The atmosphere does not flow smoothly and tends to have swirls and eddies, also known as turbulence. Turbulence is basically formed by two processes: thermal turbulence and mechanical turbulence. Thermal turbulence is caused by the interaction of heated air rapidly rising from the heated earth's surface, with cooler air descending from the atmosphere. Mechanical turbulence is caused as moving air interacts with objects such as trees, buildings, and wind turbines. Turbulent eddies generated by wind turbines and other objects can cause sound waves to scatter, which in turn, provides sound attenuation between the wind turbine and the receiver. The acoustical model assumes laminar air flow, which minimizes sound attenuation that would occur in a realistic inhomogeneous atmosphere. This assumption also causes the predicted sound levels to be higher than would actually occur.

### 5.2.5 Sound Emission Data

Acoustical modeling was conducted for the entire Project. Wind turbine heights and acoustical emissions were input into the model. The expected worst-case sound power levels for the GE 3.8-137 turbines were contained in documents provided by GE and were based on various wind speeds. The sound emissions data supplied was developed using the International Electrotechnical Commission (IEC) 61400-11 acoustic measurement standards. The expected sound power level and modeled heights for the turbines are displayed in Table 5-1.

**Table 5-1: Wind Turbine Sound Power Levels**

Turbine	Height	Sound Power Level (dBA)									
		31.5	63	125	250	500	1000	2000	4000	8000	A-wt. <sup>a</sup>
GE 3.8-137	111.5 m	78.5	86.8	92.6	96.4	99.4	102.1	102.0	93.7	79.2	<b>107.0</b>

(a) A-wt. = A-weighted decibels

A point source at the hub was used to model sound emissions from the wind turbines. This approach is appropriate for simulating wind turbine noise emissions due to the large distances between the turbines and the receivers as compared to the dimensions of the wind turbines. The corresponding sound levels from the table above were applied to every point source.

Figure 4-1 shows the entire wind farm layout. Locations of receivers and wind turbines around the Project area were provided by the developer and are shown in Appendix B. Each receiver was assumed to have a height of 1.52 meters (5.0 feet) above ground level. Compliance with the regulation was assessed at the physical residence (each receiver).

The following assumptions were made to maintain the inherent conservativeness of the model and to estimate the worst case modeled sound levels:

- Attenuation was not included for sound propagation through wooded areas, existing barriers, and shielding
- All turbines were assumed to be operating at maximum power output (and therefore, maximum sound levels) at all times to represent worst-case noise impacts from the wind farm as a whole

### **5.3 Acoustical Modeling Results**

Sound pressure levels were predicted for the identified receivers in the CadnaA noise modeling software using the manufacturer-specified sound power levels at each frequency and the assumptions listed above. CadnaA modeling results have been demonstrated in previous studies to conservatively approximate real-life measured noise from a source when extraneous noises are not present.

As previously mentioned, decibels are a logarithmic ratio of a sound pressure to a reference sound pressure. Therefore, they must be logarithmically added to determine a cumulative impact (i.e., logarithmically adding 50 dBA and 50 dBA results in 53 dBA). Logarithmically adding each of the individual turbine's impacts together at each receiver provides an overall Project impact at each receiver.

The maximum model-predicted  $L_{eq}$  sound pressure levels at each receiver (the logarithmic addition of sound levels from each frequency from every turbine) are included in Appendix C. These values represent only the noise emitted by the wind turbines and do not include any extraneous noises (traffic, etc.) that could be present during physical noise measurements. There are no expected exceedances of the identified regulations due to operation of any of the proposed wind turbine locations of the Project. Extraneous sounds (grain dryers, traffic, etc.) may make the overall sound level higher than 45.0 dBA in some circumstances, but the turbines alone are not expected to cause that to happen.

Appendix D contains graphical representation of the Project's impact on the surrounding area for the GE turbines. The figure depicts the sound level propagation attributable to the new turbines.

## **6.0 CONCLUSION**

Burns & McDonnell conducted a predictive sound assessment study for the proposed Prevailing Wind Park. The study included identification of applicable sound regulations and predictive modeling to estimate Project-related sound levels in the surrounding community.

Sound pressure levels were predicted at occupied receivers within and surrounding the Project area using manufacturer-specified sound power levels for each wind turbine. A number of conservative assumptions were applied to provide worst-case predicted sound pressure levels. Those results were then compared to the identified applicable regulations. There are no expected exceedances of the identified regulations due to operation of any of the proposed wind turbine locations of the Project.



**APPENDIX A - AMBIENT MEASUREMENT DATA**

## Appendix A - Ambient Measurement Data

Prevailing Winds

<i>Point Number</i>	<i>LAeq</i>	<i>LA90</i>	<i>Notes</i>
<b>03/12/18 - 5:00PM to 7:00PM</b>			<b>Meter1 Calibration before: 114.11      Meter2 Calibration before: 114.05</b>
<b>36°F, 60% hm, 31°F dp, 4-9mph , clear skies</b>			<b>Meter1 Calibration after: 113.91      Meter2 Calibration after: 113.91</b>
MP1	34.6 dBA	26.0 dBA	Distant traffic, light wind, existing wind farm not audible
MP2	36.5 dBA	29.6 dBA	Distant traffic, birds, light wind, fan noise from nearby business
MP3	37.7 dBA	29.2 dBA	Birds, light wind, distant traffic including large trucks, very distant airplane
MP4	39.6 dBA	29.1 dBA	Birds, light wind, distant traffic
MP5	36.9 dBA	28.0 dBA	Highway traffic, birds
MP6	47.9 dBA	33.4 dBA	Highway traffic dominant, paused for local traffic
MP7	38.3 dBA	31.0 dBA	Highway traffic, birds
MP8	34.8 dBA	28.4 dBA	Birds, distant high speed traffic
MP9	35.7 dBA	27.0 dBA	Nearby high speed traffic (409th Street), birds
MP10	37.4 dBA	30.6 dBA	Distant high speed traffic, birds, horns
MP11	62.7 dBA	45.0 dBA	Birds dominant, two high speed car passbys
MP12	39.5 dBA	32.6 dBA	Birds, farm equipment, slight wind
MP13	36.3 dBA	27.1 dBA	Slight wind
MP14	35.7 dBA	28.8 dBA	Slight wind, distant high speed traffic
MP15	33.8 dBA	28.4 dBA	Slight wind, distant birds, distant high speed traffic, backup alarm
MP16	49.8 dBA	36.9 dBA	Birds dominant, slight wind

## Appendix A - Ambient Measurement Data

Prevailing Winds

<i>Point Number</i>	<i>LAeq</i>	<i>LA90</i>	<i>Notes</i>
<b>03/13/18 - 12:00AM to 2:00AM</b>			<b>Meter1 Calibration before: 114.19    Meter2 Calibration before: 113.87</b>
<b>29°F, 74% hm, 21°F dp, 6-9 mph , clear skies</b>			<b>Meter1 Calibration after: 113.83    Meter2 Calibration after: 114.20</b>
MP1	40.4 dBA	30.0 dBA	Wind turbines audible, light winds
MP2	35.7 dBA	28.6 dBA	Wind turbines audible, light winds, sheep noise
MP3	32.6 dBA	22.3 dBA	Very quiet, faint traffic
MP4	33.7 dBA	24.3 dBA	Very quiet, faint traffic
MP5	34.6 dBA	22.6 dBA	Distant traffic, large trucks, bull snort
MP6	34.7 dBA	26.3 dBA	Traffic
MP7	30.2 dBA	24.0 dBA	Traffic
MP8	28.6 dBA	22.7 dBA	Distant high speed traffic
MP9	35.3 dBA	29.5 dBA	Distant high speed traffic
MP10	39.4 dBA	35.2 dBA	Slight wind
MP11	35.6 dBA	31.6 dBA	Slight wind
MP12	37.1 dBA	21.5 dBA	Distant high speed traffic
MP13	38.9 dBA	32.1 dBA	Slight wind
MP14	34.1 dBA	27.4 dBA	Slight wind
MP15	35.7 dBA	28.7 dBA	Slight wind, distant high speed traffic
MP16	39.0 dBA	29.8 dBA	Distant high speed traffic

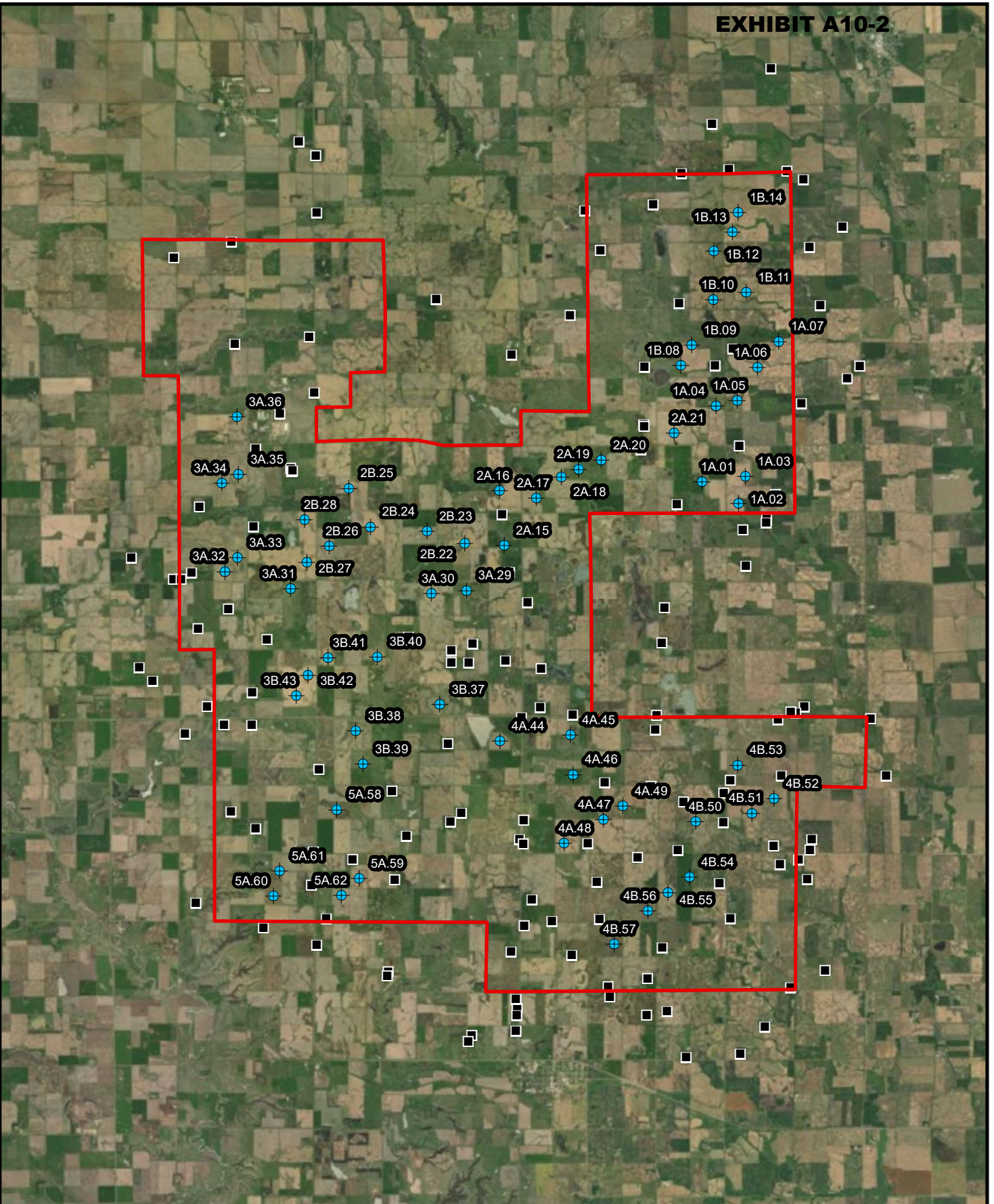
## Appendix A - Ambient Measurement Data







Prevailing Winds

<i>Point Number</i>	<i>LAeq</i>	<i>LA90</i>	<i>Notes</i>
<b>03/13/18 - 10:00AM to 12:00PM</b>			<b>Meter1 Calibration before: 114.24    Meter2 Calibration before: 114.04</b>
<b>30°F, 62% hm, 19°F dp, 3-4 mph , clear skies</b>			<b>Meter1 Calibration after: 113.82    Meter2 Calibration after: 113.97</b>
MP1	35.2 dBA	25.1 dBA	Distant traffic, distant plane, wind turbines barely audible
MP2	39.0 dBA	30.2 dBA	Birds, wind turbines barely audible, tractor distant loading/unloading Birds,
MP3	41.0 dBA	28.0 dBA	distant traffic, wind
MP4	35.0 dBA	28.9 dBA	Birds, distant traffic, wind, distant airplane
MP5	35.4 dBA	25.4 dBA	Birds, wind, distant traffic
MP6	40.0 dBA	31.8 dBA	Birds, highway traffic
MP7	42.6 dBA	37.7 dBA	Birds, distant traffic, paused for local traffic
MP8	47.7 dBA	27.9 dBA	Owl, birds, distant high speed traffic, woman speaking (very end) Birds
MP9	33.2 dBA	24.4 dBA	Birds, dog barking, distant high speed traffic
MP10	35.0 dBA	27.1 dBA	High speed car passing
MP11	69.1 dBA	28.1 dBA	Farm equipment, cows
MP12	40.6 dBA	29.4 dBA	Birds, one car passing
MP13	59.5 dBA	28.4 dBA	Distant constant high speed traffic, birds
MP14	35.1 dBA	28.9 dBA	Birds, distant high speed traffic
MP15	35.0 dBA	29.3 dBA	Distant birds, distant high speed traffic
MP16	35.0 dBA	28.8 dBA	

**APPENDIX B - SITE LAYOUT AND RECEIVER LOCATIONS**

Path: Z:\Clients\BTS\PowerDC\105644\_PrvWindStudies\Studies\Permitting\Modeling\Noise\GIS\Figure B-1 - Project Layout V6.mxd gweger 10/2/2018  
 COPYRIGHT © 2018 BURNS & McDONNELL ENGINEERING COMPANY, INC.  
 Service Layer Credits: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community



<ul style="list-style-type: none"> <li> Turbine Location</li> <li> Occupied Residence</li> <li> Project Area</li> </ul> <div style="text-align: center;">               0 5,000 10,000                Scale in Feet         </div>		<p style="text-align: center;">Figure B-1</p> <p style="text-align: center;">Prevailing Wind Park Project Layout</p> <p style="text-align: center;"><b>Page 27 of 34</b></p>
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**APPENDIX C - MODELING RESULTS**

## Appendix C - Modeling Results

All Turbines: GE 3.8-137, 111.5 m hub height

Receiver	Participating/Non-Participating	Coordinates		Base Elevation (m)	Modeled		Exceed 45 dBA? (Y/N)
		Easting (m)	Northing (m)		LAeq <sup>A</sup>	Limit Value	
REC-001	Non-participating	583178.93	4781949.36	473.94	24.7	45	N
REC-002	Participating	578731.00	4782428.97	540.99	29.1	45	N
REC-003	Non-participating	580506.89	4783273.92	505.27	33.7	45	N
REC-004	Non-participating	582678.66	4780104.52	480.03	32.4	45	N
REC-005	Non-participating	583326.78	4778396.84	476.81	27.5	45	N
REC-006	Non-participating	583615.28	4778695.43	471.94	26.2	45	N
REC-007	Non-participating	579386.45	4783171.84	519.65	29.7	45	N
REC-008	Non-participating	579364.54	4780122.78	515.18	38.2	45	N
REC-009	Non-participating	582485.70	4779597.03	481.47	35.1	45	N
REC-010	Non-participating	570706.40	4779232.69	531.85	20.3	45	N
REC-011	Non-participating	568954.92	4779049.93	516.88	23.1	45	N
REC-012	Non-participating	575450.96	4778869.67	571.47	-	45	N
REC-013	Non-participating	570834.43	4777923.92	539.22	27.4	45	N
REC-014	Non-participating	578568.31	4777265.47	526.35	38.1	45	N
REC-015	Non-participating	578578.94	4777228.45	526.13	38.3	45	N
REC-016	Participating	569437.95	4774776.35	523.53	38.9	45	N
REC-017	Non-participating	567999.72	4773683.50	489.60	36.8	45	N
REC-018	Participating	575893.85	4773069.05	525.25	32.6	45	N
REC-019	Participating	568870.35	4772837.61	510.51	36.3	45	N
REC-020	Non-participating	568170.58	4772373.09	491.63	30.5	45	N
REC-021	Participating	574122.73	4771641.66	507.46	34.8	45	N
REC-022	Non-participating	574117.98	4771913.43	508.31	34.5	45	N
REC-023	Non-participating	567115.19	4771132.04	470.89	-	45	N
REC-024	Non-participating	569455.79	4770885.60	499.55	34.2	45	N
REC-025	Participating	582409.59	4770691.28	486.10	26.3	45	N
REC-026	Non-participating	582205.90	4770538.43	489.18	27.7	45	N
REC-027	Non-participating	569450.78	4770122.57	499.25	32.0	45	N
REC-028	Participating	578915.96	4770106.59	519.65	30.5	45	N
REC-029	Non-participating	567890.47	4769896.98	472.42	19.1	45	N
REC-030	Non-participating	574057.84	4769738.20	530.58	35.3	45	N
REC-031	Non-participating	571038.40	4769099.63	510.51	36.6	45	N
REC-032	Participating	579594.58	4768433.69	507.46	40.2	45	N
REC-033	Non-participating	574388.42	4768112.11	502.26	28.9	45	N
REC-034	Non-participating	575856.91	4767968.51	509.35	34.0	45	N
REC-035	Non-participating	568988.11	4768088.17	487.50	27.6	45	N
REC-036	Non-participating	574139.54	4767903.27	507.06	28.0	45	N
REC-037	Participating	580534.75	4767955.77	497.42	40.6	45	N
REC-038	Non-participating	569570.52	4767693.73	493.87	33.1	45	N
REC-039	Non-participating	575753.59	4767511.52	511.25	33.3	45	N
REC-040	Non-participating	575853.92	4767408.85	513.56	34.2	45	N
REC-041	Participating	577365.54	4767429.45	496.85	41.4	45	N
REC-042	Non-participating	580534.93	4768649.62	501.93	40.0	45	N
REC-043	Non-participating	582314.18	4767105.01	476.98	30.8	45	N
REC-044	Participating	577581.91	4766535.38	501.37	35.6	45	N
REC-045	Participating	580459.53	4766528.35	495.27	37.9	45	N
REC-046	Participating	570892.00	4766384.10	500.34	39.9	45	N
REC-047	Non-participating	576071.91	4766099.10	511.58	28.5	45	N
REC-048	Non-participating	575888.47	4765484.03	507.46	26.2	45	N
REC-049	Non-participating	579136.06	4765003.57	501.37	36.3	45	N
REC-050	Participating	575594.26	4764877.78	513.56	22.9	45	N
REC-051	Participating	577014.96	4764806.12	483.08	32.7	45	N
REC-052	Non-participating	571034.71	4764976.49	483.08	32.4	45	N
REC-053	Non-participating	575751.76	4763553.72	504.89	18.1	45	N
REC-054	Non-participating	579261.02	4763508.83	493.92	26.2	45	N
REC-055	Non-participating	575738.19	4763383.18	501.37	18.7	45	N
REC-056	Non-participating	578784.40	4763423.45	495.27	26.7	45	N
REC-057	Non-participating	575728.70	4763020.56	496.19	-	45	N
REC-058	Non-participating	574689.98	4762905.51	489.18	-	45	N
REC-059	Non-participating	574608.88	4762765.31	484.23	-	45	N
REC-060	Non-participating	575719.36	4763758.78	507.46	19.6	45	N
REC-061	Non-participating	566590.17	4774005.26	470.89	25.5	45	N
REC-062	Non-participating	566794.52	4771446.01	467.84	-	45	N
REC-063	Non-participating	567575.59	4773523.26	480.49	32.1	45	N
REC-064	Non-participating	568169.85	4775221.75	493.83	37.4	45	N
REC-065	Non-participating	568402.45	4770548.21	483.08	24.8	45	N

## Appendix C - Modeling Results

All Turbines: GE 3.8-137, 111.5 m hub height

Receiver	Participating/Non-Participating	Coordinates		Base Elevation (m)	Modeled		Exceed 45 dBA? (Y/N)
		Easting (m)	Northing (m)		LAeq <sup>A</sup>	Limit Value	
REC-066	Participating	569474.73	4776605.15	525.75	39.0	45	N
REC-067	Non-participating	569782.41	4765373.88	493.98	36.0	45	N
REC-068	Non-participating	570301.18	4776152.11	533.82	35.8	45	N
REC-069	Non-participating	570320.63	4776086.07	530.62	36.0	45	N
REC-070	Non-participating	570930.65	4767169.47	502.79	37.7	45	N
REC-071	Non-participating	571246.87	4765598.42	488.81	38.5	45	N
REC-072	Participating	571847.73	4767001.23	507.46	41.7	45	N
REC-073	Non-participating	572712.41	4764371.30	476.98	25.2	45	N
REC-074	Non-participating	572760.45	4768609.65	494.96	35.3	45	N
REC-075	Participating	572875.14	4775183.93	528.80	39.1	45	N
REC-076	Non-participating	573023.77	4775137.74	528.80	39.6	45	N
REC-077	Non-participating	573104.39	4767558.79	488.61	31.1	45	N
REC-078	Non-participating	572689.83	4764269.58	472.84	24.7	45	N
REC-079	Participating	572840.24	4766532.05	483.08	35.8	45	N
REC-080	Participating	574527.24	4771635.20	508.86	33.6	45	N
REC-081	Participating	574606.23	4772084.46	513.56	33.9	45	N
REC-082	Participating	575265.41	4775117.32	552.59	41.9	45	N
REC-083	Participating	575384.42	4771695.61	513.56	33.8	45	N
REC-084	Participating	575459.57	4773771.95	533.47	39.3	45	N
REC-085	Participating	576210.31	4770611.18	524.57	35.1	45	N
REC-086	Participating	576537.52	4765598.06	498.89	30.2	45	N
REC-087	Participating	576971.43	4770447.24	531.85	40.6	45	N
REC-088	Participating	577659.69	4765661.22	489.18	38.1	45	N
REC-089	Participating	577747.37	4768859.92	513.80	40.5	45	N
REC-090	Non-participating	577878.24	4764078.53	490.80	32.8	45	N
REC-091	Non-participating	577915.85	4763844.06	489.18	30.5	45	N
REC-092	Participating	578531.67	4767119.28	501.56	37.6	45	N
REC-093	Participating	578575.67	4778618.52	525.75	36.7	45	N
REC-094	Participating	578514.65	4776677.36	519.65	37.9	45	N
REC-095	Non-participating	578804.05	4764274.93	501.37	32.8	45	N
REC-096	Non-participating	578827.98	4768793.31	520.74	37.4	45	N
REC-097	Non-participating	578943.49	4770454.51	519.65	29.0	45	N
REC-098	Non-participating	579475.34	4767289.07	507.32	40.3	45	N
REC-099	Participating	579720.64	4762441.83	480.38	-	45	N
REC-100	Non-participating	580720.17	4765706.10	489.18	32.2	45	N
REC-101	Non-participating	580991.94	4762540.89	476.98	-	45	N
REC-102	Non-participating	581560.41	4763175.20	470.14	-	45	N
REC-103	Participating	581721.12	4767420.32	484.05	35.9	45	N
REC-104	Non-participating	581794.35	4770381.50	494.21	30.1	45	N
REC-105	Non-participating	581890.50	4769063.10	495.27	40.1	45	N
REC-106	Participating	581882.94	4766984.50	478.66	32.1	45	N
REC-107	Non-participating	582089.90	4770568.08	488.75	27.9	45	N
REC-108	Participating	582148.44	4764102.27	470.89	-	45	N
REC-109	Non-participating	582609.65	4767582.94	483.08	31.6	45	N
REC-110	Non-participating	583963.39	4770430.23	460.42	18.2	45	N
REC-111	Non-participating	582577.80	4767332.36	480.99	30.7	45	N
REC-112	Non-participating	570034.28	4777428.88	531.85	33.7	45	N
REC-113	Participating	580225.65	4778670.25	516.61	41.3	45	N
REC-114	Participating	580643.69	4779065.86	510.51	40.5	45	N
REC-115	Participating	580812.98	4776797.89	507.54	39.5	45	N
REC-116	Participating	581676.22	4775653.66	495.49	37.4	45	N
REC-117	Participating	579367.75	4775404.23	525.75	36.8	45	N
REC-118	Non-participating	580095.28	4784336.60	507.46	25.3	45	N
REC-119	Non-participating	581867.73	4783246.46	489.52	29.7	45	N
REC-120	Non-participating	582410.57	4781467.20	486.13	30.9	45	N
REC-121	Non-participating	582256.16	4783054.99	483.20	28.4	45	N
REC-122	Participating	582261.38	4777793.15	487.45	33.8	45	N
REC-123	Non-participating	581460.71	4785645.95	483.97	-	45	N
REC-124	Non-participating	577505.30	4781336.06	557.16	19.3	45	N
REC-125	Non-participating	580995.88	4773976.31	501.99	29.4	45	N
REC-126	Participating	580915.69	4774830.29	502.29	38.6	45	N
REC-127	Participating	581473.61	4775075.61	495.27	37.0	45	N
REC-128	Participating	581468.21	4774997.26	495.27	36.4	45	N
REC-129	Non-participating	576815.58	4779814.18	556.23	21.4	45	N
REC-130	Non-participating	567502.00	4781060.00	502.37	-	45	N

## Appendix C - Modeling Results

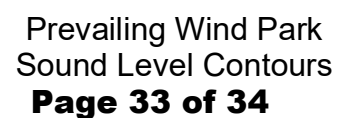
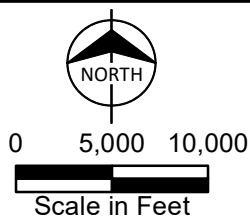
All Turbines: GE 3.8-137, 111.5 m hub height

Receiver	Participating/Non-Participating	Coordinates		Base Elevation (m)	Modeled		Exceed 45 dBA? (Y/N)
		Easting (m)	Northing (m)		LAeq <sup>A</sup>	Limit Value	
REC-131	Non-participating	568850.00	4781446.00	523.04	-	45	N
REC-132	Non-participating	570408.00	4783811.00	527.44	-	45	N
REC-133	Non-participating	570806.00	4783497.00	538.25	-	45	N
REC-134	Non-participating	570845.00	4782153.00	543.29	-	45	N
REC-135	Non-participating	573665.00	4780153.00	564.37	-	45	N
REC-136	Non-participating	579049.00	4772150.00	519.65	-	45	N
REC-137	Non-participating	579104.00	4772978.00	519.65	17.9	45	N
REC-138	Participating	573105.45	4772224.12	513.56	37.1	45	N
REC-139	Non-participating	569781.24	4772133.60	510.51	35.5	45	N
REC-140	Cemetery	580689.30	4768952.27	507.46	43.2	45	N
REC-141	Non-participating	577129.69	4782270.05	574.52	-	45	N
REC-142	Non-participating	584339.55	4769092.88	460.78	19.4	45	N
REC-143	Non-participating	582521.68	4766643.44	470.89	27.4	45	N
REC-144	Non-participating	582964.12	4764513.68	462.13	-	45	N
REC-145	Non-participating	568186.44	4765929.46	457.18	26.7	45	N
REC-146	Participating	576220.57	4771526.69	525.75	33.2	45	N
REC-147	Participating	575778.28	4770360.98	519.65	37.2	45	N
REC-148	Non-participating	568806.39	4770128.32	487.99	27.0	45	N
REC-149	Cemetery	567762.65	4773526.07	482.79	33.8	45	N

"-" represents no expected impacts at the receiver location

**APPENDIX D - SOUND LEVEL CONTOURS**









CREATE AMAZING.

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October 8, 2018

**VIA ELECTRONIC FILING**

Ms. Patricia Van Gerpen  
Executive Secretary  
South Dakota Public Utilities Commission  
500 E Capitol Ave  
Pierre, SD 57501-5070

**RE: In the Matter of the Application by Prevailing Wind Park, LLC for a Permit  
of a Wind Energy Facility in Bon Homme County, Charles Mix County and  
Hutchinson County, South Dakota, for the Prevailing Wind Park Project  
Docket EL18-026**

Dear Ms. Van Gerpen:

In connection with the above-referenced matter, enclosed please find the following exhibits and a Certificate of Service:

- Exhibit A16R (Revised Rebuttal Testimony of Michael MaRous); and
- Certificate of Service.

If you have any questions, please let me know.

Sincerely,

*/s/ Mollie M. Smith*

Mollie M. Smith  
*Attorney at Law*  
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Enclosures

cc: Certificate of Service/Service List

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Minneapolis, Minnesota  
55402-1425

**PUBLIC UTILITIES COMMISSION  
OF THE STATE OF SOUTH DAKOTA**

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**IN THE MATTER OF THE  
APPLICATION BY PREVAILING  
WIND PARK, LLC, FOR A WIND  
ENERGY FACILITY PERMIT FOR  
THE PREVAILING WIND PARK  
PROJECT**

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**CERTIFICATE OF SERVICE**

**EL18-026**

Bridget Duffus, of Fredrikson & Byron, P.A., hereby certifies that on the 8th day of October, 2018, true and correct copies of the following documents and this Certificate of Service were served electronically on the persons listed below:

- Exhibit A16R (Revised Rebuttal Testimony of Michael MaRous); and
- Filing letter.

Ms. Patricia Van Gerpen Executive Director South Dakota Public Utilities Commission 500 E. Capitol Ave. Pierre, SD 57501 patty.vangerpen@state.sd.us	Ms. Kristen Edwards Staff Attorney South Dakota Public Utilities Commission 500 E. Capitol Ave. Pierre, SD 57501 Kristen.edwards@state.sd.us
Ms. Amanda Reiss Staff Attorney South Dakota Public Utilities Commission 500 E. Capitol Ave. Pierre, SD 57501 amanda.reiss@state.sd.us	Mr. Darren Kearney Staff Analyst South Dakota Public Utilities Commission 500 E. Capitol Ave. Pierre, SD 57501 darren.kearney@state.sd.us
Mr. Jon Thurber Staff Analyst South Dakota Public Utilities Commission 500 E. Capitol Ave. Pierre, SD 57501 jon.thurber@state.sd.us	Ms. Mollie Smith - Representing: Prevailing Wind Park, LLC Fredrikson & Byron, P.A. 200 S. 6th St., Ste. 4000 Minneapolis, MN 55402 msmith@fredlaw.com
Ms. Bridget Canty - Representing: Prevailing Wind Park, LLC Permitting Project Manager sPower 201 Mission St., Ste. 540 San Francisco, CA 94105	Ms. Lisa M. Agrimonti - Representing: Prevailing Wind Park, LLC Fredrikson & Byron, P.A. 200 South Sixth Street, Suite 4000 Minneapolis, MN 55402-1425 lagrimonti@fredlaw.com

bcanty@spower.com	
Ms. Tamara Brunken Auditor Bon Homme County PO Box 605 Tyndall, SD 57066 Tamara.Brunken@state.sd.us	Ms. Diane Murtha Auditor Hutchinson County 140 Euclid, Rm. 128 Olivet, SD 57052 auditor@gwtc.net
Ms. Sara Clayton Auditor Charles Mix County PO Box 490 Lake Andes, SD 57356 sclayton@charlesmixcounty.org	Mr. Reece M. Almond - Representing: Gregg C. Hubner, Marsha Hubner, Paul M. Schoenfelder and Lisa A. Schoenfelder Davenport, Evans, Hurwitz & Smith LLP 206 W. 14th St. PO Box 1030 Sioux Falls SD 57101-1030 <a href="mailto:ralmond@dehs.com">ralmond@dehs.com</a>
Ms. Marsha Hubner 29976 - 406th Ave. Avon, SD 57315-5446 mjhubner@gmail.com	Mr. Paul M. Schoenfelder 40228 - 296th St. Wagner, SD 57380 PAULLISA5@msn.com
Ms. Lisa A. Schoenfelder 40228 - 296th St. Wagner, SD 57380 PAULLISA5@msn.com	Mr. Keith Mushitz Chairperson Charles Mix County Commission PO Box 490 Lake Andes, SD 57356 sclayton@charlesmixcounty.org
Ms. Karen D. Jenkins 28912 - 410th Ave. Tripp, SD 57376 jenkinskd55@gmail.com	Mr. Sherman Fuerniss 40263 293rd St. Delmont, SD 57330 sol@midstatesd.net
Mr. Gregg C. Hubner 29976 - 406th Ave. Avon, SD 57315-5446 gregghubner@gmail.com	Ms. Kelli Pazour 29668 402nd Ave. Wager, SD 57380 kepazour@hotmail.com

*/s/ Bridget Duffus*

Bridget Duffus

**BEFORE THE PUBLIC UTILITIES COMMISSION  
OF THE STATE OF SOUTH DAKOTA**

**IN THE MATTER OF THE APPLICATION BY PREVAILING WIND PARK, LLC  
FOR A PERMIT FOR A WIND ENERGY FACILITY IN BON HOMME, CHARLES MIX,  
AND HUTCHINSON COUNTIES, SOUTH DAKOTA, FOR PREVAILING WIND  
PARK ENERGY FACILITY**

**SD PUC DOCKET EL-18-026**

**REVISED PREFILED REBUTTAL TESTIMONY OF MICHAEL MAROUS  
ON BEHALF OF PREVAILING WIND PARK, LLC**

October 8, 2018

## **I. INTRODUCTION**

**Q. Please state your name.**

A. My name is Michael MaRous.

**Q. Did you provide Supplemental Direct Testimony in this Docket?**

A. Yes. I submitted Supplemental Direct Testimony in this docket on August 10, 2018.

**Q. What is the purpose of your Rebuttal Testimony?**

A. The purpose of my Rebuttal Testimony is to respond to the testimony of South Dakota Public Utilities Commission Staff witness Darren Kearney regarding a property value guarantee.

## **II. PROPERTY VALUE GUARANTEE**

**Q. Mr. Kearney discusses the difficulty of administering a property value guarantee. What is your response?**

A. I do not believe a property value guarantee is warranted for this Project or workable. As I testified, the Project is not expected to have any adverse impact on property values. I also agree with Mr. Kearney's position that "the implementation of a property value guarantee would be extremely difficult to do." Many variables can influence the criteria to establish value or re-establish value at a later date. For example, if maintenance and modernization has not been done, the condition of the property can deteriorate and negatively impact value. Alternatively, it would be difficult to determine how an improvement, such as a new kitchen or bathroom, should be factored in. Further, ideally, the same appraiser should do the appraisal years later if an allegation of an impact due to proximity to a wind farm is suggested. There are very few residential appraisers in the Project area, and there is a reasonable chance that the same appraiser would be retired or no longer working in the area when the future appraisal is needed. I want to emphasize that these are just some, not all, of the reasons I believe a property value guarantee is unworkable.




### **III. CONCLUSION**

**Q. Does this conclude your Rebuttal Testimony?**

A. Yes.

Dated this 8<sup>th</sup> day of October, 2018.



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Michael MaRous

64983973

**BEFORE THE PUBLIC UTILITIES COMMISSION  
OF THE STATE OF SOUTH DAKOTA**

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**EL18-026 - IN THE MATTER OF THE  
APPLICATION BY PREVAILING  
WIND PARK, LLC FOR A PERMIT OF  
A WIND ENERGY FACILITY IN BON  
HOMME COUNTY, CHARLES MIX  
COUNTY AND HUTCHINSON  
COUNTY, SOUTH DAKOTA, FOR THE  
PREVAILING WIND PARK PROJECT**

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**APPLICANT’S RESPONSES TO  
STAFF’S FIFTH SET OF DATA  
REQUESTS**

**EL18-026**

Below, please find Applicant’s Responses to Staff’s Fifth Set of Data Requests to Applicant.

- 5-1) Refer to the direct testimony of Mr. Richard James, Page 10, line 342 through Page 11, line 353:

*“Second, I reviewed the information on the computer model prepared for the report. I find the model is deficient in many ways. One significant way is that it fails to include two important sets of tolerances. The sound power data used as input to the model is derived using a method that has about a  $\pm 2$  dB tolerance for measurement repeatability. This tolerance should have been added to the sound power levels used as input to the model to account for known variability in measurement data. Also, the model uses the formulas and protocols from ISO 9613-2 which states it is not applicable for noise sources that are more than 30 meters above 350 the ground or receiver elevation. Even if the model was appropriate for wind turbine noise the model has known tolerances of  $\pm 3$  dBA. This should have also been applied as an adjustment to the Burns-McDonnell sound model. Given these two tolerances the predicted sound levels are as much as 5 dBA low.”*

- a) Please respond to Mr. James’ comment regarding a 2 dBA tolerance for measurement repeatability and explain how the Applicant incorporated the tolerance in the sound model.

Chris Howell: The vendor data used in our modeling is developed per IEC 61400-11 and reflects the loudest sound levels the turbines are expected to produce at any given time. Further, the model assumes all turbines are operating at maximum sound levels at all times in all directions. A residence between two turbines is assumed to experience downwind sound from both turbines (which is a physical impossibility). In general, the plus or minus (+/-) 2-dBA tolerance referenced by Mr. James captures

unexpected situations. It is worth noting that the situations captured by +/- 2-dBA are as likely to be over-predicted by up to 2 dBA as they are to be under-predicted by 2 dBA. In our experience, our model predicts the most likely outcome for loudest impacts. We have developed and refined our modeling techniques using actual measurement data as a basis for comparison, and our modeling has proven accurate through the years when compared to post-construction measurements. Therefore, the model predicts the most likely loudest sound levels for the Project, and adding or subtracting 2 dB would be less accurate.

- b) Please respond to Mr. James' comment regarding a 3 dBA tolerance from the formulas and protocols from ISO 9613-2 and explain how the Applicant incorporated the tolerance in the sound model.

Chris Howell: ISO 9613-2 includes language for tolerance; we did not include this tolerance in our modeling. As previously stated, we approached the modeling using conservative assumptions, and the model predicts the most likely loudest sound levels. The accuracy of our modeling has been confirmed by comparing our pre-construction modeling to post-construction sound measurements. There is no reason to apply overly conservative assumptions to the modeling, as doing so would result in a less accurate prediction of the Project's projected loudest sound levels.

- c) Is the predictive sound levels reflected in the model as much as 5BA low? Please explain.

Chris Howell: No. We are confident that our modeling results are not under-predicting by 5-dBA. It would not be prudent to under-predict potential sound levels in a regulatory setting, so we use conservative inputs. That said, we do not always use the most conservative selections because it is also important to be accurate, and we have to weigh the compounding effects of always making conservative choices in a model. Doing so could result in very unrealistic predictions, which, as noted previously, are not helpful to clients or regulators because they do not present an accurate picture of the Project's projected loudest sound levels. As noted previously, our modeling techniques use actual measurement data as a basis for comparison, and our modeling method has proven to be accurate through the years for other projects.

- 5-2) Refer to the direct testimony of Mr. Richard James, Page 11, lines 354 through 359:

*"Further, the values used for ground attenuation are not disclosed. The proper value for ground attenuation is "0" to turn off any calculations of ground effect. This is because the height of the wind turbines means that the sound emitted by them radiates directly from the blades to the homes without interaction with the ground. The ISO ground attenuation calculations are intended for ground-based*

*noise sources where the sound radiates along a line from source to receiver just above the ground.”*

Please respond to Mr. James’ comment regarding the values for ground attenuation reflected in the sound model.

Chris Howell: Mr. James continues to advocate for overly conservative methods that would not accurately predict the Project’s sound levels. Specifically, using “0” is overly conservative in these circumstances because it is representative of “hard ground,” (i.e. paving, ice, concrete). However, the Project area is predominantly agricultural in nature, which according to ISO 9613-2 is considered “porous ground.” ISO 9613-2 suggests a ground absorption value of 1.0 for “porous ground.” However, a ground absorption factor of 0.5 was conservatively used within the model to simulate mixed ground (equally hard and porous).

According to ISO 9613-2, the ground absorption plays a role in three distinct areas: the source; middle; and receiver. While the source and middle are elevated, the receiver area is near-grade and will be influenced by the ground absorption. The influence of ground absorption due to elevation of the source and receiver, and therefore the middle area, are automatically determined within the model. Again, assuming 0 for ground absorption near the receiver is considered overly conservative and would not present an accurate picture of the Project’s projected sound levels.

- 5-3) Is compliance with the Bon Homme County’s noise regulation associated with wind energy systems achieved through a sound model based on predicted sound levels, or is compliance based on actual sound levels? Please explain.

Lisa Agrimonti: Section 1741 of the Bon Homme County Ordinance states: “Noise level produced by the LWES shall not exceed forty five (45) dBA, average A-weighted sound pressure at the perimeter of occupied residences existing at the time the permit application is filed, unless a signed waiver or casement is obtained from the owner of the residence. The permittees shall submit a report of predicted noise levels at habitable residential dwellings within one mile of proposed tower locations to the Board no less than forty five (45) days prior to commencing construction.”

Compliance with this provision requires, prior to construction, submission of a report showing that modeled sound levels will meet the stated limit. In operations, the Ordinance requires that actual noise levels from the wind farm not exceed the stated limit.

- 5-4) Refer to the direct testimony of Mr. Richard James, Page 11, line 381 through Page 12, 388:

*“Before any decisions are made on permitting this project the applicant should be required to submit a new model that applies the known tolerances to the input data. It should also show the contour lines for 30, 35, and 40 dBA. These new sound levels should then be viewed as indicators of what the community will experience on a day when the wind turbines are operating under optimum conditions for the lowest noise emissions. They are not precision predictions. Review of the model should be done keeping in mind that the operating values can be as much as 10 dB higher than what is predicted, under operating conditions that would be considered normal.”*

- a) Please comment on Mr. James’ request above.

Chris Howell: Published noise emissions by the wind turbine vendor indicate that the turbines will vary by 10 to 15 dBA. The loudest published sound levels were used within our modeling. I am confident in our modeling, for the reasons discussed above, and do not believe additional modeling is necessary or helpful.

- b) Please submit a map that shows the contour lines for 30, 35, and 40 dBA using the sound model results that the Applicant believes accurately reflects predictive sound levels.

Chris Howell: See Attachment 5-4

- 5-5) Refer to the direct testimony of Mr. Richard James, Page 6, line 174 through 206. Does the Applicant agree or disagree that noise limits should be applied to the property lines or to the homes? Please explain.

Chris Howell: The noise modeling conducted for the Project was modeled at residences in accordance with general practice and requirements. *See, e.g., Bon Homme County Ordinance, Section 1741 (setting sound standard “at the perimeter of occupied residences” not the property line).*

- 5-6) Refer to the direct testimony of Prof. Mariana Alves-Pereira, Page 27, lines 461 – 466:

*However, in the absence of zoning laws based on scientific information, then the governmental agencies responsible for Public Health should step in to conduct appropriately designed epidemiological studies. Ideally, this would study relevant health endpoints before and after installation of the industrial wind turbines. It would also include the quantification of ILFN before and after the installations of the industrial wind turbines, with the same wind speed and wind direction, and evaluated inside the affected homes.*

What is the Applicant's position on the Intervenor's request for an epidemiological study by the governmental agencies responsible for Public Health? Please explain.

Dr. Mark Roberts: Referring to my Supplemental Direct and Rebuttal Testimony, multiple state, federal, and international governmental bodies have independently reviewed the peer-reviewed, published literature many times over and have reached similar conclusions that there is no evidence of wind turbines being associated with a specific health effect. (Massachusetts (2012), Germany (2016), Japan (2017), France (2017), Denmark (2009), Switzerland (2017), New Zealand (2010), and Australia (2015).) With respect to Dr. Alves-Pereira's call for more study, science is an evolving knowledge base that will be influenced by discussions of societal change (climate change, alternate energy sources, medical treatments) and demands of life, but decisions are made based on the science that we know. The science related to wind turbines has been assessed multiple times by multiple groups of scientists, and they have all come to the similar conclusion – there is no specific health effect associated with sounds produced by wind turbines. As I have pointed out in my testimony, science evolves, and with it comes new knowledge. In this area, there has been no scientifically verifiable evidence that wind turbines are associated with a specific health effect.

5-7) Refer to the direct testimony of Mr. Jerry Punch, Page 11, lines 303 – 314.

a) Does the Applicant agree that LA<sub>max</sub> is the optimal measurement metric to protect sleep? Please explain.

Chris Howell: This metric is intended to quantify sound levels from instantaneous and non-continuous noise sources, such as dogs barking, thunder, car passing by, etc., that occur during an otherwise quiet time period. As such, it may be a useful metric to gauge if a person is likely to wake from one of these sources. The WHO Night Noise Guidelines for Europe state that LA<sub>max</sub> is intended for non-continuous sources of sound and would therefore not be relevant to sounds emitted from wind turbines.

b) Based on the WHO Night Guidelines, is a 40 dB LA<sub>max</sub> level a reasonable maximum allowable noise level during nighttime? Please explain.

Chris Howell: No, this is not a reasonable maximum level, and it is not the recommended limit from the WHO Night Noise Guidelines. The WHO Night Noise Guidelines recommend a L<sub>night</sub>, outdoor level of 40 dBA. This is an average sound level during all nighttime hours (8-hour period) over each night of an entire year and is inclusive of any sounds that may occur. In the case of a wind farm, the metric also incorporates time periods when sounds levels don't include the source of interest (e.g., when the turbines are not operating). Bon Homme County's limit of 45 dBA



would apply on any given night, not be averaged out over an entire year, and would differentiate wind turbine noise from other intrusive noises.

Dated this 5th day of October, 2018.

By: /s/ Lisa M. Agrimonti

Mollie M. Smith

Lisa M. Agrimonti

FREDRIKSON & BYRON, P.A.

Attorneys for Applicant

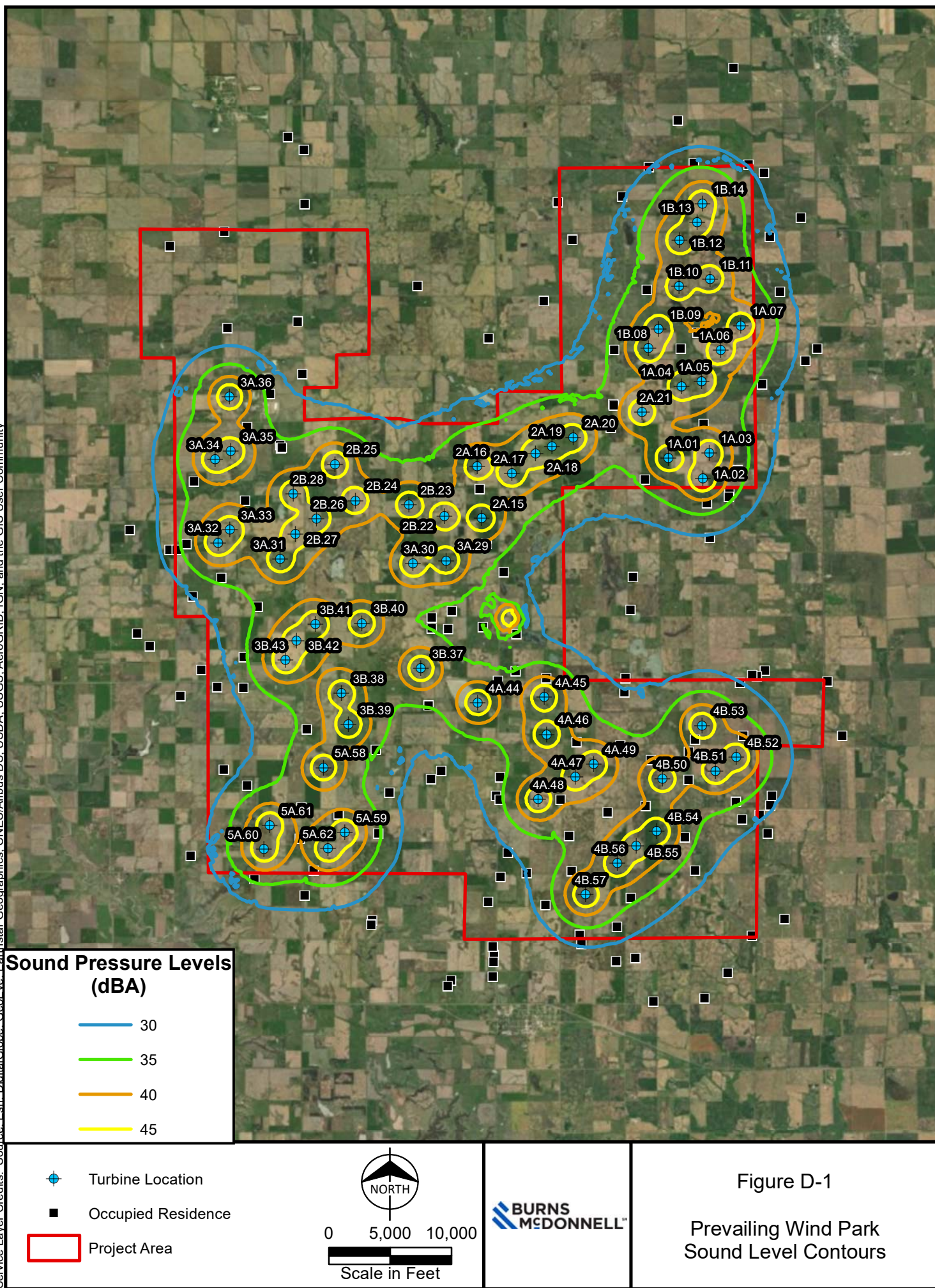
200 South Sixth Street, Suite 4000

Minneapolis, MN 55402

Phone: (612) 492-7270

Fax: (612) 492-7077

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 Service Layer Credits: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community



Source: ESRI, Burns & McDonnell Engineering Company, Inc.

Issued: 10/3/2018

010767

BEFORE THE PUBLIC UTILITIES COMMISSION  
OF THE STATE OF SOUTH DAKOTA

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IN THE MATTER OF THE  
APPLICATION BY PREVAILING  
WIND PARK, LLC FOR A PERMIT OF  
A WIND ENERGY FACILITY IN BON  
HOMME COUNTY, CHARLES MIX  
COUNTY AND HUTCHINSON  
COUNTY, SOUTH DAKOTA, FOR  
THE PREVAILING WIND PARK  
PROJECT

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APPLICANT’S RESPONSES TO  
STAFF’S SIXTH SET OF DATA  
REQUESTS  
EL 18-026

Below, please find Applicant’s Responses to Staff’s Sixth Set of Data Requests to Applicant.

**6-1) Refer to the Application, Page 15-14. Please provide all studies and supporting documentation that show a shadow flicker requirement of less than 30 minutes per day or 30 hours per year will avoid a significant adverse impact on neighboring land uses and a significant adverse impact on health.**

Peter Pawlowski: Based on the studies and documentation addressed in testimony by Prevailing Wind Park, a shadow flicker requirement of less than 30 minutes per day or 30 hours per year is not necessary to avoid adverse impacts on land use or health. See, e.g., the testimony submitted by Aaron Anderson and Dr. Mark Roberts. In addition, the Project will comply with all applicable shadow flicker requirements and commitments.

**6-2) Refer to the Applicant’s Disclosure of Lay Witnesses, which identifies Karen Peters and Dustin Brandt as participating landowners that will testify at the hearing. For each individual testifying, please provide the following information:**

**a) How many acres of land does the landowner have in the project?**

Bridget Canty: Prevailing Wind Park has a lease with Larry Peters and Karen Peters Living Trust, Larry Peters, Trustee, and Karen Peters, Trustee, Husband and Wife, with respect to 260 acres. Prevailing Wind Park has a lease with Dustin Brandt and Elizabeth Brandt with respect to 60 acres.

**b) Provide a map which identifies each landowners’ leased land within the project area, including where the turbines, if any, are sited on their land.**

Bridget Canty: See attachment 6-2b.

**c) Provide a map that shows the proposed turbines within 2 miles from their residence. Please provide a map similar to Page 88 of 156 of Staff Exhibit\_JT-1**

in Docket EL18-003 for Ms. Teresa Kaaz  
(<http://puc.sd.gov/commission/dockets/electric/2018/EL18-003/exhibits/staff/s1.pdf>).

Bridget Canty: See Attachment 6-2c.

**d) Provide the predicted sound level from the Project at their residence.**

Chris Howell:

Receptor	Sound Power Level
REC-016 (Peters)	38.9 dBA
REC-051 (Brandt)	32.7 dBA

**e) Provide the estimated annual frequency of shadow flicker associated with the operation of the Project wind turbines at their residence.**

Aaron Anderson:

Receptor	Flicker, Hours	Flicker, Minutes
REC-016 (Peters)	4.78 hours / year	27 minutes/day
REC-051 (Brandt)	4.90 hours / year	26 minutes/day

**6-3) Please provide a study, with calculations included, signed by a professional engineer that demonstrates ice throw will not occur beyond 620 feet.**

Lisa Agrimonti: Prevailing Wind Park does not possess such a study. In lieu thereof, see the Rebuttal Testimony of Scott Creech.



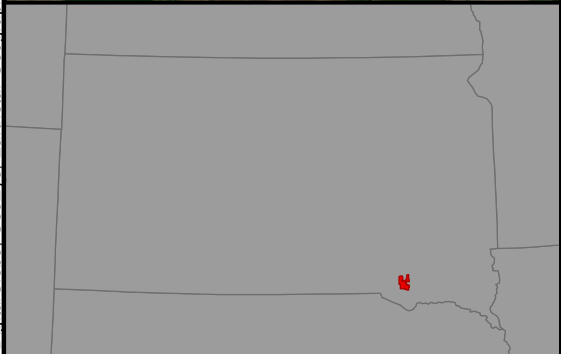
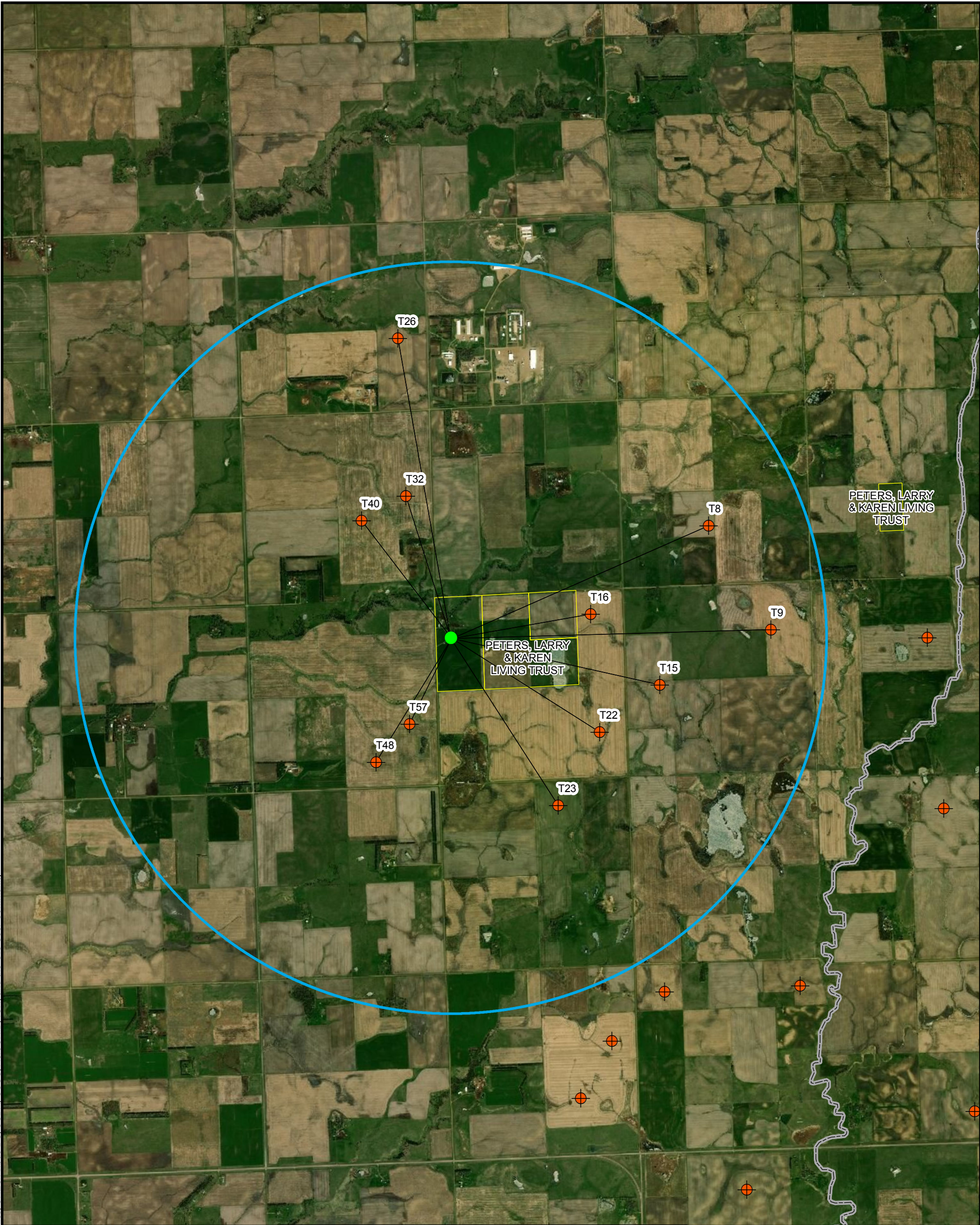
Dated this 5th day of October, 2018.

By: /s/ Lisa M. Agrimonti

Mollie M. Smith  
Lisa M. Agrimonti  
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Phone: (612) 492-7000  
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64944538.1





**Residence and  
Property of  
Larry & Karen Peters  
29416 402nd Avenue  
Charles Mix County  
South Dakota**

Turbine Distance to Residence		
Turbine	Length Miles	Length Feet
T57	0.5	2658
T16	0.75	3948
T48	0.77	4050
T40	0.78	4106
T32	0.78	4138
T22	0.93	4909
T23	1.05	5556
T15	1.13	5969
T8	1.49	7869
T26	1.61	8513
T9	1.7	8955

Residence

Turbine

Distance Line

2 Mile Radius

Parcels

County Boundary

NORTH

0

0.5

1

Miles

Path: Z:\Resources\Local\Clients\KCM\EN\S\PowerGroup\104294\_PrevailingWind\ArcGIS\Geospatial\DataFiles\ArcDocs\PUC Data Requests\Peters\_Karen.mxd 10/2/2018

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Source: ESRI, sPower, Burns & McDonnell





Turbine Distance to Residence

Turbine	Length Miles	Length Feet
T38	0.64	3364
T43	1.28	6738
T14	1.63	8590
T44	1.67	8795

Residence

Proposed Turbine

Distance Lines

2 Mile Buffer

Parcels

Project Area

NORTH

0

0.5

1

Miles



**Residence & Property of**  
**Dustin A. Brandt**  
**30049 407th Avenue**  
**Bon Homme County**  
**South Dakota**



**BEFORE THE PUBLIC UTILITIES COMMISSION  
OF THE STATE OF SOUTH DAKOTA**

---

**IN THE MATTER OF THE APPLICATION  
BY PREVAILING WIND PARK, LLC FOR  
A PERMIT OF A WIND ENERGY  
FACILITY IN BON HOMME COUNTY,  
CHARLES MIX COUNTY AND  
HUTCHINSON COUNTY, SOUTH  
DAKOTA, FOR THE PREVAILING  
WIND PARK PROJECT**

**INTERVENORS' RESPONSES TO  
APPLICANT'S SECOND SET OF  
DATA REQUESTS TO  
INTERVENORS MARSHA HUBNER,  
GREGG HUBNER, PAUL  
SCHOENFELDER, AND  
LISA SCHOENFELDER**

**EL 18-026**

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Intervenors Gregg Hubner, Marsha Hubner, Paul Schoenfelder, and Lisa Schoenfelder ("Intervenors"), through counsel, provide the following Responses to Applicant Prevailing Wind Park, LLC's ("Applicant") Second Set of Data Requests to Intervenors.

- 2-1) Reference Attachment 1, did the law firm of Davenport, Evans, Hurwitz & Smith, LLP send this May 27, 2015 letter to Mr. Roland Jurgens on one or more of the Intervenors' behalf? If so, identify the intervenor(s) on whose behalf the letter was sent.

**RESPONSE: Objection. This data request seeks information which is irrelevant and is protected by the attorney-client privilege.**

- 2-2) Reference Attachment 1, do all Intervenors agree with the statements contained in the letter? If not, explain why not.

**RESPONSE: Objection. This data request is vague and ambiguous as to the phrase "agree with the statements contained in the letter."**

- 2-3) Reference Attachment 1, identify all intended recipients of the letter.

**RESPONSE: Objection. This data request seeks information which is irrelevant. Without waiving that objection, the intended recipient of the letter is Roland Jurgens.**

- 2-4) Reference Attachment 1, has any one of the Intervenors or any lawyer on one of the Intervenor's behalf sent a letter to any other person that similarly purports to put the recipient "on notice" of alleged medical concerns with wind turbines? If the answer is yes, provide copies of all such letters and any responses provided by recipients.

**RESPONSE: Objection. This data request seeks information which is irrelevant.**

- 2-5) Reference Attachment 1, has any one of the Intervenor(s) commenced a lawsuit or participated as a witness or party in litigation relating to wind turbines? If so, provide the case name and docket number. Also, provide copies of all pleadings and any statements made by one or more Intervenor(s).

**RESPONSE: Objection. The data request is vague and ambiguous as to its reference to Attachment 1. Subject to that objection, no Intervenor has commenced a lawsuit or participated as a witness or party in litigation relating to wind turbines.**

- 2-6) Reference Mr. Gregg Hubner's role as President of South Dakotans for Safe and Responsible Renewable Energy ("SDSRRE"), identify any Intervenor(s) who are members of SDSRRE. For each identified Intervenor, describe how the Intervenor participates in SDSRRE.

**RESPONSE: SDSRRE does not have members.**

- 2-7) Describe any financial or in-kind support SDSRRE has provided to any Intervenor in this docket.

**RESPONSE: Objection. This data request seeks information which is irrelevant. Without waiving that objection, none.**

- 2-8) Provide copies of any documents regarding the Prevailing Wind Park that SDSRRE has distributed since its formation in March 2018, including, but not limited to, documents distributed to members of SDSRRE.

**RESPONSE: Objection. This data request seeks information which is irrelevant. Without waiving that objection, none.**

- 2-9) Provide copies of all written communications Mr. Hubner sent to residents and elected officials within the Project area regarding the Project.

**RESPONSE: Objection. This data request seeks information which is irrelevant. Subject to and without waiving that objection, see those communications previously provided.**

Dated this 3<sup>rd</sup> day of October, 2018.

DAVENPORT, EVANS, HURWITZ &  
SMITH, L.L.P.



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*Attorneys for Intervenors Gregg Hubner,  
Marsha Hubner, Paul Schoenfelder and  
Lisa Schoenfelder*

**CERTIFICATE OF SERVICE**

The undersigned, one of the attorneys for Intervenors Gregg C. Hubner, Marsha Hubner, Paul M. Schoenfelder, and Lisa A. Schoenfelder, certifies that a true and correct copy of the foregoing was served on October 3, 2018, via email, upon the following:

Kristen Edwards  
[kristen.edwards@state.sd.us](mailto:kristen.edwards@state.sd.us)  
Amanda Reiss  
[Amanda.Reiss@state.sd.us](mailto:Amanda.Reiss@state.sd.us)  
Staff Attorneys  
South Dakota Public Utilities Commission  
500 E. Capitol Ave.  
Pierre, SD 57501

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*Attorneys for Intervenors*

**BEFORE THE PUBLIC UTILITIES COMMISSION  
OF THE STATE OF SOUTH DAKOTA**

**IN THE MATTER OF THE APPLICATION  
BY PREVAILING WIND PARK, LLC FOR  
A PERMIT OF A WIND ENERGY  
FACILITY IN BON HOMME COUNTY,  
CHARLES MIX COUNTY AND  
HUTCHINSON COUNTY, SOUTH  
DAKOTA, FOR THE PREVAILING  
WIND PARK PROJECT**

**INTERVENORS' RESPONSES TO  
APPLICANT'S THIRD SET OF DATA  
REQUESTS TO INTERVENORS**

**EL 18-026**

Intervenors Gregg Hubner, Marsha Hubner, Paul Schoenfelder, and Lisa Schoenfelder ("Intervenors"), through counsel, provide the following Responses to Applicant Prevailing Wind Park, LLC's ("Applicant") Third Set of Data Requests to Intervenors.

**2-1) Reference the disclosures for Vickie May, Scott Rueter, Richard Daughtery, Josh Larson, Jerome Powers, Travis Krumvieda, Kevin Andersh in Intervenors' Disclosure of Lay Witnesses dated September 19, 2018 ("Lay Witness Disclosures"):**

- a) Generally describe each witness's educational background;**
- b) Generally describe each witness's employment history;**
- c) Identify any other proceedings, hearings, or other actions in which the witness has offered sworn testimony and provide copies of any such written testimony; and**
- d) Identify and provide any exhibits the witness will refer to, sponsor, or introduce.**

**RESPONSE:**

a) Intervenors object to this request to the extent it seeks information not in the possession, custody, or control of Intervenors. Furthermore, this information is as readily available to the Applicant as it is to Intervenors.

b) Intervenors object to this request to the extent it seeks information not in the possession, custody, or control of Intervenors. Furthermore, this information is as readily available to the Applicant as it is to Intervenors.

c) Intervenors object to this request to the extent it seeks information not in the possession, custody, or control of Intervenors. Furthermore, this information is as readily available to the Applicant as it is to Intervenors.



- d) See Intervenors' Exhibit List.

**2-2) Identify the "Hutchinson County Representative" listed as lay witness No. 17.**

**RESPONSE:** Intervenors do not intend to call a Hutchinson County Representative to testify.

**2-3) Reference disclosure of Vickie May,**

- a) **Has Ms. May sought medical attention for the alleged maladies in the disclosure? If she has sought such medical attention, provide any medical records that would in any way indicate that the maladies resulted from a wind turbine. Prevailing Wind Park is agreeable to entering into a confidentiality agreement and protective order for responsive documents.**
- b) **Provide any measurements of sound levels or shadow flicker at Ms. May's home that Ms. May has in her possession.**

**RESPONSE:**

a) Intervenors object to this request to the extent it seeks information not in the possession, custody, or control of Intervenors. Furthermore, this information is as readily available to the Applicant as it is to Intervenors.

- b) See Exhibit I-5.

**2-4) Reference disclosures for Lori Fuerniss and Sherm Fuerniss, have the witnesses sought medical attention for the alleged maladies in the disclosure? If they have sought such medical attention, provide any medical records that would in any way indicate that the maladies resulted from a wind turbine. Prevailing Wind Park is agreeable to entering into a confidentiality agreement and protective order for responsive documents.**

**RESPONSE:** Intervenors object to this request to the extent it seeks information not in the possession, custody, or control of Intervenors. Furthermore, this information is as readily available to the Applicant as it is to Intervenors.

**2-5) Reference the disclosure for Richard Daugherty, provide copies of any studies or reports relating to shadow flicker at his home.**

**RESPONSE:** Intervenors object to this request to the extent it seeks information not in the possession, custody, or control of Intervenors. Furthermore, this information is as readily available to the Applicant as it is to Intervenors. Subject to that objection, Intervenors do not intend to call Richard Daugherty to testify.

- 2-6) Reference the disclosure for Josh Larson, provide any documents relating to the level of sound in Mr. Larson's home caused by the wind turbine located 1,400 from his home and provide any documents relating to the level of background sound in Mr. Larson's home.**

**RESPONSE:** Intervenor object to this request to the extent it seeks information not in the possession, custody, or control of Intervenor. Furthermore, this information is as readily available to the Applicant as it is to Intervenor. Without waiving that objection, Intervenor do not have any such documents.

- 2-7) Reference the disclosure for Mr. Powers:**

- a) Describe, in detail, the alleged ice shedding event, including the date and location of the event.**
- b) Describe in detail, how Mr. Powers measured the distance of ice shedding from the turbine.**
- c) Provide copies of all documents relating to the alleged ice shedding event.**
- d) Has Mr. Powers sought medical attention for the alleged maladies in the disclosure? If so, provide copies of any medical records that would in any way indicate that the maladies resulted from a wind turbine. Prevailing Wind Park is agreeable to entering into a confidentiality agreement and protective order for responsive documents.**
- e) Provide copies of all documents that support Mr. Powers' claim that his pheasant business will lose \$15,000 to \$20,000 per year if the Prevailing Wind Park Project ("Project") is constructed.**
- f) Identify and provide contact information for the 50 customers Mr. Powers spoke to regarding whether they would return to hunt pheasants at his business if the Project is constructed.**
- g) For each of the 50 customers Mr. Powers contacted, state on how many occasions they paid to hunt with Mr. Powers' business.**

**RESPONSE:** Intervenor object to this request to the extent it seeks information not in the possession, custody, or control of Intervenor. Furthermore, this information is as readily available to the Applicant as it is to Intervenor. Without waiving that objection, Intervenor

respond as follows: Mr. Powers has seen ice shards approximately 210 feet<sup>1</sup> from turbine nos. six and nineteen of the Beethoven Wind Farm. He measured that distance with a tape measurer.

**2-8) Reference the disclosure for Travis Krumvieda:**

- a) **Identify the wind project in which Travis Krumvieda is a participating landowner;**
- b) **Provide a map that shows the existing turbines within 2 miles from Mr. Krumvieda's residence. A marked up Google Earth map or similar would be acceptable;**
- c) **Describe the wind project facilities located on and within two miles of Travis Krumvieda's property;**
- d) **Provide copies of recorded land records relating to Travis Krumvieda's lease agreement for the wind project.**

**RESPONSE:** Intervenors object to this request to the extent it seeks information not in the possession, custody, or control of Intervenors. Furthermore, this information is as readily available to the Applicant as it is to Intervenors. Without waiving that objection, Intervenors do not intend to call Travis Krumvieda to testify.

**2-9) Reference the disclosure for Kevin Andersh, describe the concerns Mr. Andersh has, if any, regarding the Project.**

**RESPONSE:** Since the Beethoven Wind Farm went operation, Mr. Andersh has had difficulties sleeping due to a vibrating sound in his ears. He resides a little over 2 miles from the nearest turbine. His contact number is 605-384-3472.

**2-10) With respect to Vickie May, Scott Rueter, Richard Daughtery, Josh Larson, Jerome Powers, Travis Krumvieda, Kevin Andersh:**

- a) **Identify whether the lay witness lives at the residence throughout the entire year and, if not, how many months of the year he/she resides at the residence;**
- b) **Provide a map that shows the existing turbines within 2 miles from the residence of each lay witness's residence. A marked up Google Earth map or similar would be acceptable;**
- c) **To the extent known by the proffered witness, Identify the regulations, including but not limited to state, county and any other applicable**

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<sup>1</sup> Intervenors, through counsel, referenced 1,000 feet and 600 feet in the First Amended Disclosure of Lay Witnesses based on a misunderstanding/miscommunication.

regulations, for noise that applied to the existing wind farm in proximity to each lay witness's residence at the time the existing wind farm was permitted;

- d) To the extent known by the proffered witness, identify the regulations, including but not limited to state, county and any other applicable regulations, for shadow flicker that applied to the existing wind farm in proximity to each lay witness's residence at the time the existing wind farm was permitted and built;
- e) To the extent known by the proffered witness, Identify the setbacks, including but not limited to state, county and any other applicable setbacks, that applied to the existing wind farm in proximity to each lay witness's residence at the time the existing wind farm was permitted and built;
- f) If the lay witness will testify regarding property values, provide all records within the last 10 years, including but not limited to studies, reports, and analyses, regarding property values as it relates to the lay witness's property.

**RESPONSE:** Intervenor object to this request to the extent it seeks information not in the possession, custody, or control of Intervenor. Furthermore, this information is as readily available to the Applicant as it is to Intervenor. Without waiving that objection, Intervenor have printed off Google Maps for certain witnesses, see Exhibit List.

**2-11) Provide any documents referred to, related to, or relied upon in Intervenor's responses to this Third Set of Discovery Requests.**

**RESPONSE:** Intervenor object to this request to the extent it calls for the production of work product. Subject to that objection, none.

**2-12) Please consider each question ongoing and update answers to the extent that the testimony of Intervenor's Lay Witnesses will be broader than identified in the Lay Witness Disclosures.**

**RESPONSE:** No response necessary.

Dated this 5<sup>th</sup> day of October, 2018.

DAVENPORT, EVANS, HURWITZ &  
SMITH, L.L.P.



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Marsha Hubner, Paul Schoenfelder and  
Lisa Schoenfelder*

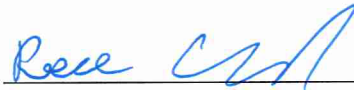


**CERTIFICATE OF SERVICE**

The undersigned, one of the attorneys for Intervenor Gregg C. Hubner, Marsha Hubner, Paul M. Schoenfelder, and Lisa A. Schoenfelder, certifies that a true and correct copy of the **Intervenors' Responses to Applicant's Third Set of Data Requests to Intervenor**, was served on October 5<sup>th</sup>, 2018, via email, upon the following:

Kristen Edwards  
[kristen.edwards@state.sd.us](mailto:kristen.edwards@state.sd.us)  
Amanda Reiss  
[Amanda.Reiss@state.sd.us](mailto:Amanda.Reiss@state.sd.us)  
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**BEFORE THE PUBLIC UTILITIES COMMISSION  
OF THE STATE OF SOUTH DAKOTA**

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IN THE MATTER OF THE APPLICATION  
BY PREVAILING WIND PARK, LLC FOR A  
PERMIT OF A WIND ENERGY FACILITY

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**APPLICANT'S FIRST SET OF DATA  
REQUESTS TO INTERVENOR  
SHERMAN FUERNISS**

IN BON HOMME COUNTY, CHARLES MIX  
COUNTY AND HUTCHINSON COUNTY,

**EL18-026**

SOUTH DAKOTA, FOR THE PREVAILING  
WIND PARK PROJECT

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Below, please find Prevailing Wind Park, LLC's ("Applicant") First Set of Data Requests to Intervenor Sherman Fuerniss. Please submit responses within 10 business days or promptly contact the undersigned to discuss an alternative arrangement.

- 1-1) Provide copies of all data requests submitted by the PUC Staff to you in this proceeding and copies of all responses to those data requests. Provide this information to date and on an ongoing basis.  
See attachment.

- 1-2) With respect to the Project, please:

- a) Identify, if any, concerns you have regarding the Project's satisfaction of the criteria for the Project to receive a facility permit from the South Dakota Public Utilities Commission; and
  - 1) Concerns about the legality of depriving property owners of the full traditional and customary use of the full extent of their private property due to the proximity of the proposed wind turbines.
  - 2) Concerns about the negative economic impact on property owners resulting from the inability to make full traditional and customary use of the full extent of their private property due to the proximity of the proposed wind turbines.
  - 3) Concerns about diminished quality of life and impaired health, safety, and welfare from the proximity of the proposed wind turbines sited according to outdated recommendations.
- b) Identify any other concerns you have regarding the Project.  
Concerns include increased acoustic energy from all directions from this project, potential exacerbation of sleeping problems leading to detrimental health issues, and detrimental effects on quality of life and welfare that have not been quantified now or after continuous and prolonged exposure to increased acoustic energy.

1-3) Identify whether you own property or reside in the vicinity of the Prevailing Wind Park Project ("Project") and, if so, the location (by section, township, and range) of such property and/or residence.

My immediate family owns 320 acres in 14-96-62 of Choteau Creek Township South and 40 acres in 18-96-61 of Choteau Creek Township South. My extended family owns 160 acres in 10-96-62 of Choteau Creek Township South which is managed by myself as an integral part of our operation.

Our family resides in the east one-half of 14-96-62 of Choteau Creek Township South.

1-4) If you have a residence in the vicinity of the Project, identify whether you live at the residence throughout the entire year and, if not, how many months of the year you reside at the residence.

Our family lives and works on our property twelve months of the year.

1-5) Identify how you use your land, including, but not limited to, whether you use your land for agricultural purposes.

Our land is used primarily for animal husbandry making extensive use of intensive and rotational grazing by means of portable break-wires and frequent movement of livestock requiring continual maintenance of both perimeter and internal fencing. Cattle movement and fencing are both accomplished mainly on foot on all areas of the property. Land not used for grazing is hayed and a small amount is used for crop production.

1-6) Identify any sensitive or unique features of your property that you assert would be impacted by the Project.

The vast majority of our property is grassland including native prairie and land replanted to native prairie grasses. Our prime native prairie would be bracketed on all sides by wind turbines.

Our farm is also home to a bow-truss barn built in 1923 by my grandfather which is still in use.

The herd of Braunvieh cattle we raise is unique to the area, perhaps to state of South Dakota.

1-7) Describe any mitigation measures that could address your concerns with respect to the Project. Preventative measures could include, but are not limited to, not building the project, requiring 2 mile setbacks from nonparticipating residences or 2 kilometer setbacks from nonparticipating property owners perimeter property lines - whichever is greater - as measured to the nearest reach of the turbine rotor, and 40dBA max daytime levels not to be exceeded more than 10% of the time and 30dBA max nighttime levels not to be exceeded more than 10% of the time as measured at nonparticipating property owners perimeter property lines.

- 1-8) Identify any documents, information, education, training, or professional experience you have relied upon to form your opinions concerning the Project. Where you have relied upon documents or other tangible materials, please provide such documents and/or materials.

Prevailing Wind Park, LLC application for a permit to the South Dakota Public Utilities Commission; three years experience living 1.25 miles from the Beethoven wind project; Bryce, R. (2010) Power Hungry, New York, NY, Public Affairs, Perseus Books Group; Hansen, C., Doolan, C. and Hansen, K. (2017) Wind Farm Noise: Measurement, Assessment and Control, Chichester, UK, John Wiley and Sons Ltd.; Crampton, G. (Ed.) (1990) Motion and Space Sickness, Boca Raton, Florida, USA, CRC Press Inc.; Salt, A. and Kaltenbach, J. (2011) Infrasound From Wind Turbines Could Affect Humans, Bulletin of Science Technology & Society 2011 31: 296, online version <http://bst.sagepub.com/content/31/4/296>; Punch, J. and James, R. (2016) Wind Farm Noise: A Four-Decade History of Evidence that Wind Turbines Pose Risks, from <https://hearinghealthmatters.org/hearingnews/watch/2016/wind-turbine-noise-health/>; Thorson, P., Persson Waye, K., Ogren, M., Smith, M., Pedersen, E., Forssin, J. (2018), Creating sound immission mimicking real-life characteristics from a single wind turbine, from <https://sciencedirect.com/science/article/pii/S003682X17312008>; McMurtry, R. and Krogh, C., (2014) Diagnostic criteria for adverse health effects in the environs of wind turbines, from [https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4221978/#\\_ffn\\_sectitle](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4221978/#_ffn_sectitle); [www.masterresource.org](http://www.masterresource.org); <https://www.researchgate.net>; Salt, A. and Lichtenhan, J. (2014) How Does Wind Turbine Noise Affect People? Acoustics Today, winter 2014, <http://www.windturbinesyndrome.com/wp-content/uploads/2014/04/Salt-et-al.-on-Wind-TurbineSyndrome>.

- 1-9) Identify any expert witnesses you plan to have testify on your behalf, and for each expert witness, describe the subject matter regarding which the witness will testify.

None.

- 1-10) Are you asserting the Project will negatively impact property value? If so, provide copies of any appraisals that have been conducted for your property within the last ten (10) years.

The value of anything is determined by agreement between a willing seller and a willing buyer. It would seem logical that the pool of willing buyers who intended to reside on a small farm surrounded in close proximity by multiple wind turbines would be smaller than the pool of willing buyers for such a property not surrounded by wind turbines. While the pool of willing buyers who would not reside there may be larger, the pool of willing sellers to such buyers in this case would be zero. The smaller the pool of potential buyers the less likely agreement of value would be found. There have not been any appraisals of which I am aware.

1-11) Identify any communications, written or otherwise, you have had with units, officials, and/or representatives of local, state, and/or federal governments or agencies concerning the Project.

- a) For any written communications, provide a copy of the communication; and  
See attachments.
- b) For any unwritten communications, provide the date of the communication, the persons involved, and the subject matter of the communication.

Dated this 30th day of August 2018.

By /s/ Lisa Agrimonti  
Mollie Smith  
Lisa Agrimonti  
FREDRIKSON & BYRON, P.A.  
Attorneys for Applicant  
200 South Sixth Street, Suite 4000  
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Phone: (612) 492-7270  
Fax: (612) 492-7077



**BEFORE THE PUBLIC UTILITIES COMMISSION  
OF THE STATE OF SOUTH DAKOTA**

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**IN THE MATTER OF THE  
APPLICATION BY PREVAILING  
WIND PARK, LLC FOR A PERMIT OF  
A WIND ENERGY FACILITY IN BON  
HOMME COUNTY, CHARLES MIX  
COUNTY AND HUTCHINSON  
COUNTY, SOUTH DAKOTA, FOR THE  
PREVAILING WIND**

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**STAFF’S FIRST SET OF DATA  
REQUESTS TO INTERVENORS**

**EL18-026**

Below, please find Staff’s First Set of Data Requests to Intervenor. Please submit responses by August 22, 2018, at 5:00 pm, or promptly contact Staff to discuss an alternative arrangement.

- 1-1) Provide copies to Staff of all data requests served on Applicant at the time of service.  
None served at this time.
  
- 1-2) Provide copies to Staff of all of your answers to data requests from Applicant at the time they are served on Applicant.  
None received at this time.
  
- 1-3) Refer to SDCL 49-41B-22. Please specify particular aspect/s of the applicant's burden that the individuals granted party status intend to personally testify on.
  - 1) Inaccuracies, errors, and omissions in the applicant’s application and supplemental information may cause injury to the environment leading to the economic detriment of some inhabitants and businesses within and near the project as well distressing other activities.
  - 2) The applicant fails to substantially prove that placement of turbines twice as powerful as existing turbines and at distances even closer than existing turbines will not substantially affect the health, safety or welfare of either participating or non-participating inhabitants. Unless health, safety, and welfare have been quantitatively measured prior to construction the amount of substantial impairment can not be measured after. Personal health and well-being will be particularly emphasized.
  - 3) There will likely be no future “orderly development” at all in the footprint of the facility if constructed as proposed.

- 1-4) Refer to SDCL 49-41B-25. Identify any “terms, conditions, or modifications of the construction, operation, or maintenance” that the Intervenor would recommend the Commission order. Please provide support and explanation for any recommendations.

The “terms, conditions or modifications” that would ameliorate nuisance, health, and negative financial concerns raised by the facility would be to simply deny the permit.

Should the permit be approved, full frequency spectrum analysis should be performed, not just modeling of projected dB(A) levels. The complete sound output needs to be accounted for not just the audible portion as with the dB(A) weighted scale. Dr. Alec Salt and colleagues, Washington University School of Medicine, St. Louis have explained the effects of extremely low frequency sound on the inner ear leading to the distress of sleep disruption, sleep deprivation and subsequent adverse health effects. Larger and more powerful turbines produce an even larger proportion of low frequency noise than earlier smaller models. This needs to be accounted for by someone.

If appropriate sound power level studies are not implemented and standards set and enforced, an alternate condition for safety, health, and welfare would be setbacks of 2 miles from non-participating residences, businesses, churches, cemeteries, and schools with waivers for those so inclined and 1500 foot setbacks from property and right of way lines. All setback measurements need to be made to the tip of the blade when horizontal not to the center of the tower.

Aircraft Detection Lighting Systems should be installed. The air ambulances from the Sioux Falls hospitals make multiple trips to the Wagner hospitals every week at all hours of the day and night through the proposed facility area.

Shadow flicker should be eliminated at non-participating residences and business and should be reduced to 8 hours annually actual following the German model at participating residences so as not to imprison people their homes behind shuttered windows unable to use their own property.

Decommissioning monies should be made available in whole upfront and reevaluated every 2 years to account for inflation and other increasing costs. Decommissioning should include complete removal of all installed components not just visible portions.

- 1-5) Is there a specific objection (example health, blinking lights, sound) you have with respect to the Project? Please briefly explain.

a. What, if anything, do you feel could be done to remedy that issue?

Concerning sight, sound, health, and safety issues:

If constructed as proposed our horizon will be in constant motion when the wind blows except for about 60 degrees to the north. As someone susceptible to motion sickness and having suffered vertigo episodes within the last few months, this may well be an unbearable situation. Infrasound and low frequency noise from existing turbines may contribute to these issues as per Navy nauseogenic studies but I can not imagine that having larger turbines on all sides could possibly help.

Existing turbine noise is routinely audible at our residence at 1.25 miles distant. Note that applicant's sound study indicates that in 2 of 3 measurements at measuring points 1 and 2 there is audible sound from existing turbines at distances of approximately 2 miles. Again, being completely surrounded by larger turbines will not help the situation.

Both audible sound and inaudible low frequency noise are known to contribute to sleep disruption and sleep deprivation. The distress of sleep deprivation over time is known to cause physiological disruptions of several body systems. We already experience sleep problems. Being surrounded by more and larger turbines can not possibly help.

Possible remedies for these issues could include but are not limited to:

- 1) Not approving the permit.
- 2) Requiring 2 mile setbacks from habitable residences, businesses, churches, cemeteries, etc. with waivers if desired by participating landowners so as to protect by distance from sound, inaudible noise, and sight disruption. All property and right of way line setbacks should be at least 1500 feet for safety from blade fragmentation and ice throw. For risk assessment it should be presumed that a person is always present at the property or right of way line.
- 3) Requiring 2 kilometer setbacks (as many European countries and Australian states have previously required 1000 meters for much smaller turbines as per summary by K. M. B. Haugen, Minnesota Department of Commerce) but from non-participating landowners property lines, along with noise limits of 25-40 dB(A) (again foreign country guidelines adjusted for turbine size per Haugen summary) at non-participating landowner property lines with lower values for measured quiet areas or 5 dB(A) above measured preconstruction background noise levels Leq with 5-15 dB penalties for tonality, impulsiveness, and modulation (Haugen summary) at the property line of non-participants so as not to imprison people in their homes unable to use or enjoy their entire property.
- 4) Further remedies to reduce audible sound and low frequency noise could include shutting down the entire facility from 7:00 pm to 7:00 am so that all inhabitants could sleep peacefully, shutting down all turbines within 2 miles of non-participating residences or 2 kilometers of non-participating owner property lines from 7:00 pm to 7:00 am, using Noise Reducing Operations (NRO) on all turbines from 7:00 pm to 7:00 am, or using NRO on turbines within 2 miles of non-participating residences or 2 kilometers of non-participating landowners property lines 24 hours a day.

Setbacks from property lines are stressed because our practice of animal husbandry requires working afoot on the majority of our property on a daily basis. Measurements to the residence are useless except for sleeping hours. No one should be denied the use of the entirety of their property.

- 1-6) Please list with specificity the witnesses the Intervenor intend to call. Please include name, address, phone number, credentials and area of expertise.

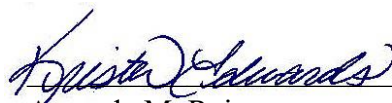
Potential witness other than self are unknown at this time.

- 1-7) Do the you intend to take depositions? If so, of whom?

Unknown at this time but doubtful.

21 August 2018  
Sherman Fuerniss  
40263 293<sup>rd</sup> Street  
Delmont, So. Dak. 57330  
605-779-5041  
sol@midstatesd.net

Dated this 8<sup>th</sup> day of August 2018.



Amanda M. Reiss

Kristen Edwards

Staff Attorneys

South Dakota Public Utilities Commission

500 East Capitol Ave.

Pierre, SD 57501

**Duffus, Bridget**

---

**From:** Edwards, Kristen <Kristen.Edwards@state.sd.us>  
**Sent:** Monday, August 06, 2018 1:57 PM  
**To:** & Sherman, Lori  
**Subject:** RE: Prevailing Winds

No problem!

**From:** sol <[sol@midstatesd.net](mailto:sol@midstatesd.net)>  
**Sent:** Monday, August 6, 2018 1:49 PM  
**To:** Edwards, Kristen <[Kristen.Edwards@state.sd.us](mailto:Kristen.Edwards@state.sd.us)>  
**Subject:** RE: [EXT] Prevailing Winds

Thanks so much for your prompt response to my inquiry. It is greatly appreciated!

Regards,

Sherman Fuerniss

On Aug 6, 2018 9:50 AM, "Edwards, Kristen" <[Kristen.Edwards@state.sd.us](mailto:Kristen.Edwards@state.sd.us)> wrote:

Not at all critical. No big deal, they never deny anyone party status.

**From:** sol <[sol@midstatesd.net](mailto:sol@midstatesd.net)>  
**Sent:** Monday, August 6, 2018 9:49 AM  
**To:** Edwards, Kristen <[Kristen.Edwards@state.sd.us](mailto:Kristen.Edwards@state.sd.us)>  
**Subject:** Re: [EXT] Prevailing Winds

Good morning,

How critical is it that I be included in the conference call tomorrow when the PUC is considering party status applications for EL18-026, Prevailing Wind ? Unfortunately I do not anticipate being able to be on the phone or even able to monitor the meeting tomorrow morning.

Sincerely,

Sherman Fuerniss

On Jul 31, 2018 9:28 AM, "Edwards, Kristen" <[Kristen.Edwards@state.sd.us](mailto:Kristen.Edwards@state.sd.us)> wrote:

Good morning,

I am email because you have filed for party status in t



Virus-free. [www.avg.com](http://www.avg.com)



July 21, 2018

Charles Mix County Commissioners

Keith Mushitz  
Neil VonEschen  
Jack Soulek

Dear Commissioners:

Several items from last Thursday's meeting kept nagging at me afterwards. It took a couple of days to sort out, but I would like to make the following points.

- 1) When Neil reported that Jonathan Wuertz said that they don't want any towers closer than 1 mile from the colony, keep in mind that the closest existing tower is about 1.25 miles from the colony. The new towers will be half again as tall and more than twice as powerful. One mile is simply not far enough! Also realize that when Jonathan says that the colony does not want any towers within a mile, the current PUC application shows that of the 9 towers on colony land only 1 is about a mile from the colony while the rest are from 1.25 to 4.5 miles from the colony while still being on colony land, but are the following approximate distances from other residences:

Tower 32 about .5 mile from T. Koupal, .75 mile from S. Fuerniss and K. Andersh

Tower 40 about .5 mile from K. Andersh, .75 mile from T. Koupal and less than 1 mile from S.Fuerniss

Tower 16 less than 1 mile from L. Peters and S. Fuerniss

Tower 57 less than 1 mile from K. Andersh, .75 mile from L. Peters and G. Link, and about 1 mile from P. Schoenfelder

Tower 48 about .5 mile from G. Link and .75 mile from L. Peters

Tower 23 less than 1 mile from G. Link and P. Schoenfelder

Tower 58 about .75 mile from C. Pazour and P. Schoenfelder

Tower 49 less than .75 mile from C. Pazour and less than 1 mile from P. Schoenfelder

So should towers be a mile or more from colony homes but towers on colony land be allowed to be closer than a mile to other homes???

- 2) Mr. Jurgens stated that there would be 57 towers. The application to the PUC shows 63 towers. Which sites have they already eliminated?
- 3) If I remember correctly, the "letter" offered by s-Power would keep towers about .75 mile from residences - was that participating or non-participating? Three-fourths of a mile would not seem to move very many towers very far and is essentially no concession from s-Power. The 40 dB(A) at non-participant and 45 dB(A) at participant residences they proposed is already what they would like the PUC to approve, so it is no concession either. Shadow flicker is also as already proposed. They stick with their plan as proposed essentially without change.
- 4) Mr. Podhrasky seemed overly impressed that the meeting room sound level of 60-70dB(A) -very unofficially measured- was not so loud. Of course, he was not trying to sleep there. Sleep deprivation/ disruption can begin at 30dB(A).

- 5) Mr. Jurgens mentioned that even your heart creates low frequency sound waves and they are not harmful. But God created the heart for the body and the body for the heart to work together. To equate the low frequency sound waves of the heart to those produced by turbine blades that are a football field and a half in diameter and moving at 200 miles per hour at the tips is ludicrous. The dangers of low frequency sound to the human body are known, what is not known is what standards for safety should be adopted. The only present safety is distance.
- 6) At the PUC meeting in Avon nearly 4 times as many people spoke against this wind energy conversion facility as spoke in favor of it. I do not believe any of those in favor were from Charles Mix County.
- 7) By my count there are 24 residences in Charles Mix County (7 in Lone Tree, 15 in Choteau Creek South, 2 in Choteau Creek North) that are in the footprint of the wind energy conversion facility. Only 7 of those 24 have their land signed up. How many of those 7 have appealed to use their property as they see fit to the potential detriment of the others?

I will continue to urge the adoption of strict regulations on wind energy conversion facilities, but especially setbacks of 2 miles or their equivalent in multiples of tower height from residences, business, etc. with waivers available and a setback of 2.5 times tower height from property lines and rights of way for the protection of Charles Mix County residents.

Sincerely, a lifelong resident of Charles Mix County,

Sherman Fuerniss  
40263 293rd Street  
Delmont, So. Dak. 57330

**EXHIBIT A23**

**BEFORE THE PUBLIC UTILITIES COMMISSION  
OF THE STATE OF SOUTH DAKOTA**

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**IN THE MATTER OF THE  
APPLICATION BY PREVAILING  
WIND PARK, LLC FOR A PERMIT OF  
A WIND ENERGY FACILITY IN BON  
HOMME COUNTY, CHARLES MIX  
COUNTY AND HUTCHINSON  
COUNTY, SOUTH DAKOTA, FOR THE  
PREVAILING WIND**

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**STAFF’S SECOND SET OF DATA  
REQUESTS TO SHERMAN FUERNISS**

**EL18-026**

Below, please find Staff’s Second Set of Data Requests to Sherman Fuerniss. Please submit responses by October 5, 2018, at 5:00 pm.

- 2-1) Refer to the rebuttal testimony of Mr. Fuerniss, Page 5, subpart (7).
- a) Provide and specifically identify all “misidentifications of land use” that Mr. Fuerniss is aware of.
  - b) Provide and specifically identify all “misidentifications of participating/nonparticipating residents” that Mr. Fuerniss is aware of.
  - c) Has the “misidentifications of participating/nonparticipating residents” that Mr. Fuerniss is aware of been corrected as part of independent review of residences within the Prevailing Wind Park project and verification area attached to Bridget Canty’s rebuttal testimony?
  - d) Please explain in detail what consideration should be provided for rural cemeteries. Please provide evidence to support this consideration.

Dated this 28<sup>th</sup> day of September 2018.



Amanda M. Reiss

Kristen Edwards

Staff Attorneys

South Dakota Public Utilities Commission

500 East Capitol Ave.

Pierre, SD 57501

**BEFORE THE PUBLIC UTILITIES COMMISSION OF THE  
STATE OF SOUTH DAKOTA**

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IN THE MATTER OF THE APPLICATION BY PREVAILING WIND  
PARK, LLC FOR A PERMIT OF A WIND ENERGY FACILITY IN  
BON HOMME COUNTY, CHARLES MIX COUNTY AND  
HUTCHINSON COUNTY, SOUTH DAKOTA, FOR THE  
PREVAILING WIND PARK PROJECT

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**APPLICANT’S FIRST SET OF DATA REQUESTS TO  
INTERVENOR KELLI PAZOUR**

**EL18-026**

Below, please find Prevailing Wind Park, LLC’s (“Applicant”) First Set of Data Requests to Intervenor Kelli Pazour. Please submit responses by October 5, 2018 in accordance with the Order Granting Party Status and Establishing Procedural Schedule or promptly contact the undersigned to discuss an alternative arrangement.

- . 1-1) Provide copies of all data requests submitted by the PUC Staff to you in this proceeding and copies of all responses to those data

requests. Provide this information to date and on an ongoing basis.

. 1-2) Identify:

. a) Your educational background;

. I went to Mitchell tech for two year degree in Agriculture. Then  
went to Dakota Wesleyan University for Special Education.

. b) Your employment background;

. Ranch and Farmer

. c) Any other proceedings, hearings, or other actions in which  
you have offered sworn testimony.

. none

. 1-3) In your Application for Party Status in the above-referenced  
action, it states: "I live on land in close proximity to or within the  
project's footprint. I have concerns regarding the applicant['s]  
compliance with applicable laws and rules, regarding  
environmental, infr[a] sounds, and acoustics. This project will  
impair the health, safety and welfare of inhabitants of the area."  
With respect to above, please respond to the following:

. a) Identify with specificity your "concerns regarding the  
applicants[s] compliance with applicable laws and rules."  
Because the Submitted Application had so many errors,  
missing data. I do not know if they have complied with the  
laws. The application was missing some of the neighbors,  
cemeteries and the report of wildlife is understated. I  
question the accuracy of a small sample observation for  
wildlife in my area.

. b) Identify with specificity your concerns "regarding  
environmental, infr[a] sounds, and acoustics." I have listed



my concern and are referenced in (1-7)

- . c) Identify with specificity your concerns that the Project “will impair the health, safety and welfare of inhabitants of the area.”
- . I am concerned with the Info-sounds as well as the acoustics that come off the wind turbines. I am concerned about how the sound waves will affect my daughter’s hearing. In 1-7, I list information that I reviewed and formed my opinion.
- . d) Identify with specificity any other concerns you have regarding the Project.
- . I am concerned about how close they are to people’s homes and their height. After talking to Dr Jay Tebbitts, who worked on the board of Health and investigated the Sherry Wind Farm, I have a greater concern now. He studied the Sherry Wind Farm and found that it was causing issues. The turbines where only 495 ft. tall and the set back to this site was 1250. Who’s to say with the new turbines that they are requesting that are about 600ft. couldn’t have the same impact? Please see the references to his work in 1-7.
- . 1-4) State whether you live at the residence throughout the entire year and, if not, how many months of the year you reside at the residence.
- . We live 12 out of 12 months at our home.
- . 1-5) Describe how you use your land, including, but not limited to, whether you use your land for agricultural purposes.
- . Ranch and Farm the land.
- . 1-6) Describe any mitigation measures that could address your concerns with respect to the Project.

Ideally, I feel there really is no mitigation that would keep our current state. Esthetically, a three-mile setback would still impact the environmental landscape. I do feel the three-mile setback would minimize the low frequency sound issues although may not eliminate them.

I strongly feel the new radar detection system is mandatory, since we are currently impacted by the existing Beethoven light system.

I will have 19 within a three mile radius around me. The Applicants proposed mitigation for shadow flicker and sound buffering is inadequate and not acceptable. We have severe concerns about the noise level and shadow flicker and would like to request independent oversight during and post construction for the entire time of the project's existence. I would like a system in place to expediate the violations or grievance of those impacted if the application is approved. I also have independent studies that show that there should be two decibel levels for day and one for night. I strongly feel based on research that the levels should be 35 daytime and 30 night. I feel this is not much to ask for to keep my daughter safe and others.

- . 1-7) Identify any documents, information, education, training, or professional experience you have relied upon to form your opinions concerning the Project. Where you have relied upon documents or other tangible materials, please provide such documents and/or materials.

I have been doing research starting back in 2014 to educate myself. I want to know or if there are any health issues around hearing or hearing aids. I am still looking up data to keep myself informed.

<https://hearinghealthmatters.org/hearingviews/2014/wind-turbine-noise-evidence-health-problems/>

*"We know that things we cannot see, touch, taste, or smell can hurt us, so why is it unreasonable also to believe that what we can't hear might also hurt us?"*

*Persons affected by wind turbine noise appear to be responding directly to acoustic stimulation of the same nerves and organs affected in that experimental environment. “*

We know x-rays can cause harm even if we can't see them so who do know without reasonable doubt that these new wind turbines will not have any harmful effects?

“The right of the public to enjoy health and well-being should be paramount to the economic and political interests of the wind industry and governmental bodies. These rights need to be protected on a proactive, and not just on a retroactive, basis. Industrial-scale wind turbines should be sited only at distances from residents that are sufficient to minimize sleep disturbance and that do not put them at risk for a variety of other serious health problems.”

<https://successforkidswithhearingloss.com/wp-content/uploads/2014/09/Wind-Turbine-Noise-What-Audiologists-Should-Know.pdf>

*“Inaudible components can induce resonant vibration in solids, liquids, and gases—including the ground, houses, and other building structures, spaces within those structures, and bodily tissues and cavities—that is potentially harmful to humans. The most extreme of these low-frequency (infrasonic) emissions, at frequencies under about 16 Hz, can easily penetrate homes. Some residents perceive the energy as sound, others experience it as vibration, and others are not aware of it at all. Research is beginning to show that, in addition to sleep disturbances, these emissions may have other deleterious consequences on health.” (p22)*

So, with these low sounds and frequencies they can't say that it can't penetrate people's houses. People's homes are where you get your rest or feel safe. If sounds or acoustics penetrate your home what effects of long term could there be? With these new turbines being 600ft do they don't know. Sound waves can affect everyone differently; I don't want my daughter to feel that she is not safe at home because if she has problems related to the wind turbines.

*“Among audiologists and acousticians, it has been understood for many decades that sufficiently intense and prolonged exposure to environmental noise can cause hearing impairment, annoyance, or both. In essence, the view has been what you can hear can hurt you. In the case of wind turbines, it seems that what you can't hear can also hurt you. Again, there is no evidence that noise generated by wind turbines, even the largest utility-scale turbines, causes hearing loss. But there is increasingly clear evidence that audible and low-frequency acoustic energy from these turbines is sufficiently intense to cause extreme annoyance and inability to sleep, or disturbed sleep, in individuals living near them. “*

With my daughter's issues, how do I know that she could be the first Ginny pig for being the first one. Knowing she has only one ear and not knowing how this could change her life!

*“According to the World Health Organization guidelines (WHO, 2007), observable effects of nighttime, outdoor wind-turbine noise do not occur at levels of 30 dBA or lower. Many rural communities have ambient, nighttime sound levels that do not exceed 25 dBA. As outdoor sound*

*levels increase, the risk of AHEs also increases, with the most vulnerable being the first to show its effects. Vulnerable populations include elderly persons; children,*

*FiGURE 2: Utility-scale wind turbines located in Huron County, Michigan.*

*especially those younger than age six; and people with pre-existing medical conditions, especially if sleep is affected. For outdoor sound levels of 40 dBA or higher, the WHO states that there is sufficient evidence to link prolonged exposure to AHEs. While the WHO identifies long-term, nighttime audible sounds over 40 dBA outside one's home as a cause of AHEs, the wind industry commonly promotes 50 dBA as a safe limit for nearby homes and properties. Recently, a limit of 45 dBA has been pro- posed for new wind projects in Canada "(Keith et al, 2008)." (p27)*

Much of the answer as to why the wind industry denies that noise is a serious problem with its wind tur- bines is because holding the noise to 30 dBA at night has serious economic consequences. Bottom line is that they would lose money! Prevailing Wind never said that they couldn't do it at our county commissioners meeting. I feel that it's not out of reach that there should be two setting for the wind turbines one for day time and one for night! I feel 45 dba is not expectable. Prevailing winds also made the remark that they could go as low as 43dba! With the technology they say they have, why couldn't they turn them off at night and control the dba at night.

<https://doi.org/10.1177%2F0270467611412548>

*"Research linking loud sounds to hearing loss in youngsters is now widespread, resulting in the issuance of warnings to protect children's hearing. However, studies attesting to the adverse effects of intrusive sounds and noise on children's overall mental and physical health and well-being have not received similar attention."*

*"Furthermore, based on our knowledge of the harmful effects of noise on children's health and the growing body of evidence to suggest the potential harmful effects of industrial wind turbine noise, it is strongly urged that further studies be conducted on the impacts of industrial wind turbines on their health, as well as the health of their parents, before forging ahead in siting industrial wind turbines".*

I truly believe that their needs to be more studies done pertaining to this! I feel the without enough studies done. This should be done before this project can go forwards. At this time, I believe that the applications should be denied.

<https://wcfm.org/2015/01/18/health-and-wind-farms/>

“Will noise or other direct or indirect consequences (and which consequences) of the operation of the Stony Gap wind farm erected as contemplated in the Application, and involving turbines of the type and dimensions referred to in the Application, in your opinion be likely to cause adverse health effects or significantly exacerbate existing adverse health effects to a significant percentage of the population living within up to 10 kilometers of the turbines from the Stony Gap Wind Farm?” “In my opinion, it is inevitable that this proposed wind development, if built in this location with turbines of the specified size, will cause serious harm to the physical and mental health of a significant percentage of the surrounding population, including particularly to vulnerable groups such as young children, the elderly, and those with pre-existing medical and psychiatric conditions, who live and work in the sound energy impact zone of this proposed Stony Gap Wind Farm (SGWF), out to a distance of at least 10 kilometers from the turbines, over the lifetime of the project. This harm will be caused directly by the audible and inaudible sound energy generated by the wind turbines, which will cause significant repetitive sleep disturbance, and physiological stress. The physiological mechanisms have been demonstrated in animals to be due to abnormal activation of the vestibular system and sympathetic nervous system by the effect of infrasound and low frequency noise (ILFN) on the inner ear.” (1)

With my daughter’s already preexisting medical condition these are true worries for me as her mom, she has had a very hard life already and I do not want to add other issues. I believe their needs to be more research done before these monster high wind turbines can be placed by people. There is already reports of health issues around the world of wind turbines that are shorter causing habit with people.

<http://windturbinechildren.org/site/the-effects-of-wind-turbines-on-children/>

*“This noise would also negatively affect children and adults who are severely hearing impaired and have a cochlear implant. The microphone on a cochlear implant picks up noise from the environment, as well as speech sounds. The constant noise from the turbines would severely inhibit the ability of a person with a cochlear implant to process sounds, especially speech.*

*The intrusive sounds created by wind turbines do not only affect children with special needs, but also negatively affect all children. The constant noise can negatively affect the physical and mental well-being of all children. The cardiovascular system, central nervous system, memory, language processing and cognition as well as learning abilities can all be affected by intrusive noises, such as the noise made from wind turbines.”*

There is no garnet that these wind turbines cannot affect kids or adults. Every single life matters! We shouldn’t be a percentage on a scale!



<https://www.wind-watch.org/documents/infrasoundlow-frequency-noise-and-wind-turbines/>

***“Noise measurements for most studies and environmental assessments have been limited to the measurement of audible sound outside homes– using dBA weighted monitoring which is insensitive to infrasound frequencies. Some studies and environmental assessments have even relied on projected audible sound averages from computer produced models.”***

In real life, there are no models to predict what the sounds will be like. We have weather that has a low front come in or a high front. Our weather is unpredictable as well as sounds, so to use a computer model is not acceptable.

[http://wiseenergy.org/Energy/Health/Summary\\_references\\_wind\\_turbines\\_and\\_health\\_April\\_2015.pdf](http://wiseenergy.org/Energy/Health/Summary_references_wind_turbines_and_health_April_2015.pdf)

***“Wind turbines produce sound that is capable of disturbing local residents and is reported to cause annoyance, sleep disturbance, and other health-related impacts. An acoustical study was conducted to investigate the presence of infrasonic and low-frequency noise emissions from wind turbines located in Falmouth, Massachusetts, USA. During the study, the investigating acousticians experienced adverse health effects consistent with those reported by some Falmouth residents. The authors conclude that wind turbine acoustic energy was found to be greater than or uniquely distinguishable from the ambient background levels and capable of exceeding human detection thresholds. The authors emphasize the need for epidemiological and laboratory research by health professionals and acousticians concerned with public health and well-being to develop effective and precautionary setback distances for industrial wind turbines that protect residents from wind turbine sound. “***

Prevailing winds made a comment that they have in the past not planned out where placing of the wind turbines, because of this who knows if they have got it right yet? With all of these issues that are related to wind turbines, do we know with a reasonable dot they have everything right yet? I feel that a three-mile set back is not too much to ask for.

<http://hearinghealthmatters.org/hearingviews/2014/wind-turbine-noise-evidence-health-problems/>

***“Wind turbine noise is not known to cause hearing loss. Interestingly, though, individuals who have hearing disorders may be more susceptible than persons with normal hearing to AHEs from wind turbine noise, and people who are deaf can suffer the same ill effects as those who have normal hearing when exposed to wind turbine noise. The latter finding supports the view that infrasound, not just the audible whooshing, low-frequency noise emitted by wind turbines, is the cause of many of the health complaints.”***

This is my biggest fear is that she could be more susceptible to the sound noise than a normal person is.

<http://hearinghealthmatters.org/hearingviews/2014/wind-turbine-noise-evidence-health-problems/>

*“Wind turbine noise is not known to cause hearing loss. Interestingly, though, individuals who have hearing disorders may be more susceptible than persons with normal hearing to AHEs from wind turbine noise, and people who are deaf can suffer the same ill effects as those who have normal hearing when exposed to wind turbine noise. The latter finding supports the view that infrasound, not just the audible whooshing, low-frequency noise emitted by wind turbines, is the cause of many of the health complaints.”*

With my daughter's hearing lose I am afraid of what this could due to her!

*Annoyance from turbine noise at 35 dBA corresponds to the annoyance reported for other common community-noise sources at 45 dBA. The World Health Organization (WHO) has concluded that observable effects of nighttime, outdoor noise levels of 40 dBA or higher [will lead to diminished health](#). This also occurs when levels inside homes (especially bedrooms) rise above 30 dBA or contain non-steady and/or low-frequency noise.”*

This is the reason I am so worried about sounds. Their needs to be more implements to help protect kids or adults with these issues.

<http://journals.sagepub.com/doi/pdf/10.1177/2331216518789551>

*“This review considers the nature of the sound generated by wind turbines focusing on the low-frequency sound (LF) and infrasound (IS) to understand the usefulness of the sound measures where people work and sleep. A second focus concerns the evidence for mechanisms of physiological transduction of LF/IS or the evidence for somatic effects of LF/IS. While the current evidence does not conclusively demonstrate transduction, it does present a strong prima facia case. There are substantial outstanding questions relating to the measurement and propagation of LF and IS and its encoding by the central nervous system relevant to possible perceptual and physiological effects. A range of possible research areas are identified.”*

I believe this need to be factored in when making a decision. With long term exposers, this can change factors of anything.

*“Other sources of sound include the aerodynamic noise generated by air flow across and leaving the trailing edge of the blades (trailing edge noise) and mechanical noise from the nacelle equipment. By contrast with BPF noise, the aerodynamic noise from the blades is broadband with a low-pass roll-off ( 5 dB per octave > 1 kHz; Figure 2 on (p2) ”*

The sounds that come off wind turbines have a high effect of peoples that live next to them. With the sounds that are generating off of them who knows what could impact on her hearing aid.

1-8) Are you asserting the Project will negatively impact the value of your property? If so, provide copies of any appraisals that have been conducted for your property within the last ten (10) years.

none

1-14) Provide all records, including but not limited to studies, reports, analyses and documents, relating to your opinion regarding adverse effects of wind turbines on hearing aids, including bone anchored hearing aids.

Refer to 1-7 to many to include.

1-15) Provide any documents referred to or relied upon in your responses to this First Set of Data Requests.

Provided above

1-16) Please consider each question ongoing and update answers to the extent that your testimony will be broader than identified in your Application for Party Status.

Dated this 24th day of September 2018.

By /s/ *Lisa M. Agrimonti* \_\_\_\_\_ Mollie M. Smith Lisa M.  
Agrimonti FREDRIKSON & BYRON, P.A. Attorneys for Applicant

200 South Sixth Street, Suite 4000 Minneapolis, MN 55402 Phone:

(612) 492-7270 Fax: (612) 492-7077 \_\_\_\_\_

**IN THE MATTER OF THE  
APPLICATION BY PREVAILING  
WIND PARK, LLC FOR A PERMIT OF  
A WIND ENERGY FACILITY IN BON  
HOMME COUNTY, CHARLES MIX  
COUNTY AND HUTCHINSON  
COUNTY, SOUTH DAKOTA, FOR THE  
PREVAILING WIND**

**Amended Response  
APPLICANTS FIRST SET OF DATA  
REQUESTS TO  
INTERVENOR**

Below, please find Prevailing Wind Park, LLC's ("Applicant") First Set of Data Requests to Intervenor Karen Jenkins. Please submit responses within 10 business days or promptly contact the undersigned to discuss an alternative arrangement.

- 1-1) Provide copies of all data requests submitted by the PUC Staff to you in this proceeding and copies of all responses to those data requests. Provide this information to date and on an ongoing basis.

**Attached**

- 1-2) With respect to the Project, please:

a) Identify, if any, concerns you have regarding the Project's satisfaction of the criteria for the Project to receive a facility permit from the South Dakota Public Utilities Commission; and b) Identify any other concerns you have regarding the Project.

Please see my Amended Response to Staff's First Set of Data Requests that I have forwarded to you.

- 1-3 Identify whether you own property or reside in the vicinity of the Prevailing Wind Park Project ("Project") and, if so, the location (by section, township, and range) of such property and/or residence.

My husband and I own an 8 acre property with a 100+ year old farmhouse and barn with outbuildings in Section 30 Fair Township 97N, and Range 60W.

- 1-4 If you have a residence in the vicinity of the Project, identify whether you live at the residence throughout the entire year and, if not, how many months of the year you reside at the residence.

We reside here year round.



- 1-5 Identify how you use your land, including, but not limited to, whether you use your land for agricultural purposes.

We use our land as our sanctuary from urban living and as a Hobby Farm. We also hay some of the acreage every year.

- 1-6 Identify any sensitive or unique features of your property that you assert would be impacted by the Project.

Our property has a unique 360 degree view of the landscape and our two story house has many large windows and doors on every side which afford us a beautiful and peaceful view of the rural landscape which includes tilled farmland, pastures with cattle grazing, a wide open view of the sky, and many types of wildlife including a large variety of birds, including bald eagles, cranes, the twice yearly migration of ducks and geese, deer, woodchucks, raccoons, coyotes, badgers, rabbits, quail, and pheasants. There is a naturally fed pond just west of our house on the adjacent property and a creek that runs from that, through our property and on to the property east of us which becomes tree-lined and feeds a pond on that property. Both properties east and west have cows and calves grazing most of the year. The adjacent north and south properties are tilled farmland which alternate from corn, soybeans, and alfalfa.

Our property fulfills the dream we have shared since we married in 1984, to retire and live in the country, experience the seasons, enjoy the peacefulness, have a hobby farm, and enjoy life. We believed we would be able to either leave a beautiful and valuable property to our children as an inheritance or if needed, as we age and become unable to maintain it, be able to sell it and use the funds from the sale to relocate to another lovely residence.

- 1-7) Describe any mitigation measures that could address your concerns with respect to the Project.

Please refer to my Amended Response to Staff's First Request for Data that I have forwarded to you.

1-8) Identify any documents, information, education, training, or professional experience you have relied upon to form your opinions concerning the Project. Where you have relied upon documents or other tangible materials, please provide such documents and/or materials.

My personal experience of the process of the development of the Beethoven Wind Farm and this Project.

My personal experience of living three miles from the Beethoven Wind Farm.

The experiences that Sherm and Lori Fuerniss have shared with me living by the Beethoven Wind Farm.

Discussions I have had with individuals who live in the communities surrounding us regarding the offensive red blinking lights seen for miles and miles, the waste of our taxpayer dollars, the secrecy of the developers of the Beethoven Project (the same developers of the Project), and the disgust of how they deceived the communities that the Beethoven Project would provide many permanent jobs to the community.

Documents and Literature

Siting Guidelines for Wind Power Projects in South Dakota / Attached

Particularly, the following paragraph was alarming to me and had a great impact on the opinion I have that the Project is proposed for the wrong location. This project is in the Missouri River area highlighted on the map, an area that is considered unique and rare in South Dakota.

“Although wind power is considered "green energy," many concerns have been expressed about the effects of their presence on plants and animals native to South Dakota. Specific areas of South Dakota have been identified as potential sites for wind energy development, and these sites are located in, but not limited to, the Coteau des Prairies in eastern South Dakota and the Missouri River in central South Dakota, which are unique/rare in South Dakota. Additional areas in other regions of the state may be identified/added by ongoing studies or further infrastructure development (e.g., transmission lines and substations). “

Wind Turbine Syndrome: A Report on a Natural Experiment by Dr. Nina Pierpont

Paradise Destroyed

The Destruction of Rural Living by the Wind Energy Scam by Gregg Hubner

Websites:

SDPUC

AWEA / Too many articles and too much info to attach.

WE-CAREsd.org website / Too many articles and too much info to attach

Wind Watch.org website / Too many articles and too much info to attach

INCEEUROPE website / Three attachments

1-9) Identify any expert witnesses you plan to have testify on your behalf, and for each expert witness, describe the subject matter regarding which the witness will testify.

My husband Mike Jenkins and myself may testify on our experiences of and with the Beethoven Wind Farm and the development of the Project, at this time no other expert witnesses are planned, however I reserve the right to call witnesses as the process unfolds.

1-10) Are you asserting the Project will negatively impact property value? If so, provide copies of any appraisals that have been conducted for your property within the last ten (10) years.

Yes, I am sure the Project will negatively impact property value. More concerning is the chance that one or both of us may not be able to remain in our home, due to adverse health effects, or whether we would even want to remain in our home next to the existing Beethoven Wind Farm and this Project. Most concerning is how we could ethically offer it up to anyone for sale. We depend on our home and property as our largest asset.

An appraisal was done when we purchased our home and property in 2010, I do not have it available.

1-11) Identify any communications, written or otherwise, you have had with units, officials, and/or representatives of local, state, and/or federal governments or agencies concerning the Project.

I participated in the process of the Bon Homme County Zoning Board on Zoning and Met Tower, and Public Hearings in the same County regarding zoning for Industrial Wind Towers.

I attended the Charles Mix County Commissioners regular hearing on August 9, 2018.

I presented to the Hutchinson County Zoning Board my concerns of the deception of the developer of the Project at the regular August 2, 2018 meeting.

I presented to the Hutchinson County Board of Adjustment my request for protection, for their strong consideration of the concerns I had, and the conditions I felt needed in the event they would not deny the Conditional Use Permit at the Public Hearing on September 4, 2018.

I amend this section to include the attachments and provide unwritten communications information:

- a) For any written communications, provide a copy of the communication; and  
Attached
- b) For any unwritten communications, provide the date of the communication, the persons involved, and the subject matter of the communication.

Simple calls to confirm the meetings were on schedule as I live 20 miles from the Hutchinson County Courthouse and the Bon Homme County Courthouse. Dates not available.

I amend this section to include:

A call to Cliff Tjaden Hutchinson Zoning Director to request minutes of the August 6, 2018 regular Zoning Board meeting and the minutes of the September 4, 2018 Public Hearing for the Conditional Use Permit requested by Applicant. I don't remember the date.

A call to Scott Podhradsky, Deputy Attorney for Charles Mix County, to inquire about the agreement the Commissioners entered into with the Applicant. August 13, 2018 I believe.

I had interactions with public employees at Bon Homme County and Hutchinson County Courthouses to request minutes of the Bon Homme County Public Hearing regarding Article 17 that had been posted twice, (but each having a different time for the hearing), to review and obtain public records, and to review the Application.

Dated this 4<sup>th</sup> day of October, 2018

Karen Jenkins

28912 410<sup>th</sup> Ave

Tripp SD 57376

**EXHIBIT A25**

**BEFORE THE PUBLIC UTILITIES COMMISSION  
OF THE STATE OF SOUTH DAKOTA**

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**IN THE MATTER OF THE  
APPLICATION BY PREVAILING  
WIND PARK, LLC FOR A PERMIT OF  
A WIND ENERGY FACILITY IN BON  
HOMME COUNTY, CHARLES MIX  
COUNTY AND HUTCHINSON  
COUNTY, SOUTH DAKOTA, FOR THE  
PREVAILING WIND**

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**AMENDED  
RESPONSE TO  
STAFF'S FIRST SET OF DATA  
REQUESTS TO INTERVENORS  
EL18-026**

Below, please find my amended responses:

Below, please find my response to Staff's

First Set of Data Requests to Intervenors. Thank you for allowing me the extension to submit my response by August 24, 2018, at 5:00 pm.

- 1-1) Provide copies to Staff of all data requests served on Applicant at the time of service.

**I will provide this information.**

- 1-2) Provide copies to Staff of all of your answers to data requests from Applicant at the time they are served on Applicant.

**I will provide this information.**

- 1-3) Refer to SDCL 49-41B-22. Please specify particular aspect/s of the applicant's burden that the individuals granted party status intend to personally testify on.

**I am in the process of reviewing the Application to find if it is sufficient to provide for the conditions set forth SDCL 49-41B-22. I have not decided if I will testify or not.**

I amend this to section to include:

I am confused about and would appreciate clarification on the process of developing this project which ultimately brought us here to the SDPUC. The developer Prevailing Winds, LLC., submitted an application to the SDPUC for 100 turbines and after the required public hearing was held, withdrew the application. The developer then split the project into 13 different projects for the purpose of selling electricity, under what I believe is related to PURPA, yet the SDPUC considered it one project during that process. After it was split up, how was it or how is it still one project? If the Commission does not have the authority or jurisdiction to determine or explain this, I ask that my question be referred to the proper authority before the Commission makes a decision on the Application.



- 1-4) Refer to SDCL 49-41B-25. Identify any “terms, conditions, or modifications of the construction, operation, or maintenance” that the Intervenor would recommend the Commission order. Please provide support and explanation for any recommendations. **To be clear, I recommend that the Commission deny this application. I recommend this from my experience of the Beethoven Wind Farm from permitting, construction, to the operation of it, to date.**

**If the Commission will not deny the application, I recommend the condition of a 4-mile setback. My support is the fact that I live 3 miles from six Beethoven Wind Farm Industrial Wind Turbines and the height of 586 foot turbines as the Applicant has chosen is unprecedented and I believe will negatively impact my husband and myself without the 4 mile setback.**

I amend this condition to:

If the Commission will not deny the application, I request a 4-mile setback from my home (not property line, my actual home) and ask that any turbines planned within 4 miles of my home be removed from the project.

A 4-mile set back, would help to diminish the cumulative effect on us, of the existing Beethoven Wind Farm and the proposed Prevailing Winds Park. The risk of negative health effects, loss of enjoyment of our property, loss of the residence to be inhabitable, and the loss of the property to be marketable may be somewhat alleviated by a 4-mile set back.

A 4-mile set back would possibly allow us to remain on our property and negate the need for us to attempt to relocate.

Additionally, of great concern to us, is the potential for future industrial wind farm projects around us. Less than a 4-mile set back will set precedence for future industrial wind farms around us that I believe are most likely in the planning stage now.

**I request the ALDS which eliminates the alarming red blinking lights at night. If the FAA does not approve them, I recommend the application be denied.**

**The red blinking lights are meant to alarm. The red blinking lights on the Beethoven Wind Farm are a nuisance. To have an additional 57 turbines, many with the alarming red blinking lights will be result in a much bigger nuisance. The Applicant should be prevented from creating a nuisance.**

I amend this to include:

I request the FAA approval of the actual use of the ALDS on this project prior to the approval of this Application or the Application be denied. If unable to obtain

FAA approval of the actual use of the ALDS on this project prior to the approval deadline of this Application, I ask the Application be denied. If the use of the ALDS on this project is in question, the project should not go forward. The cumulative effect of red blinking lights from the Beethoven Wind Farm and Prevailing Winds Park would disturb the peacefulness of the rural landscape views from within nearby residences and cause alarm. The cumulative effect of Beethoven Wind Farm and Prevailing Winds Wind Park would destroy the nighttime peacefulness of the rural landscape outside for residences nearby at night and as well as for residents and those traveling for miles and miles and miles, changing the setting from rural to industrial.

**I request a Bat Detection and Shutdown System be installed on all Industrial Wind Turbines in this project. Bat fatalities negatively affect agriculture and the environment.**

I withdraw my request for a Bat Detection and Shutdown System.

**I request a decommissioning bond, paid for up front. Once the Industrial Wind Turbines are up, they are up. Whether or not the proposed Industrial Wind Farm will be lucrative enough to produce the income to provide for a bond in ten years is not and cannot be proven.**

**I request a liaison person to monitor the project as it is being built to insure compliance and an avenue for those in the footprint to voice concerns and complaints. A project of this size must have a liaison.**

**I request a liaison person to monitor the project from the commencing of operation through the decommissioning. I have not been able to reach anyone to assist me when I have had concerns with the existing Beethoven Wind Farm.**

I withdraw my request for a liaison person to monitor the project from commencing of operation through the decommissioning.

**I request there be no shadow flicker on non-participating residences, as shadow flicker presents a nuisance and the Applicant should be prevented from creating a nuisance.**

**I request a Guarantee of Property Value to be funded and developed by the Applicant, subject to approval of the Property Owner to protect residents in the footprint and buffer zone from financial loss should the residence become unlivable**

**and / or unmarketable. The Applicants project will have serious financial implications on many of the residents in the footprint and the buffer zone.**

I amend this to withdraw my request for a Guarantee of Property Value.

- 1-5)** Is there a specific objection (example health, blinking lights, sound) you have with respect to the Project? Please briefly explain.

I amend this section to include:

I stated in my comments at the Public Hearing for this docket in Avon, SD on July 12, 2018 that as the Commissioners consider “the views of governing bodies of affected local units of government” to please consider this: **We have not been represented properly by our local government.** When asked by Commissioner Nelson which county I was referring to I responded Bon Homme.

The Applicant makes direct reference to the Bon Homme County Zoning in the Application and is using that zoning to substantiate its fulfillment of burden of proof of the SDPUC requirement of the Applicant;

#### Applicant Responsibility

Applicant Responsibility The applicant that seeks the PUC’s approval must show its proposed project:

- will comply with all applicable laws and rules;
- will not pose a threat of serious injury to the environment nor to the social or economic condition of inhabitants or expected inhabitants in the siting area;
- will not substantially impair the health, safety or welfare of the inhabitants;
- and
- will not unduly interfere with the orderly development of the region with due consideration having been given to the views of

The Bon Homme County Zoning does not adequately protect the resident’s health, safety, and welfare and should not be considered or relied upon to establish or substantiate the Applicants required burden of proof is being met.

I amend this section to include:

I object to the Cumulative Effect of the existing Beethoven Wind Farm and the proposed Prevailing Winds Wind Park.

Cumulative Effect discussed in the Application Section 20 states:

“The Prevailing Wind Park Project, in combination with the 80-MW Beethoven Wind Project, would result in the construction and operation of up to 104 wind turbines and associated access roads, collector lines, and other facilities in Bon Homme, Hutchinson, and Charles Mix counties. The projects would result in an estimated 70 acres of cumulative ground disturbance during the life of the projects. This disturbance acreage represents less than 0.2 percent of the combined acreage of both project areas. As discussed in this Application, impacts to the physical environment, hydrologic resources, terrestrial and aquatic ecosystems, and socioeconomic and community resources have been avoided or minimized during the siting and design of the Project. Furthermore, implementation of the mitigation measures identified in this Application would minimize potential impacts of the Project on all resources. Therefore, the cumulative effects of siting the proposed Project in combination with the Beethoven Wind Project on resources within Bon Homme, Hutchinson, and Charles Mix counties are not expected to be significant.”

I am very concerned that the Commission will rely on it to use it as grounds to approve the Application as it did in the decision on Crocker EL17-055 under:

## **FINDINGS OF FACT**

### **I. PROCEDURAL**

“48. Crocker has demonstrated that it will minimize and/or avoid impacts to visual resources. 86 For example, consistent with the South Dakota Bat Working Group's and GFP's Siting Guidelines for Wind Power Projects in South Dakota for reducing impacts to visual resources, Crocker has collocated linear Project features such as access roads, crane paths, and collector and communication systems with existing disturbances to the extent practicable. 87 “

I refer specifically to this sentence:

**“Due to the presence of existing wind farms in the vicinity of the Project Area, significant adverse impacts to visual resources are not anticipated.88”**

Clearly, the addition of another industrial wind farm will have a negative Cumulative Effect , not only by changing the current view shed negatively for those in the footprint and the buffer zone, it will affect the view shed for miles, and miles, and miles.. It will change our visual of a rural setting to an industrial setting. This is not an insignificant change.

This project would, as planned, would introduce 57 (this is the amount of turbines to be in the project at the time of this writing) more industrial wind turbines onto what is now a beautiful rural countryside. The industrial wind turbines will be sited from twelve miles north to south on the projects eastern border, nine miles from east to west on the north and south borders, and seven miles from north to south on the western border. This Cumulative Effect will certainly negatively affect residents in three Counties. This will not be insignificant.

As for our property and home; it will all encompass the west, southwest, and south of our view shed. This will substantially impair the welfare of my husband and I by most likely causing us to try to relocate, if we could sell our home and property.

I amend this section to include:

As I witnessed with the developers of the Project, who were the same for the Beethoven Wind Farm Project, I am concerned and object to the Prevailing Winds Wind Park being another stepping stone, to infiltrate the areas surrounding our home with additional industrial wind parks thus changing our dream of rural living, that we were fortunate to realize, into a nightmare of living in one huge Industrial Wind Park or worse, of having to relocate, possibly with little means to do so.

From the Application: 23.0 FUTURE ADDITIONS AND MODIFICATIONS (ARSD 20:10:22:25) ARSD 20:10:22:25. Future additions and modifications. The applicant shall describe any plans for future modification or expansion of the proposed facility or construction of additional facilities which the applicant may wish to be approved in the permit. No future additions and modifications are anticipated. Prevailing Wind Park does request the turbine location flexibility and other facility flexibility specified in Section 8.1.

The Project was being planned as early as or earlier than the year 2014. I am concerned a third phase is being planned.



**The nuisance of red blinking lights as mentioned above in section 1-4. If the FAA will not approve the use of the ALDS the application should be denied.**

**Most concerning is sound, both audible and infrasound. There are many complaints about both audible and inaudible noise from Industrial Wind Turbines, they are well documented. The result of negative health effects to some residents from both audible and inaudible noise is also well documented.**

I amend this to include LFN and sound pressure.

**Health, again the size of the Industrial Wind Turbines the Applicant has chosen is unprecedented. The area and range they will impact is unknown and will likely cause the loss of enjoyment of property, loss of use of property, loss of the residence to be inhabitable, and the marketability of property will be greatly diminished.**

What, if anything, do you feel could be done to remedy that issue?

**Deny the Application.**

**If the Commissioners will not deny the application, the Commission must then approve the Application with conditions that will truly protect the health, safety, and welfare of all of the residents living in and near the footprint.**

I amend this to emphasize: truly protect the health, safety, and welfare of all of the residents living in and near the footprint. While I have specific experience of living near Beethoven Wind Farm I have asked for the set -back I believe to be a minimum to satisfy our particular situation. I am not prepared to recommend an appropriate set back of others, although I would not recommend anything closer than 4 miles.

**Sound should not exceed 35 decibels for non-participating residences.**

I amend this to sound should not exceed 35 dB A for non-participating residences and participating residences.

**Setbacks should be 4-miles from a non-participating residence.**

I amend this to request a 4 mile setback from our residence (not our property

line, specifically our home) and I request that any turbines located within 4 miles from our home be removed from the project plans.

While I have specific experience of living near Beethoven Wind Farm I have asked for the setback I believe to be a minimum to satisfy our particular situation.

**An ALDS must be installed. If the FAA does not approve an ALDS the application should be denied.**

I amend this to include: I request the FAA approval of the actual use of the ALDS on this project prior to the approval of this Application or the Application be denied. If unable to obtain FAA approval of the actual use of the ALDS on this project prior to the approval deadline of this Application, I ask the Application be denied.

Please list with specificity the witnesses the Intervenors intend to call. Please include name, address, phone number, credentials and area of expertise.

**I am still reviewing the Application and have not decided if I will call witnesses.**

I amend this to:

I reserve the right to call witnesses or testify on behalf of myself during this hearing.

**1-6) Do the you intend to take depositions? If so, of whom? Not at this time.**

I amend this to I do not intend to take depositions.

Dated this 1st day of October, 2018

Karen Jenkins

28912 410<sup>th</sup> Ave

Tripp, SD 57376

605-680-5646

Jenkinskd55@gmail.com

**WIND TURBINE NOISE 2013  
PROVISIONAL PROGRAMME**

**Tuesday 27 August 2013**

**13.00 – 17.00 Short Course on Noise**

**15.00 – 19.00 Registration**

**17.30 – 19.30 Exposition Reception (Joint with Noise-Con 2013)**

**Wednesday 28 August 2013**

08.00 – 09.30 Plenary Lecture (Joint with Noise-Con 2013)

Wind Turbines: What's all the noise about? An American retrospective and prognostication

Mark Bastasch, USA

**Low Frequency Noise and IS: Measurements**

09.45 Infrasound measurement, interpretation and misinterpretation

Bruce Walker, USA

10.00 Measuring and analyzing wind turbine infrasound and audible immissions at a site experiencing adverse community response

George Hessler, USA

10.15 The measurement of infrasound and low frequency noise for wind farms

Steven Cooper, Australia

*10.30 – 10.45 Discussion*

*10.45 – 11.15 Coffee Break*

**Low Frequency Noise and IS: Effects**

11.15 Infrasound and the ear

Geoff Leventhall, UK

11.30 A proposed theory to explain some adverse physiological effects of the infrasonic emissions at some wind farm sites

Paul D. Schomer et al, USA

11.45 Perception of low frequency components contained in wind turbine noise

Sakae Yokoyama, Shinichi Sakamoto and Hideki Tachibana, Japan

*12.00 – 12.15 Discussion*

*12.15 – 13.30 Lunch*

**Amplitude Modulation**

13.30 Amplitude modulation and complaints about wind turbine noise

Joachim Gabriel et al, Germany

13.45 Audible amplitude modulation - results of field measurements and investigations compared to psycho-acoustical assessment and theoretical research

Mike Stigwood, Sarah Large and Duncan Stigwood, UK

14.00 Amplitude modulation noise analysis and first look at off-shore wind turbine aeroacoustics simulation study

Sidney Xue et al, China

14.15 Thump noise prediction

Rufin Makarewicz, Poland

14.30 Application of phased array techniques for amplitude modulation mitigation

Steven Buck, Scott Palo and Patrick Moriarty, USA

*14.45 – 15.15 Discussion*

*15.15 – 15.45 Coffee Break*

**Transducers Instrumentation**

15.45 Evaluation of secondary windshield designs for outdoor measurement of low frequency noise and infrasound

Kristy Hansen, Branko Zajamek and Colin Hansen, Australia

16.00 Improvement of regression analysis on wind noise effects for low frequency sound measuring in natural wind

Noboru Kamiakito et al, Japan

## **EXHIBIT A25**

- 16.15 How frequency response influences measurement and audibility of periodic wind turbine sound  
Werner Richarz, USA and Harrison Richarz, UK
- 16.30 Wind turbine noise measurements in practice  
Carsten Thomsen and Simon Møller Nielsen, Denmark
- 16.45 Highly distributed data acquisition on wind turbines with PAK  
Dejan Arsic and John Huff, Germany

*17.00 – 17.30 Discussion*

**Thursday 29 August 2013  
Session Room A**

**Aerodynamic Noise Generation and Control**

- 08.00 Review of NACA 0012 turbulent trailing edge noise data at zero angle of attack  
Con Doolan and Danielle Moreau, Australia
- 08.15 Wind turbine noise modelling based on Amiet's Theory  
Y. Tian, B. Cotté and A. Chaigne, France
- 08.30 Broadband noise prediction of small horizontal wind turbine rotor  
Bavuudorj Ovgor and Seungbae Lee, Republic of Korea
- 08.45 Hybrid methods for noise prediction in aeroacoustic simulations of small vertical axis wind turbines  
Johannes Weber et al, Germany and Austria
- 09.00 Wake patterns and noise in a dual rotor wind turbine  
K. Asfar and A. Mahasneh, Jordan
- 09.15 The effect on noise emission from wind turbine due to ice accretion on rotor blades  
Peter Arbinge and Paul Appelqvist, Sweden
- 09.30 Noise prediction of wind turbine and low noise blade design  
Kentaro Hayashi et al, Japan
- 09.45 Aeroacoustic noise mitigation investigation for wind turbine blades  
Michael Asheim, Patrick Moriarty and David Munoz, USA
- 10.00 – 10.30 *Discussion*
- 10.30 – 11.00 *Coffee Break*

**Structureborne Noise/Vibration**

- 11.00 Noise from one stage of helical gears by wind turbine load  
Chan IL Park, Republic of Korea
- 11.15 A validated virtual prototyping approach for avoiding wind turbine tonality  
Goris Sonja et al, Belgium and Germany
- 11.30 Suppression of the structure-borne sound from a wind turbine generator using active vibration control devices: model experiment  
Tetsuya Miyazaki et al, Japan
- 11.45 – 12.00 *Discussion*

**Source Identification**

- 12.00 Noise source localization on a 8kW wind turbine using a compact microphone array with advanced beamforming algorithm  
Rakesh Chandran Ramachandran et al, USA
- 12.15 Acoustic array design for wind turbine noise measurements  
Steven Buck et al, USA
- 12.30 Identification of wind turbine noise through signal analysis  
Michael Medal et al, Canada
- 12.45 – 13.00 *Discussion*
- 13.00 – 13.45 *Lunch*

**Session Room B**

**Effects of WTN on Individuals**

- 08.00 Audit report: Literature reviews on wind turbine noise and health  
Brett Horner, Carmen Krogh and Roy Jeffrey, Canada
- 08.15 Wind turbine noise: What has the science told us?  
Loren D. Knopper et al, Canada
- 08.30 Perception change of soundscape as wind turbine alters community sound profile  
William K.G. Palmer, Canada
- 08.45 Trading off human health: Wind turbine noise and government policy  
Carmen Krogh et al, Canada
- 09.00 Wind turbine facilities' perception: a case study from Canada  
Peter N. Cole and Carmen Krogh, Canada
- 09.15 Correlation between people perception of noise from large wind turbines and measured noise levels  
Federica Andreucci et al, Italy      Enrico Mazzocchi will give this paper.
- 09.30 Masking of sage-grouse display calls by noise from wind turbines  
Scott Noel, USA
- 09.45 – 10.15 *Discussion*
- 10.15 – 10.45 *Coffee Break*



**Sound Immission Measurements Part 1**

- 10.45 Noise's measure inside homes generated by the functioning of wind farm in southern Italy  
Amelia Trematerra and Gino Iannace, Italy
- 11.00 Hiding wind farm noise in ambient measurements - noise floor, wind direction and frequency limitations  
Steven Cooper, Australia
- 11.15 Tonality assessment at a residence near a wind farm  
Jonathan Cooper, Tom Evans and Dick Petersen, Australia
- 11.30 Evaluation of wind turbine-related noise in western New York State  
Martin T. Schiff et al, USA
- 11.45 The variability factor in wind turbine noise  
Jim Cummings, USA
- 12.00 Annoyance from wind turbine noise – what can we learn from different assessment methods?  
Sabine von Hünenbein, UK
- 12.15 – 12.45 *Discussion*
- 12.45 – 13.45 *Lunch*

**Sound Immission Measurements Part 2**

- 13.45 Simultaneous indoor low-frequency noise, annoyance and direction of arrival monitoring  
Branko Zajamsek et al, Australia
- 14.00 Generating a better picture of noise immissions in post construction monitoring using statistical analysis  
Payam Ashtiani, Canada
- 14.15 Wind farm noise commissioning methods: A review of methods based on measuring at receiver locations  
Christophe Delaire et al, Australia
- 14.30 Assessment of wind turbine noise in immission areas  
Hideki Tachibana, Hiroo Yano and Akinori Fukushima, Japan
- 14.45 – 15.15 *Discussion*
- 15.15 – 15.45 *Coffee Break*

**Sound Emission Measurements**

- 15.45 Wind turbine noise measurements - how are results influenced by different methods of deriving wind speed?  
Sylvia Broneske, UK
- 16.00 RoBin: Meeting the requirements of the IEC 61400-11 standard for measuring the acoustic emission of wind turbines with a one-man operated system  
D. Vaucher De La Croix, France and T. Klaas, Germany
- 16.15 Tonality in wind turbine noise. IEC 61400-11 ver. 2.1 and 3.0 and the Danish/Joint Nordic method compared with listening tests  
Lars Sommer Søndergaard and Torben Holm Pedersen, Denmark
- 16.30 The production of a good practice guide to assess wind turbine noise in the United Kingdom using ETSU-R-97  
Richard Perkins et al, UK
- 17.00 – 17.30 *Discussion*
- 19.00 – 22.30 *Reception and Banquet at Denver Art Museum*

**Friday 30 August 2013****Propagation Wind Effects Modelling Part 1**

- 08.30 Sound propagation from wind turbines under various weather conditions  
Olof Öhlund and Conny Larsson, Sweden
- 08.45 Proposed method for characterizing wind turbine noise and their dependence on meteorological effects for validation of existing studies  
David S. Woolworth, Roger Waxler and Jeremy Webster, USA
- 09.00 Wind farm layout optimization in noise constrained areas  
Andrew Brunskill, Canada
- 09.15 Validation of WindPRO implementation of Nord2000 for low frequency wind turbine noise  
Lars Sommer Søndergaard and Thomas Sørensen, Denmark
- 09.30 Environmental noise assessment of proposed wind farms using annual average Ldn  
Mark Bliss, Canada
- 09.45 – 10.00 *Discussion*
- 10.00 – 10.30 *Coffee Break*

**Propagation Wind Effects Modelling Part 2**

- 10.30 Accuracy of noise predictions for wind farms  
Jonathan Cooper and Tom Evans, Australia
- 10.45 Large-scale calculation of possible locations for specific wind turbines under consideration of noise limits  
Fabian Probst, Wolfgang Probst and Bernd Huber, Germany
- 11.00 The new good-practice-guide to help assessment of wind turbine noise in Finland  
Denis Siponen et al, Finland
- 11.15 Physics based spatial acoustics in virtual scenes with application to wind farm noise  
Kevin Nelson and Steven G. Mattson, USA
- 11.30 – 11.45 *Discussion*
- 11.45 – 13.00 *Lunch*

**Regulations & Policies Part 1**

- 13.00 Which limits for wind turbine noise? A comparison with other types of sources using a common metric  
Gaetano Licitra and Luca Fredianelli, Italy
- 13.15 International legislation and regulations for wind turbine noise  
Kevin Fowler, USA, Erik Koppen, The Netherlands and Kyle Matthis, USA
- 13.30 New environmental regulation for wind turbines in Flanders (Belgium)  
Arjan Goemé, Belgium
- 13.45 Danish regulation of low frequency noise from wind turbines  
Jørgen Jakobsen and Jesper Mogensen, Denmark
- 14.00 Low frequency noise from wind turbines: Do the Danish regulations have any impact?  
Bo Søndergaard, Denmark
- 14.15 – 14.30 *Discussion*
- 14.30 – 15.00 *Coffee Break*

**Regulations & Policies Part 2**

- 15.00 Low frequency noise proposed wind farm in Maastricht, The Netherlands  
Erik Koppen, The Netherlands
- 15.15 How does noise influence the design of a wind farm?  
Matthew Cassidy, Alden D'Souza and Jeremy Bass, UK
- 15.30 Wind power development trends in Denmark: Targets, legislation and social acceptance  
Karina Lindvig, Denmark
- 15.45 Projected contributions of future wind farm development to community noise and annoyance levels in Ontario, Canada  
Melissa L. Whitfield Aslund, Christopher A. Ollson and Loren D. Knopper, Canada
- 16.00 State of wind turbine developments in northeastern USA – 2013  
James D. Barnes, Marc S. Newmark and Bill Yoder, USA
- 16.15 Recent developments in wind farm noise in Australia  
Chris Turnbull and Jason Turner, Australia
- 16.30 – 17.00 *Discussion*
- 17.00 – 17.15 *Closing Ceremony*

## Siting Guidelines for Wind Power Projects in South Dakota



### Introduction

The South Dakota Bat Working Group in cooperation with the Department of South Dakota Game, Fish and Parks compiled these siting guidelines for wind power developers and other stakeholders to utilize as they consider potential wind power sites in South Dakota. Wind power siting and permitting processes vary by county and/or city. The Public Utilities Commission has agreed to distribute siting guidelines to all stakeholders involved in the development of wind power in South Dakota, since at this time no state environmental regulations exist in association with siting of wind turbines.

Wind siting guidelines relevant to South Dakota were adapted from the National Wind Coordinating Committee's (NWCC) Permitting of Wind Energy Facilities: A Handbook and the Kansas Renewable Energy Working Group (KREWG) Environmental and Siting Committee's Siting Guidelines for Windpower Projects in Kansas. The National Wind Coordinating Committee's guidelines are available online at the following website address: <http://www.nationalwind.org/publications/sitingq.htm> and the Kansas Renewable Energy Working Group's guidelines are available online at the following address: <http://www.kansasenergy.org/krewg/reports/KREWGSitingGuidelines.pdf>.

South Dakota's guidelines address activities and concerns associated with siting and permitting wind turbines. Successfully siting a wind power project often relies on trade-offs between community acceptability and economic viability, which relates to adequate communication.

Although wind power is considered "green energy," many concerns have been expressed about the effects of their presence on plants and animals native to South Dakota. Specific areas of South Dakota have been identified as potential sites for wind energy development, and these sites are located in, but not limited to, the Coteau des Prairies in eastern South Dakota and the Missouri River in central South Dakota, which are unique/rare in South Dakota. Additional areas in other regions of the state may be identified/added by ongoing studies or further infrastructure development (e.g., transmission lines and substations).

Wind energy issues in South Dakota are similar to those in other states. Most residents of South Dakota respect their local resources, wildlife, and environment, and have concerns regarding the exploitation and/or degradation of those resources. Developers, recognizing the opportunity to establish renewable energy generation facilities, may not be aware of concerns expressed by agencies, groups, or individuals regarding wind farm impacts. Each project should be evaluated on a case by case basis. Cumulative impacts will undoubtedly accrue as development proceeds within regions (e.g., Missouri River, Coteau des Prairies, Prairie Pothole) and across the state. These

cumulative effects may differ in type and significance from those experienced at individual project sites. In particular, the cumulative effects on natural and biological resources, such as habitat (e.g., native prairie) and wildlife (e.g., birds and bats), require consideration from all stakeholders; however, impacts on other resources are also important. For further development and sustainability of the wind energy industry, it is important by all stakeholders to evaluate the context of the collective merits of all projects.

Most guidelines within this document are issues and concerns identified by other parties, e.g., NWCC and KREWG, which are shared in South Dakota, but some guidelines are tailored to address the concerns and issues specifically to this state. These guidelines address issues/concerns associated with the pre-construction, construction or post-construction of wind turbines and have been divided into eleven general categories:

- 1) Land Use
- 2) Natural and Biological Resources
- 3) Noise
- 4) Visual Resources
- 5) Public Interaction
- 6) Soil Erosion and/or Water Quality
- 7) Health and Safety
- 8) Cultural, Archaeological, and Paleontological Resources
- 9) Socioeconomic, Public Service, and Infrastructure
- 10) Solid and Hazardous Wastes
- 11) Air Quality and Climate.

The guidelines outlined in this document are neither mandates nor regulations. They have been compiled/developed: 1) to encourage developers to select potential wind sites using a process that is acceptable to all stakeholders (e.g., state agencies/departments, federal agencies, sportsmen/women groups, local communities, developers, landowners, wildlife advocacy groups, and/or tribal agencies); 2) to protect South Dakota rare/unique areas (e.g., Coteau des Prairies, Missouri River, and Prairie Potholes) and thus the state's natural beauty; 3) to minimize deleterious effects to wildlife; 4) to help provide information to all involved/interested parties; and 5) to promote a responsible, guided, uniform approach to the siting of wind power projects in South Dakota.

- 1) Land Use - Wind development may be compatible with a variety of other land uses, including agriculture, grazing, open space, and habitat conservation, depending on the site, size, and design of the project. Other land uses, such as hunting/fishing, bird watching, and wildlife photography as well as resource values need to be considered when siting large wind projects in remote areas of South Dakota. Stakeholders need to understand all the land use issues associated with a site before finalizing development plans, permit conditions, or other requirements.
  - a) Contact resource agencies (Table 1), property-owners and other stakeholders early to identify potentially sensitive land uses and issues. Ensure that all the stakeholders fully understand the entire project in order to address and resolve potential land use issues.
  - b) Look at all the land use relationships and objectives for an entire wind resource area. Land use concerns are specific to different regions of South Dakota thus early scoping and planning is crucial to reducing potentially incompatible uses. Contact appropriate experts (Table 2) and resource agencies to research and evaluate the issues prior to selecting a specific site within the respective region.
  - c) Careful consideration should be given to the impact of wind power projects in areas that are unique/rare in South Dakota, such as the Missouri and Prairie coteaus (Figure 1), the Prairie Pothole region and the Missouri River. Special care should be given to avoid damage to unfragmented landscapes and high quality remnants in wetland and prairie ecosystems (e.g., tall grass, mixed grass, and short grass prairie). If possible, wind energy development should be located on already altered landscapes, such as cultivated or developed lands. An undeveloped buffer adjacent to intact prairies is also desirable.
  - d) Consider the potential impacts of both wind and non-wind (e.g., roads, transmission lines, substations) project development in the wind resource area before development projects are proposed, and develop a plan for the area that avoids or minimizes land use conflicts. Design the project site layout to limit the use of the land, consolidate necessary infrastructure requirements wherever possible, and evaluate current transmission lines and market access.
  - e) Learn the rules that govern where and how a wind project may be developed in the project area. Become aware of potential conflicts between lease provisions and permitting agency (e.g., The Public Utilities Commission and/or local governments) conditions for project development.

- 2) Natural and Biological Resources - Bird and bat collision mortality and behavioral avoidance associated with wind energy facilities have been a controversial siting consideration. Typically, bats have a higher incidence of mortalities at wind energy sites than birds, though this depends on the site. Biological resource surveys at each potential wind power site in the early stages of planning can help determine whether serious conflicts are likely to occur at a particular site, but cumulative effects with multiple sites in a particular region/area must also be acknowledged and/or investigated and minimized/avoided. In some instances, the impact wind turbines have on birds, bats, and other sensitive biological resources can be adequately mitigated. However, wind development may be inappropriate in certain areas in South Dakota.
- a) Consider the biological setting early in project evaluation and planning. Use biological and environmental experts to conduct a preliminary biological reconnaissance of the likely site area. Communicate with personnel from wildlife agencies (e.g., South Dakota Game, Fish and Parks (SDGFP), U. S. Fish and Wildlife Service, U. S. Geological Survey, and Natural Resources Conservation Service; Table 1) and universities (e.g., South Dakota State University, University of South Dakota, Dakota State University, Black Hills State University, and Northern State University; Table 2). If a proposed turbine site has a large potential for biological conflicts and an alternate site is eventually deemed appropriate, the time and expense of detailed wind resource evaluation work may be lost.
  - b) Contact the local resource management agency (e.g., local South Dakota Conservation District and SDGFP regional office, Appendix A) early in the planning process to determine if there are any resources of special concern in the area under consideration.
  - c) Involve local environmental/natural resources groups (e.g., South Dakota Wildlife Federation, local chapters of Audubon Society, local chapters of The Wildlife Society, Izaak Walton League, The Nature Conservancy, South Dakota Bat Working Group, Ducks Unlimited, United Sportsmen for South Dakotans; Table 3) as soon as practicable. Early involvement of these organizations may provide additional resource information as well as minimize potential conflicts.
  - d) Avoid unnecessary ecological impacts of wind power development through proper planning. Examine landscape levels of key wildlife habitats, migration corridors, staging/concentration area, and breeding/brood-rearing areas to help develop general siting strategies. Situate turbines so they do not interfere with important wildlife movement corridors and staging areas.



- e) Avoid large, intact areas of native vegetation. Sites where native vegetation is scarce or absent will have substantially fewer biological resource concerns.
- f) Careful review should be given to sites with legally protected wildlife (e.g., state or federal threatened or endangered species, migratory birds) present or potentially present. Recognize that other declining or vulnerable species (not legally protected) may also be present. Investigate wildlife issues associated with each potential wind energy site and determine the apparent impacts of each potential wind energy site on species of concern.
- g) Avoid lattice-designed towers or other designs providing perches for avian predators. Avoid placing perches of any sort on the nacelles of turbines. Address potential adverse affects of turbine warning lights on migrating birds and bats. Minimize effects of meteorological towers when investigating wind energy potential by using tubular monopoles rather than lattice structures with guy wires and lighting systems, which could represent a hazard to birds.
- h) Bury power lines and/or place turbines near existing transmission lines and substations, where possible. Infrastructure should be able to withstand periodic burning of vegetation, where prescribed burns are practiced. Minimize number of roads and fences.
- i) Mitigate for habitat loss in areas where there is ecological damage in the siting of a wind power facility. Appropriate actions include but are not limited to ecological restoration, long-term management agreements, conservation easements, or fee title acquisitions to protect lands with similar or higher ecological quality as that of the wind power site.
- j) Consider possible cumulative regional impacts from multiple wind energy projects when conducting environmental assessments and making mitigation decisions. Evaluation of these impacts could result in significant changes to project plans.
- k) Consider turbine designs (e.g., wind turbines with tubular monopoles rather than lattice structures with guy wires) or deterrents, which minimize potential impacts on flying animals such as birds and bats.
- l) Consider timing of construction and maintenance activities (including mowing) to minimize impacts on native flora (plants) and fauna (animals), including ground-nesting birds. Avoid construction and maintenance activities during breeding season (April to July) and, if possible, during migration (April – June and August – October).

- m) Develop a stringent plan for preventing the introduction or establishment of non-native/invasive flora (plants) in disturbed areas and establishing the financial means to do so the duration of the wind power project.
- 3) Noise - Noise emitted by wind turbines tends to be masked by the ambient (background) noise from the wind itself and tends to fall off sharply with increased distance, therefore noise-related concerns are likely to occur at residences closest to the site, particularly those sheltered from prevailing winds. Advanced turbine technology and preventive maintenance can help minimize noise during project operation.
  - a) Design projects with adequate setbacks from dwelling units, especially where the dwelling unit is in a relatively less windy or quieter location than the turbine(s). Recognize that residents who object to noise created by wind energy may replace residents who support wind systems. Efforts should be made to place the turbines in disturbed areas (e.g., croplands) as stated above.
  - b) Avoid locating marginally noisy turbines in projects with nearby residences. In areas potentially sensitive to acoustic levels, e.g., nearby residences or natural surroundings, consider taking efforts to prevent problems by upgrading turbines with sound reduction technology.
- 4) Visual Resources - There are ways to reduce the visual impact of wind projects, but there may be tradeoffs to consider. One of the best tools for assessing project impact is the use of visual simulations.
  - a) Consider visual impact of wind power projects when siting turbines. Evaluate the impact of siting turbines on the quality of the surrounding landscape, especially in areas where aesthetic qualities and/or neighboring properties might be affected. Prepare and use visual simulations and/or viewshed analyses to provide information to landowners, the general public, and other key stakeholders to identify potential impacts to visual resources from wind power developments.
  - b) Educate all stakeholders about what to expect from a wind project.
  - c) Prepare to make impact tradeoffs and coordinate planning efforts in all jurisdictions and with all stakeholders.
  - d) Listen to the communities and stakeholders in all project phases and be prepared to adapt design to minimize industrial characteristics and structures and minimize visual exposure from sensitive areas.
  - e) Minimize the need for developed roads or cut and fill techniques. Consider possibilities and benefits of using roadless project designs or designs relying on current roads, especially in remote or sensitive visual areas.

- f) Identify designated scenic byways and popular landscapes and avoid siting turbines in areas that are readily visible from those sites. Priority should be given to wind power projects in sites where the natural landscape has already experienced significant change from human-related causes.
- 5) Public Interaction - It is important to inform all stakeholders of the benefits and tradeoffs associated with each wind power project, therefore wind projects entail public involvement. This makes it easier for all stakeholders to communicate and cooperative with each other in order to make informed decisions in the best interest of all parties.
- a) Prepare and implement a public education program to discuss the benefits and tradeoffs involved in wind generation.
  - b) Provide objective information or access to objective information that allows interested parties to make informed decisions. Decision making by all stakeholders is enhanced through accurate and comprehensive information sharing and opportunities for communication between stakeholders. Invite public input in regards to wind power projects through public meetings and public forums.
- 6) Soil Erosion and/or Water Quality - Temporary and permanent soil disturbance results from wind projects. Care must be taken to estimate and control both runoff and erosion from each wind power site, particularly in areas where access roads and facilities are located in steep terrain, especially near waterways (e.g., creeks and rivers) and wetlands.
- a) Minimize the footprint of the project and evaluate alternative turbine pad and access road siting and layouts. Minimize improved roads and construction staging areas and avoid sensitive habitats (e.g., native prairies and wetlands).
  - b) Preferably conduct construction and maintenance of wind power sites when the ground is frozen or when soils are dry and the native vegetation is dormant. Conduct ongoing operation and maintenance activities, as practical, by using light conveyances in order to minimize habitat disturbance and the need for improved roads.
  - c) Whenever possible, avoid road construction on steep slopes.
  - d) When selecting the appropriate erosion control measures, be aware that although some measures may require greater initial expense, significant savings will occur over the life of the project in reduced maintenance and replacement costs. Furthermore, a well-developed erosion and sediment control plan may also reduce regulatory delays in approving and monitoring the project.

- e) Use certified weed-free seed of local ecotypes of native vegetation when reseeding disturbed areas and consider revegetation re-growth and cover. Consider animal and plant compositions when determining the frequency and timing of mowing near turbines.
- 7) Health and Safety - Most of the safety issues associated with wind energy projects can be dealt with through adequate setbacks, security, safe work practices, and the implementation of a fire control plan.
  - a) Consider safety setback distances from wind turbines and habitable dwellings, public highways, and property lines when evaluating specific parcels for development. Setbacks should provide adequate spacing from falling ice, blown turbine parts, and major structural failure, which can mitigate siting issues.
  - b) Design facilities and turbine pads to prevent or avoid public and worker safety problems. Consider the benefits of underground wiring between turbines and project substation.
- 8) Cultural, Archaeological, and Paleontological Resources - During project design and site development, important cultural and fossil resource sites should be avoided and protected or else a mitigation plan should be developed. Special care should be taken to preserve the confidentiality as well as the integrity of certain sensitive resources or sites sacred to Native Americans.
  - a) Identify and avoid potentially sensitive cultural, historical, or pre-historical resources and involve all stakeholders early on.
  - b) Consult with the South Dakota State Historical Society (Table 1) and other qualified professional specialists familiar with cultural and fossil resources in the project development area.
  - c) Some sensitive resources and sites may be confidential to Native Americans. Respect this confidentiality and work closely with tribal representatives to protect these resources by avoiding disruption to these sites.
  - d) Design project site layout to avoid sensitive resources, if possible.
  - e) Prepare a monitoring and mitigation plan for protection of sensitive resources during construction and operation of the project. Require appropriate mitigation of unavoidable impacts and monitor to ensure measures are implemented.
  - f) Allow adequate time in the project schedule for data and specimen recovery, mapping, analysis, and reporting.

- 9) Socioeconomic, Public Services, and Infrastructure - Developers and other stakeholders should coordinate with local communities and/or agencies to determine how the project may affect the community's fire protection and transportation systems and nearby airports and communications systems. Communities should work with wind project developers to ensure that any financial burden placed on them will be compensated through appropriate/reasonable property tax or other revenues.
- a) Identify any community services, costs, and infrastructure that may be affected by a project and work to involve all stakeholders in solving any conflicts and designing mitigation plans. Work with all the concerned stakeholders to develop appropriate mitigation for unavoidable impacts and monitor compliance to ensure the measures are implemented. Attempt to avoid or minimize potential impacts on community services, costs, and infrastructure.
  - b) House Bill 1235, passed during Legislative Session 2003, is an act to provide for the taxation of wind energy property in South Dakota, encouraging developers to build in South Dakota yet help local communities. As any changes to the property tax rate are considered, local taxing jurisdictions should seek to recover only those costs directly associated with services to the wind development to avoid discouraging new wind projects. Involve local communities in economic plan and work to be good neighbors.
  - c) Recognize that some districts, counties, and/or cities do not have an established zoning and/or permitting process applicable to wind power development. Do not exploit this fact rather work with appropriate local officials to establish reasonable parameters and make the process as clear to the public as possible.
  - d) Use local contractors and providers for supplies, services, and equipment, when possible, during the construction and operation phases of the project.
  - e) Acknowledge that there may not be specific needs by local communities for electricity generated by the proposed wind power project, therefore substantive public benefits should be provided beyond hosting the renewable energy facility.
  - f) Provide information to all stakeholders in regards to future project expansions to ensure all stakeholders have precise information. Recognize that developers may not be fully informed about future expansions and stakeholders may have issues and concerns that are dependent on the project scale.

- g) Expanded projects may involve impacts not specifically addressed during the initial project. Anticipate and make provisions for future site decommissioning and restoration.
- 10) Solid and Hazardous Wastes - Solid wastes need to be collected from dispersed sites and properly disposed of in a manner consistent with other power plants or facilities. Non-hazardous fluids should be used where possible, and a Hazardous Materials Waste Plan should be developed if their use cannot be avoided. By performing major maintenance and repair work off-site, certain problems can be avoided.
- a) Ensure that construction wastes are collected from all wind power sites and disposed of at a licensed facility. Waste disposal practices should not be different in wind power from those required at other power plants or repair facilities.
  - b) Anticipate fluid leaks and avoid hazardous leaks by using non-hazardous fluids. Design a Hazardous Materials Waste Plan to address avoidance, handling, disposal, and cleanup, when necessary.
  - c) Conduct turbine maintenance facilities and major turbine repairs off-site.
- 11) Air Quality and Climate - Wind projects produce energy without generating many of the pollutants associated with fuel combustion. Temporary, local emissions associated with project construction and maintenance can be minimized, and any micro-climatic impacts should be insignificant.
- a) Address air quality issues potentially associated with construction and operation of the wind generation project. Mitigate any impacts during sensitive operations so the overall impact is relatively small and temporary.



**EXHIBIT A25****Table 1. Contact information for agencies in South Dakota.**

<b>Name</b>	<b>Specialty</b>	<b>Agency</b>	<b>Address</b>	<b>Telephone</b>	<b>Email</b>
Silka Kempema	Birds and Bats	SDGFP	523 E Capitol Ave Pierre, SD 57501	605-773-2742	silka.kempema@state.sd.us
Natalie Gates	Federal Wildlife Regulations	USFWS	420 South Garfield Avenue, Suite 400 Pierre, SD 57501	605-224-8693	natalie_gates@fws.gov
Jill Shaffer	Bird Research	USGS/NPWRC	8711 37th St. SE Jamestown, ND 58401	701-253-5547	jshaffer@usgs.gov
Ken Higgins	Grassland Birds	USGS/SDSU	Dept of Wildlife & Fisheries Sciences Box 2140B, Brookings, SD 57007	605-688-6121	terry_symens@sdstate.edu
Kevin Luebke	Wildlife Conservation	NRCS	200 4th St SW Huron, SD 57350	605-352-1242	kevin.luebke@sd.usda.gov
Great Plains Office	Diane Mann-Klager	BIA	115 4th Ave SE Aberdeen, SD 57401	605-226-7343	Diane.Mann-Klager@bia.gov
Paige Hoskinson	Archeology	SHPO	900 Governors Drive Pierre, SD 57501	605-773-6004	paige.hoskinson@state.sd.us

**Table 2. Contact information for experts and/or universities in South Dakota**

<b>Name</b>	<b>Specialty</b>	<b>Organization</b>	<b>Address</b>	<b>Telephone</b>	<b>Email</b>
Scott Pedersen	Bats	SDSU	Dept of Biology Box 2207B Brookings, SD 57007	605-688-5529	scott_pedersen@sdstate.edu
Cheryl Schmidt	Bats	BS BioServ, Inc.	18897 Eichler Rd Newell, SD 57760	605-456-1470	cschmidt@bsbioserv.com
Joel Tigner	Bats	Batworks	2416 Cameron Drive Rapid City, SD 57702	605-721-4564	batworks@rushmore.com
Kristel Bakker	Birds	DSU	Dept of Biology SC 128 Madison, SD 57042	605-256-5182	kristel.bakker@dsu.edu
Kent Jensen	Birds	SDSU	Dept of Wildlife & Fisheries Sciences Box 2140B Brookings, SD 57007	605-688-6121	kent.jensen@sdstate.edu
Dave Swanson	Birds	USD	Dept of Biology 191 Churchill-Laines Labs Vermillion, SD 57069	605-677-5211	dlswanso@usd.edu
Dan Tallman	Birds	NSU	Dept of Biology; emeritus professor 1200 South Jay Street Aberdeen, SD 57401	605-626-7707	tallmand@northern.edu
Corey Huxoll	Eagles	SDGFP	523 E Capitol Ave Pierre, SD 57501	605-773-4195	corey.huxoll@state.sd.us
Rocco Murano	Waterfowl	SDGFP	South Dakota State Univeristy Brookings, SD 57007	605-688-4786	rocco.murano@state.sd.us
Dennis Skadsen	Butterflies	SDACD/Day Co.	600 Hwy 12, Suite 1 Webster, SD 57274	605-345-4661	dennis.skadsen@sd.nacdnet.net

**Table 2. Contact information for experts and/or universities in South Dakota, cont.**

<b>Name</b>	<b>Specialty</b>	<b>Agency</b>	<b>Address</b>	<b>Telephone</b>	<b>Email</b>
Paul Coughlin	Habitat	SDGFP	523 E Capitol Ave Pierre, SD 57501	605-773-4194	paul.coughlin@state.sd.us
Dave Ode	Native Plants	SDGFP	523 E Capitol Ave Pierre, SD 57501	605-773-4227	dave.ode@state.sd.us
Dan Hubbard	Wetlands	SDSU	Dept of Wildlife & Fisheries Sciences Box 2140B Brookings, SD 57007	605-688-4780	hubbardd@sdstate.edu
Tim Olson	Wetlands	SDGFP	523 E Capitol Ave Pierre, SD 57501	605-773-3658	tim.olson@state.sd.us
Karen Gaines	Landscape Ecology	USD	Dept of Biology 414 E Clark, Vermillion, SD 57069	605-677-6567	kfgaines@usd.edu
Carter Johnson	Landscape Ecology	SDSU	Dept of Horticulture, Forestry & Parks NPB 201, Box 2140A Brookings, SD 57007	605-688-4729	carter_johnson@sdstate.edu
Holly Downing	Dean of Dept	BHSU	Dept of Biology Jonas Rm 108 Spearfish, SD 57799	605-642-6056	hollydowning@bhsu.edu

**Table 3. Contact information for environmental/wildlife interest groups in South Dakota.**

<b>Name</b>	<b>Agency</b>	<b>Address</b>	<b>Telephone</b>	<b>Email</b>
Rick Warhurst/Paul Bultsma	Ducks Unlimited (Great Plains)	22525 River Rd Bismarck, ND 57503	701-355-3500	rwarhurst@ducks.org pbultsma@ducks.org
Pete Bauman	The Nature Conservancy (Tallgrass Prairie)	PO Box 816, Clear Lake, SD 57226	605-874-8517	pbauman@tnc.org
Bob Paulson	The Nature Conservancy (Black Hills)	8100 Sheridan Lake Rd Rapid City, SD 57702	605-342-4040	bpaulson@tnc.org
Brad Phillips	South Dakota Bat Working Group	3406 Ivy Ave Rapid City, SD 57701	605-721-6607	bphillips@rushmore.com
Jerry Schlekeway	South Dakota Chapter of Izaak Walton League	1008 N Huron Ave. Pierre, SD 57501-1438	605-224-7780	gschlek@pie.midco.net
Kurt Forman	South Dakota Chapter of The Wildlife Society	419 Hunters Ridge Brookings, SD 57006	605-692-8359	sdtws@brookings.net
Chris Hesla	South Dakota Wildlife Federation	PO Box 7075, Pierre, SD 57501	605-224-7524	sdwf@pie.midco.net
Dave Johnson	Missouri Breaks Audubon Society	PO Box 832 Pierre, SD 57501		mbas@pie.midco.net
Richard Barnett	United Sportsmen for South Dakotans	PO Box 526 Aberdeen, SD 57402		

**Appendix A. Local resource management agency contacts.**

<b>Name/Title</b>	<b>Agency</b>	<b>Address</b>	<b>Telephone</b>	<b>Email</b>
Mike Kintigh/Regional Supervisor	SDGFP Region 1	3305 West South St Rapid City, SD 57702	605-394-6837	mike.kintigh@state.sd.us
Arden Petersen/Regional Supervisor	SDGFP Region 3	4500 S Oxbox Ave Sioux Falls, SD 57106	605-362-2706	arden.petersen@state.sd.us
Cliff Stone/Regional Supervisor	SDGFP Region 2	1550 King Ave Chamberlain, SD 57325	605-734-4532	cliff.stone@state.sd.us
Doug Alvine/Regional Supervisor	SDGFP Region 4	400 West Kemp Watertown, SD 57201	605-882-5201	doug.alvine@state.sd.us
Head Office	SDACD	PO Box 515 Presho, SD 57568	605-895-4099	info@sdconservation.org
Private lands biologist	USFWS Partners for Fish & Wildlife	PO Box 247 Brookings, SD 57006	605-697-2500	kurt_forman@fws.gov
Manager	USFWS Waubay NWR	44401 134A St Waubay, SD 57273	605-947-4521	douglas_leschisin@fws.gov
Manager	USFWS Sand Lake NWR	39650 Sand Lake Drive Columbia, SD 57433	605-885-6320	sandlake@fws.gov
Manager	USFWS Lacreek NWR	HC5 Box 114 Martin, SD 57551	605-685-6508	lacreek@fws.gov
Manager	USFWS Lake Andes NWR	38672 291st Street Lake Andes, SD 57356	605-487-7603	LakeAndes@fws.gov
Manager	USFWS Madison WMD	PO Box 48 Madison, SD 57042	605-256-2974	MadisonWetlands@fws.gov
Manager	USFWS Huron WMD	Rm 309 Federal Bldg 200 4th St SW Huron, SD 57350	605-352-5894	HuronWetlands@fws.gov

**Appendix B. Acronyms used in tables and appendices.**

<b>Acronyms</b>	<b>Description</b>
BHSU	Black Hills State University
BIA	Bureau of Indian Affairs
DSU	Dakota State University
NPWRC	Northern Prairie Wildlife Research Center
NRCS	Natural Resources Conservation Service
NSU	Northern State University
NWR	National Wildlife Refuge
SDGFP	South Dakota Game, Fish and Parks
SDACD	South Dakota Association of Conservation Districts
SDSU	South Dakota State University
SHPO	State Historic Preservation Office
USD	University of South Dakota
USFWS	U. S. Fish and Wildlife Service
USGS	U. S. Geological Survey
WMD	Wetlands Management District



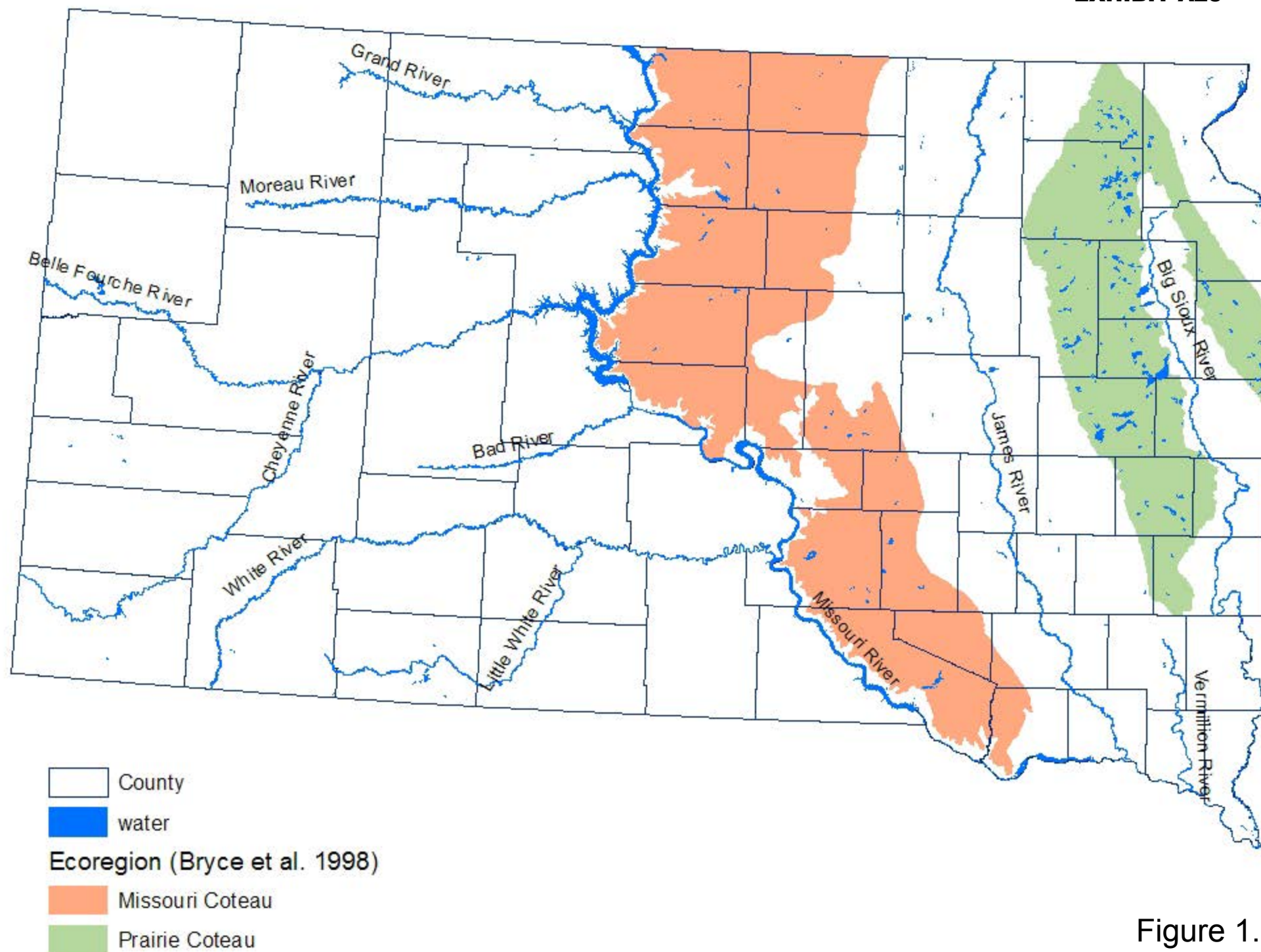


Figure 1.

**ROTTERDAM 2<sup>ND</sup> TO 5<sup>TH</sup> MAY 2017****POST CONFERENCE REPORT**

Another intensive four days of conference but still time to meet old friends and make new ones. The venue at de Doelen worked well and the food and refreshments were good and varied. Thanks to Daniele Ragni and his team at TU Delft for all their help; also to Gijsjan van Blokland and NAG (the Acoustical Society of the Netherlands) and Eric Roelofsen and NSG (the Dutch Noise Abatement Society) for their support.

A few statistics. 195 delegates. Can't quite break that 200 ceiling. We have had one hundred and ninety something at the last four events. 80% from Europe with 38 delegates from Germany topping the country league for the first time. But not to dismiss the huge support we have from outside Europe with 40 delegates. We do have a record this year with delegates from 27 different countries, so we are truly international.

The make up of delegates is changing. More manufacturers and industry people this time. Are delegates getting younger? I think so, or is it just me getting older? A few more women this year, but still only around 20%. It would be nice to see more next time.

We had 76 papers – just under 40% of delegates presented. That's a bit lower than 2015 and eased the pressure on the programme a bit – allowing us to have a guest speaker – professional miller Willem Roose to tell us the story of windmills. And an extra workshop on cyclical pitch control (CPC) – of which more later.

The two evening workshops were well attended - the first on propagation and other poster subjects and the second run by TU Delft and GRAS on the Aeroacoustic Investigation of Noise Sources. Thanks to everyone who organised and contributed to those.

We invited papers on Shadow Flicker this year as there does not seem to be any other forum where this can be discussed. We had four good papers and hope to repeat it next time.

I said in my last post conference report in 2015 that 4 days is really too long. I know that many people can't get that much time off. We will see how things develop next time but, if we can bring it down to three full days without compromising the programme we will certainly consider that.

Finally, the conference dinner was held on the 90 year old paddle steamer Majesteit as it toured the Rotterdam river and docks. Excellent food and craic.

### **WHERE ARE WE NOW – AND WHERE NEXT?**

In my last post conference report I tried to summarise where we were and where we were going. I suggested possible themes for 2017. I have to say that generally my predictions were not very accurate! But that won't stop me from trying again.

#### **Propagation**

I think perhaps I was too complacent last time that we had a good understanding of the propagation mechanism of sound from wind turbines. Papers, particularly from Sjoblom and Conrady showed that perhaps we need to get together more with our meteorologist colleagues to look more closely at how the atmosphere works. On the whole we can be pretty accurate, but perhaps more work in propagation over such surfaces as water, snow or sand would be useful.

#### **Regulations, Perception and Health Effects.**

Surprisingly few papers on regulations this time but plenty on perception and health effects. There is an enormous range of noise limits throughout the world which reflects the fact that none appear to be based on any real research on what levels affect people and what the balance should be between protecting the amenity of wind farm neighbours and the need for renewable energy. It would be good to see some of the resources currently being devoted to infrasound research diverted to work on the impact of audible sound levels. And more work involving stakeholders of the type described by van den Berg in his paper.

#### **Designing the Windfarm for Compliance**

After 2015, I thought there would be more papers on the optimisation of windfarms – that is ways of running windfarms close to the noise limit for more of the time. As it happened there was none. But it is a subject that may become increasingly important in the future.

#### **Background Noise, Assessment and Compliance Testing.**

We only categorised three papers this year as background noise. However, they gave us a very helpful insight into how background noise varies with the conditions of measurement.

A good selection of papers on assessment and compliance testing. There was a wide variation in the approach taken so perhaps this is a subject that will run for some time yet. For those who would like a standardised approach there is more work to be done.

### **Tones**

In 2015 I noted that there were less papers on tonal noise and that trend continued this time to the extent that we put tones together with low frequency noise in a single session. Manufacturers generally seem to have ways of mitigating tones, but they do still occur.

### **Small Turbines**

I was disappointed that we did not have enough papers on small turbines even to have a session. One of the difficulties is that noise from small turbines varies greatly from turbine to turbine so it is difficult to generalise findings on a single turbine. Some case studies on small turbines would be a useful addition to the conference though.

### **Trailing Edge Noise**

As in 2015 we had a whole day's session centred round trailing edge noise – including theoretical and wind tunnel modelling, combined source and propagation modelling and source location using arrays. University of Siegen and TU Delft had almost half the papers between them but interesting contributions from all presenters.

### **Infrasound**

We had a small session on infrasound. We separated it from low frequency noise this year because the two are often erroneously lumped together when describing turbine noise.

### **Amplitude Modulation**

Plenty of papers on amplitude modulation again this time. Some of the activity was related to the work that has been done recently in the UK. The metric developed by the Institute of Acoustics Noise Working Group seems to have been widely accepted. I suggested in my 2015 post conference report that I was not convinced that stall was the whole story as far as AM was concerned. There were suggestions this year that we should be talking about flow separation rather than stall and that would seem to be appropriate. There is still more work to be done on both the mechanism causing it and on its impact on people. But it remains a feature that appears to hit the headlines in a small number of countries.

### **Cyclical Pitch Control**

And whilst we are on the subject of AM, I was keen to try to get people talking about CPC and so we had a mid-day workshop run by Matthew Cand. It was cautiously titled "CPC and other avenues . . ." in case the CPC part of it came to a halt. As it happened there was a good debate and we had to extend ten minutes into the lunch break. Understandably, those who know most about the subject (turbine manufacturers) are not willing to say anything. But those of us involved in noise assessment and mitigation are keen to know whether we can use this to remedy AM. More in 2019?

### **WTN 2019 - Themes**

Here are a few thoughts of what we need to address between now and 2019:

Build on how background noise varies with various factors. Does it vary with seasons, wind directions types of foliage and other factors?

How well does background noise mask turbine noise? We have had a few papers over the years on this – but we still need more.

Assessment and compliance testing. Should we be aiming at an agreed standard method? Or not?

Small turbines – some case studies describing the particular problems that have arisen with small turbines.

Cyclical Pitch Control. Can it help reduce AM? Does it reduce overall sound power?

More dose response tests on turbine audible noise to allow us to produce more robust regulations.

Why do some people become ill near wind turbines? Perhaps this is no longer a study that acousticians are qualified to do?

And one from 2015 - are LF tones being missed or wrongly interpreted as merely low frequency noise or even infrasound as suggested by Evans in Glasgow?

And, of course any other subjects that are useful to further the knowledge of Wind Turbine Noise.

Any feedback will be welcome – good or bad. Please contact me by email.

Dick Bowdler

[dick@windturbinenoise.eu](mailto:dick@windturbinenoise.eu)





Karen Jenkins &lt;jenkinskd55@gmail.com&gt;

**Proposed Wind Farm**

1 message

**Karen Jenkins** <jenkinskd55@gmail.com>  
To: hutzzone@gwtc.net

Wed, Aug 15, 2018 at 2:14 PM

Mr. Clifford Tjaden  
Hutchinson County Zoning Administrator

Mr Tjaden,

I want to thank you for your assistance at the zoning meeting on Monday August 6. I appreciate your input and clarity. I would also like to apologize if I stepped over the boundaries of public input or offended you in any way.

I am going to send a separate email with links for the board to research on their own. I will appreciate if you will let me know if you feel anything I send is not appropriate according to the permit process.

If you would please send me the names and position/title of each of the members that were at the meeting on Aug 6th, whether they are elected or appointed, and also what their term is I would appreciate it. I am just trying to familiarize myself with those involved and the process of the consideration of the PWWP, LLC. application. If there is another source for this information please refer me to it instead.

Please tell me what document Roland Jurgens handed out to all of you at the meeting, was it the Bon Homme County zoning for wind farms? Please tell me the exact title so I may obtain one from Bon Homme County. Or is a matter of Public Record in Hutchinson. I would like to review what the members are reviewing. I do not have a copy of the map that we identified my home on, would you be able to send a copy to me through email?

When PWWP, LLC submits their application is that done by just walking in and handing it to you? Is it in a special or regular meeting? Or in a Public Hearing?

Please tell me how to be informed as to what is happening without calling you or emailing you everyday. I know you have many other duties and time is limited.

Thank you for your help.

Respectfully,

Karen Jenkins  
28912 410th Ave  
Tripp SD 57376  
605-680-5646  
jenkinskd55@gmail.com



**EXHIBIT A25**

Karen Jenkins &lt;jenkinskd55@gmail.com&gt;

**RE: Please forward to board members**

1 message

Karen Jenkins &lt;jenkinskd55@gmail.com&gt;

Wed, Aug 15, 2018 at 3:14 PM

To: hutzone@gwtc.net

The links provided below are public record on the PUC Website for Electric Dockets:

**EL18-026 - In the Matter of the Application by Prevailing Wind Park, LLC for a Permit of a Wind Energy Facility in Bon Homme County, Charles Mix County and Hutchinson County, South Dakota, for the Prevailing Wind Park Project**

•

Please read comments the public has sent in to this docket:

Click for link to: [Comments and Responses](#) and click on link.

Please to listen to the recording of the PUC Public Meeting in Avon on July 12, 2018.

This is easy and clearly shows the human element of this very important decision to be made by Hutchinson County and by the PUC:

Click for link to: [Recording](#) and click on link.

Thank you for your time and consideration.

Respectfully,

Karen Jenkins  
28912 410th Ave  
Tripp SD. 57376



Karen Jenkins &lt;jenkinskd55@gmail.com&gt;

**Cliff, Please review and forward if appropriate. Thanks!**

1 message

Karen Jenkins &lt;jenkinskd55@gmail.com&gt;

Wed, Aug 15, 2018 at 4:04 PM

To: hutzzone@gwtc.net

Ladies and Gentlemen,

I am Karen Jenkins and I spoke to you on August 6 at your regularly scheduled meeting. I would like to thank you for your time that evening and for your patience. A lot is on the line for my husband and I and our future and those in this footprint. Your consideration of this matter is greatly appreciated.

I would also like to apologize for anything I did at that meeting that overstepped the boundaries of the process. While I am confident what I told you is the truth, I find it very difficult to diplomatic while exposing the issues I have encountered since the Beethoven Wind Farm was in planning in 2013 and since this current project came to light in 2015.

I hope you will accept my apology if I offended any of the board, it was certainly not my intent. It had been a long day and this is a very trying issue.

I have included links to the South Dakotans for Responsible Renewable Energy website. It simply contains links to many organizations websites and contains a wealth of information.


Also, I figured out how to send you a direct link to the PUC Docket for this project.

Finally, I ran across an article about battery storage that might be of interest to you.

Thank you again for your time.

Respectfully,  
Karen Jenkins  
28912 410th Ave  
Tripp SD 57376

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**3 attachments** **EL18-026.url**  
1K **South Dakotans for Safe and Responsible Renewable Energy.url**  
1K **Battery Storage.docx**  
55K

Hutchinson County Public Hearing 9-4-2018

September 4, 2018

Thank you for this opportunity.

Please do not make your decision tonight. You have the right and the responsibility, to table this discussion, seriously consider what has been brought to you, and to come back at a later date to continue this discussion, **before making a decision.**

The Applicant filed their Application with the PUC on May 30, 2018, without permits from the three counties in the project footprint. It may seem urgent to the Applicant to have your decision tonight, however it was the Applicant's choice to wait until August to apply for the Conditional Use Permit in Hutchinson County.

The Counties of Bon Homme and Charles Mix have not represented the citizens and residents properly in this matter. We **urge** you to take your time and give this matter great consideration.

**We are here to ask you to protect us. This protection can come when you deny this application.**

Our greatest concern is health. Some people fail to understand that the health effects associated with turbines depend on individual sensitivities, length of exposure, wind speeds, geography and a host of other factors. The effect of extremely low frequency sound on the inner ear leads to the distress of sleep disruption, sleep deprivation, and subsequent adverse health effects.

Recently, we experienced the effect of noise inside our home from the fans on a grain bin that is on the adjacent property. The noise outside was acceptable, simply a part of rural living. The noise inside the house however was amplified and had an irritating, reverberating effect on my ears. Our neighbors were simply taking care of their grain and we knew the fans would be turned off. We knew the sound would not be something we have to deal with day in and day out.

A wind turbine is different. How will we stop the noise inside our house when it comes from the turbines that could be built one and two miles from our home? If we are not able to tolerate the noise what will we do? We would not want to have anyone else experience trouble, so how will we sell our house if we couldn't live there anymore? Will it even be marketable?

We were not able to protect ourselves from the Beethoven Wind Project. The only notice we received was the Notice of Public Hearings for Conditional Use Permits for B&H Wind Farm, LLC. First there were six and then they came back with ten more. The Board of Adjustment gave no consideration to our concerns at the last hearing.

If you do not deny this permit, you will not only fail to protect us, you will most likely be setting a precedent for future projects around us. Directly north of us are 234 acres owned, by the same property owner, who is hoping to host turbines #30 and #51 to the southwest of us. It makes sense that the property he owns north of us would host turbines from a future project, **a project which most likely is already being planned.** This is of great concern to us, we have been able to live with Beethoven so far, however to be surrounded by turbines would definitely be unacceptable. **We need you to protect us from the Prevailing Winds Project.**

If you will not deny this application please place these conditions to protect our health, safety, and welfare. These are the same conditions we have asked the PUC to place on the Applicant.

Condition #1: A four mile setback from a resident.

Support: To protect by distance from sound, inaudible noise, and sight disruption. The turbines chosen by the applicant are 586 feet tall and twice as powerful as Beethoven. This size is unprecedented in South Dakota and certainly unprecedented for us. We would be within 1.07 miles of #55 and many other turbines just increments further.

The distances of the turbines from our home, that are in this project and in Hutchinson County would be as follows, if allowed.

55 - 1.07 miles

51 - 1.8 miles

56 - 1.28 miles

30 - 1.67 miles

25 – 2.2 miles

In addition to these turbines, there are four others in Bon Homme County, which if allowed, would have the following distance from our home:

47 – 2.4 miles

46 – 2.8 miles

20 – 2.9 miles

18 – 3.3 miles

We live 3 miles from six Beethoven Turbines now. We can hear them, see them, and we consider them a nuisance. The cumulative effect of the existing turbines and the proposed turbines will be substantial and will negatively affect our peaceful enjoyment of our property, our view shed, and most importantly may cause us to have to leave our home.

Condition 2: Require an ALDS be installed on the turbines and if the FAA does not approve the use of the ALDS the Conditional Use Permit shall be revoked.

Support: The red blinking lights are meant to alarm. And they do, still after three years. The red blinking lights we have been forced to live with from the Beethoven Project are a nuisance, adding more will only increase that nuisance. The Applicant should be prevented from creating a nuisance.

Condition 3: A decommissioning bond, paid for up front, and arranged between the PUC and the Applicant. If the bond is not paid for upfront the Conditional Use Permit shall be revoked.

Support: Once the turbines are up, they are up. Whether or not the proposed industrial wind project will be lucrative enough to produce the income to provide for a bond or an escrow fund in ten years is not and cannot be proven. An escrow fund, as the PUC is currently setting as a condition, cannot be funded if the entity owning the industrial wind project goes bankrupt.

Condition 4: A liaison person must be appointed to monitor the project as it is being built to insure compliance and an avenue for those in the footprint to voice concerns and complaints. If the PUC does not provide this condition the Conditional Use Permit shall be revoked.

Condition 5: A liaison person must be appointed to monitor the project from the commencing of operation through the decommissioning of the project. If the PUC does not provide this condition the Conditional Use Permit shall be revoked.

Condition 6: No shadow flicker on non-participating residences.

Support: Shadow flicker is a nuisance and the Applicant should be prevented from creating a nuisance.

Condition 7: Sound may not exceed 35 dB(A) for non-participating residences.

This will protect us against audible and inaudible sound.

Finally, please protect us. Please do not make your decision tonight. Your decision will have a great impact on our lives. Thank you for your time.

Mike and Karen Jenkins  
28912 410<sup>th</sup> Ave  
Tripp SD 57376  
605-680-5646





Karen Jenkins &lt;jenkinskd55@gmail.com&gt;

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**Minutes**

1 message

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**Cliff Tjaden; Zoning Admin.** <hutzone@gwtc.net>  
To: jenkinskd55@gmail.com

Mon, Sep 10, 2018 at 1:32 PM

Here are the Aug 6 minutes. The Sep 4 meeting will not be official until Oct 1, therefore I am unable to send them to you.

Clifford L. Tjaden

Zoning Administrator

Hutchinson County SD

**Aug 6 Meeting MINUTES.docx**  
39K

**PLANNING COMMISSION MEETING MINUTES**

**August 6, 2018 @ 8:00 p.m.**

**Call to Order:**

Chairman Schnabel called the meeting to order @ 8:02p.m.

Members Present: Schnabel, Frey, Ulmer, Schultz, Edlund, Werning and Administrator Tjaden

Citizens Present: Ernest Scheetz, Karen Jenkins, Mark Rames, Roland Jurgens, Erik Johnson, Bruce Voigt, Terry Goehring, Tracy Goehring, Janet Wagner, Ron Wagner

**Approve Current Agenda**

Motion to Approve: Frey, 2<sup>nd</sup> Werning

All Votes Aye; Motion Carries

**Approve Minutes of July 9, 2018**

Motion to Approve: Edlund, 2<sup>nd</sup> Frey

All Votes Aye; Motion Carries

**Convene as Board of Adjustment**

Motion to Convene as Board of Adjustment: Werning, 2<sup>nd</sup> Frey

All Votes Aye; Motion Carries

**CONDITIONAL USE APPLICATION**

**VARIANCE APPLICATIONS**

Terry Goehring

Request to build a storage shed with a 12' setback of the rear property line

Legal: Parcel D NE ¼ Section 9 Sweet Township

Motion to Approve: Schultz, 2<sup>nd</sup> Ulmer

Roll Call Vote: Aye; Werning, Schultz, Schnabel, Edlund, Ulmer, Frey. Nay; None

Dennis Fuerst

Request for an acreage of 11.9+/- acres instead of 20 acres

Legal: E ½ SE ¼ Section 13 Township German

Motion to Approve: Frey, 2<sup>nd</sup> Werning

Roll Call Vote: Aye; Schultz, Schnabel, Edlund, Ulmer, Frey, Werning. Nay; None

Lakeview Kennels, Inc.

Request for an acreage of 1.8 +/- acres, side setback of 25' and lot front of 188'

Legal: E 900' of the S 1250' of the SE ¼ of the SW ¼ of the SW ¼ Section 4 Susquehanna Township

Motion to Approve: Edlund, 2<sup>nd</sup> Schultz

Roll Call Vote: Aye; Schnabel, Edlund, Ulmer, Frey, Werning, Schultz. Nay; None

**Reconvene as Planning and Zoning Committee**

Motion to Reconvene as Planning and Zoning: Frey, 2<sup>nd</sup> Ulmer

All Votes Aye; Motion Carries

**PLATS**

Gary Scheetz

Scheetz tract 1 E. 900' of the S 1250' of the SE ¼ of the SW ¼ of Section 4, T99N R61W of the 5<sup>th</sup> P.M. Hutchinson County, SD

Motion to Approve: Schultz, 2<sup>nd</sup> Werning

All Votes Aye; Motion Carries

David Baltzer

Baltzer Tract 1 in the SW ¼ of Section 22, T98N R59W of the 5<sup>th</sup> P.M. Hutchinson County, SD

Motion to Approve: Frey, 2<sup>nd</sup> Ulmer

All Votes Aye; Motion Carries

Wilmar Mehlhaf

Tract 1 Mehlhaf Addition, NE ¼ of Section 32, T98N R56W of the 5<sup>th</sup> P.M. Hutchinson County, SD

Motion to Approve: Edlund, 2<sup>nd</sup> Frey

All Votes Aye; Motion Carries

Dennis Fuerst

Tract 1 NE ¼ of the SE ¼ of Section 13, T98N R60W of the 5<sup>th</sup> P.M. Hutchinson County, SD

Motion to Approve: Werning, 2<sup>nd</sup> Ulmer

All Votes Aye; Motion Carries

Vernon C. Neugebauer, LaVerna L. Neugebauer, Bryan Neugebauer, Terry Neugebauer, Kevin Neugebauer, LeAnn Moe, Tracy Neugebauer

Neugebauer Tract 1 NW ¼ of Section 17, T100N R61W, of the 5<sup>th</sup> P.M. Hutchinson County, SD

Motion to Approve: Frey, 2<sup>nd</sup> Werning

All Votes Aye; Motion Carries

Ronald Dale Guthmiller

Tracts 1 & 2 Guthmiller's Addition, SW ¼ of Section 13, T97N R58W of the 5<sup>th</sup> P.M. Hutchinson County, SD

Motion to Approve: Edlund, 2<sup>nd</sup> Frey

All Votes Aye; Motion Carries

**DISCUSSION**

Roland Jurgens: S Power

Mr. Jurgens explained the S power project to the Planning and Zoning Committee. It will be a total of 220 mega watts being generated by 57 turbines of which 6 will be located in Hutchinson County. The turbines will be tall and the blades are bigger than that of the pervious project constructed in 2014. They will also be more advanced; less noise, radar lights, maximum of 45db. Mr. Jurgens will file conditional uses on behalf of S Power and send informational packets to the committee.

Karen Jenkins: Concerned Citizen

Chairman Schnabel allowed Ms. Jenkins to speak as she was not on the agenda to speak and this was not a conditional use hearing at this time. Ms. Jenkins explained her stance on the project and that she thought that it was detrimental to the citizens of Hutchinson County. She based this on the sight of the turbines, noise and vibration to area residents.

**Adjournment:**

Motion to Adjourn and set the next meeting date of 4 September 2018 at 7:00p.m.

Ulmer, 2<sup>nd</sup> Werning

All Votes Aye; Motion Carries

Zoning Board  
Bon Homme County  
Tyndall, SD

9/17/2017

**Mr Chairman and members of the Zoning Board**

I am Karen Jenkins, my address is 28912 410<sup>th</sup> Ave, Tripp, SD. My home is located near the intersection of 410<sup>th</sup> Ave and 289<sup>th</sup> Street, which is also referred to as Tripp Lake Road.

**Introduction**

I am here today to ask this board to deny the Conditional Use Permit application submitted by Prevailing Winds, LLC. Clearly this application is the second application for a MET to be erected within the same tract, yet in a slightly different location within the tract. In essence, the developer and investors are ignoring the decision made during the Public Hearing on August 28, 2017, when for lack of a motion, the first application was denied.

This application should be denied just as the first application was denied. Please understand, this is more than just a MET tower. The purpose of the MET tower is to obtain information on wind. If the “criteria” that is being sought is found, we are one step closer to another Industrial Wind Farm. In essence, a continuation of the Beethoven Wind Farm in North West Bon Homme and South West Hutchinson Counties. This should not be allowed to happen. You must take this opportunity to protect your citizens. Please deny this application.

I have experienced disappointment, frustration, and helplessness since the Beethoven Industrial Wind Farm was in the permitting process, the construction process, and when it went online. I live three miles from where the towers start. I guess you can say I was lucky they aren’t closer. Yet I feel violated more than anything. I would not wish living in or near an Industrial Wind Farm on anyone.

I feel a deep sense of loss, a sadness that is from experiencing a dream come true and watch a large part of it being taken away. Just the blight on the horizon was not enough, now comes the nuisance of noise that increases as the towers age, the red blinking lights that can be seen for miles and miles. Now, we face the looming threat of more towers and the subsequent loss of property value.

This is why I have stood before you, your commissioners, the PUC in opposition of MET and more Industrial Wind Farms. They are not good neighbors and they don’t go away.

Your citizens deserve better and they need your help.

Thank you,

Karen Jenkins

Owner

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**BEFORE THE PUBLIC UTILITIES COMMISSION  
OF THE STATE OF SOUTH DAKOTA**

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**IN THE MATTER OF THE  
APPLICATION BY PREVAILING  
WIND PARK, LLC FOR A PERMIT OF  
A WIND ENERGY FACILITY IN BON  
HOMME COUNTY, CHARLES MIX  
COUNTY AND HUTCHINSON  
COUNTY, SOUTH DAKOTA, FOR THE  
PREVAILING WIND**

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**RESPONSE TO  
  
STAFF’S FIRST SET OF DATA  
REQUESTS TO INTERVENORS  
  
EL18-026**

Below, please find my response to Staff’s  
First Set of Data Requests to Intervenor. Thank you for allowing me the extension to submit  
my response by August 24, 2018, at 5:00 pm.

- 1-1) Provide copies to Staff of all data requests served on Applicant at the time of service.  
**I will provide this information.**
- 1-2) Provide copies to Staff of all of your answers to data requests from Applicant at the time  
they are served on Applicant.  
**I will provide this information.**
- 1-3) Refer to SDCL 49-41B-22. Please specify particular aspect/s of the applicant's burden  
that the individuals granted party status intend to personally testify on.  
**I am in the process of reviewing the Application to find if it is sufficient  
to provide for the conditions set forth SDCL 49-41B-22. I have not  
decided if I will testify or not.**
- 1-4) Refer to SDCL 49-41B-25. Identify any “terms, conditions, or modifications of the  
construction, operation, or maintenance” that the Intervenor would recommend the  
Commission order. Please provide support and explanation for any recommendations.

**To be clear, I recommend that the Commission deny this application. I recommend  
this from my experience of the Beethoven Wind Farm from permitting,  
construction, to the operation of it, to date.**

**If the Commission will not deny the application, I recommend the condition of a 4-  
mile setback. My support is the fact that I live 3 miles from six Beethoven Wind  
Farm Industrial Wind Turbines and the height of 586 foot turbines as the Applicant  
has chosen is unprecedented and I believe will negatively impact my husband and  
myself without the 4 mile setback.**

**I request the ALDS which eliminates the alarming red blinking lights at night. If  
the FAA does not approve them, I recommend the application be denied.**



**The red blinking lights are meant to alarm. The red blinking lights on the Beethoven Wind Farm are a nuisance. To have an additional 57 turbines, many with the alarming red blinking lights will result in a much bigger nuisance. The Applicant should be prevented from creating a nuisance.**

**I request a Bat Detection and Shutdown System be installed on all Industrial Wind Turbines in this project. Bat fatalities negatively affect agriculture and the environment.**

**I request a decommissioning bond, paid for up front. Once the Industrial Wind Turbines are up, they are up. Whether or not the proposed Industrial Wind Farm will be lucrative enough to produce the income to provide for a bond in ten years is not and cannot be proven.**

**I request a liaison person to monitor the project as it is being built to insure compliance and an avenue for those in the footprint to voice concerns and complaints. A project of this size must have a liaison.**

**I request a liaison person to monitor the project from the commencing of operation through the decommissioning. I have not been able to reach anyone to assist me when I have had concerns with the existing Beethoven Wind Farm.**

**I request there be no shadow flicker on non-participating residences, as shadow flicker presents a nuisance and the Applicant should be prevented from creating a nuisance.**

**I request a Guarantee of Property Value to be funded and developed by the Applicant, subject to approval of the Property Owner to protect residents in the footprint and buffer zone from financial loss should the residence become unlivable and / or unmarketable. The Applicants project will have serious financial implications on many of the residents in the footprint and the buffer zone.**

- 1-5) Is there a specific objection (example health, blinking lights, sound) you have with respect to the Project? Please briefly explain.**

**The nuisance of red blinking lights as mentioned above in section 1-4. If the FAA will not approve the use of the ALDS the application should be denied.**

**Most concerning is sound, both audible and infrasound. There are many complaints about both audible and inaudible noise from Industrial Wind Turbines, they are well documented. The result of negative health effects to some residents from both audible and inaudible noise is also well documented.**

**Health, again the size of the Industrial Wind Turbines the Applicant has chosen is unprecedented. The area and range they will impact is unknown and will likely cause the loss of enjoyment of property, loss of use of property, loss of the residence to be inhabitable, and the marketability of property will be greatly diminished.**

What, if anything, do you feel could be done to remedy that issue?

**Deny the Application.**

**If the Commissioners will not deny the application, the Commission must then approve the Application with conditions that will truly protect the health, safety, and welfare of all of the residents living in and near the footprint.**

**Sound should not exceed 35 decibels for non-participating residences.**

**Setbacks should be 4-miles from a non-participating residence.**

**An ALDS must be installed. If the FAA does not approve an ALDS the application should be denied.**

- 1-6)** Please list with specificity the witnesses the Intervenors intend to call. Please include name, address, phone number, credentials and area of expertise.

**I am still reviewing the Application and have not decided if I will call witnesses.**

- 1-7)** Do the you intend to take depositions? If so, of whom? **Not at this time.**

Dated this 24<sup>th</sup> day of August, 2018

Karen Jenkins

28912 410<sup>th</sup> Ave

Tripp, SD 57376

605-680-5646

jenkinskd55@gmail.com

**EL18-026**

010860

residence in the center of section 11-96-62 CCTS have other land leased to the project ( Figure 5 of appendix A) on which nine turbines are proposed to be built. Perhaps there is a fine line between participating and nonparticipating about which I am confused? Are the residents of the center of section 11-96-62 CCTS nonparticipating residents but participating landowners? Would they be nonparticipating residents due to the fact that no physical part of the facility would be constructed on the leased property on which they reside? If so, would there be something in play here like the definitions of ‘participating and nonparticipating noise receptors’ found in the Ontario Technical Guide to Renewable Energy Approvals, specifically Chapter 3: Required setback for wind turbines (<https://www.ontario.ca/document/technical-guide-renewable-energy-approvals/required-setback-wind-turbines>) which states in part:

“ 2.2.1 Participating vs. Non-participating Receptors Setback distances do not apply to noise receptors (so-called “participating” noise receptors) on a parcel of land where any part of a renewable energy generation facility will be located once the facility is installed, constructed or expanded in accordance with the REA. It must be emphasized that for setback distances not to apply, all or part of the renewable energy generation facility (e.g. turbine, transmission line) must be constructed on the parcel of land. Thus, this does not apply to lease options that do not result in the construction of facility components or other agreements to waive the 550m setback distance in consideration of financial compensation or other arrangements. Further, it should be noted that a temporary structure that does not form part of the operational facility is not considered sufficient to create a participating noise receptor.”

I am not aware of any other situations similar to this in the project area, but again this casts doubt on the application, at least for me.

- c) Has the “misidentifications of participating/nonparticipating residents” that Mr. Fuerniss is aware of been corrected as part of independent review of residences within the Prevailing Wind Park project and verification area attached to Bridget Canty’s rebuttal testimony?

I do not know that the review and verification apply to my concern.

- d) Please explain in detail what consideration should be provided for rural cemeteries. Please provide evidence to support this consideration.

The existing Beethoven wind farm locates one turbine within 1.1 miles of a rural Charles Mix County cemetery and nine within 1 mile (15 within 1.25 miles) including two within 500 ft. of a Hutchinson County rural cemetery. The proposed project would put two turbines less than 1.25 miles from a Hutchinson County rural cemetery, two turbines less than 1.0 mile from a Charles Mix County rural cemetery, three turbines less than 1.0 mile from a Bon Homme County rural cemetery where my Civil War veteran great-grandfather is buried, and two turbines less than 1.0 mile from a Bon Homme County church and cemetery. This ought not to be. The proponents of these facilities seem to care little enough for the living let alone for the living who are mourning the loss of a loved one.

When we laid my father to rest beneath the prairie beside St. Paul Evangelical Lutheran Church, on the western edge of this proposed project, on a clear crisp January

day we could hear the birds singing while the church bells rang. We prayed and sang hymns. We could hear the handfuls of soil thrown by family members as they hit the casket. We stayed talking, crying, laughing and grieving until the last shovelful. If we had had to endure the noise that we sometimes hear at our farm from a distance of 1.25 miles from Beethoven, I would have been angry enough to want to tear someone's head off and spit in their neck. I do not believe a one-mile setback for the amenity of a rural cemetery is too much to ask and an active church should have two miles.

4 October, 2018  
Sherman Fuerniss  
40263 293<sup>rd</sup> St.  
Delmont, So. Dak. 57330  
[sol@midstatesd.net](mailto:sol@midstatesd.net)

Dated this 28<sup>th</sup> day of September 2018.

A handwritten signature in blue ink, appearing to read "Kristen Edwards", is written over a horizontal line.

Amanda M. Reiss

Kristen Edwards

Staff Attorneys

South Dakota Public Utilities Commission

500 East Capitol Ave.

Pierre, SD 57501

**BEFORE THE PUBLIC UTILITIES COMMISSION  
OF THE STATE OF SOUTH DAKOTA**

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**IN THE MATTER OF THE  
APPLICATION BY PREVAILING  
WIND PARK, LLC FOR A PERMIT OF  
A WIND ENERGY FACILITY IN BON  
HOMME COUNTY, CHARLES MIX  
COUNTY AND HUTCHINSON  
COUNTY, SOUTH DAKOTA, FOR THE  
PREVAILING WIND**

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**\* INTERVENORS' RESPONSES TO  
\* STAFF'S SECOND SET OF DATA  
\* REQUESTS TO INTERVENORS  
\*  
\* EL18-026  
\*  
\*  
\***

Intervenors Gregg Hubner, Marsha Hubner, Paul Schoenfelder, and Lisa Schoenfelder ("Intervenors"), through counsel, provide the following Responses to Applicant Prevailing Wind Park, LLC's ("Applicant") Second Set of Data Requests to Intervenors.

- 2-1) Refer to the Intervenor's response to Staff Data Request 1-4. The Intervenors "recommend a 2-mile setback from non-participating residences and a 1,500 ft. setback from a property line and public rights-of-way with waivers available for those who want them closer." Please provide references to the direct testimony, including page and line numbers, submitted by Richard R. James, Jerry L. Punch, and Prof. Mariana Alves-Pereira, that support this condition.**

**RESPONSE:**

Gregg Hubner: I was advocating for a 2-mile setback since the spring of 2015. My first support for this idea was from the book "Wind Turbine Syndrome" by Dr. Nina Pierpont, MD, PhD on page 254. (Attachment A) In the Shirley Wind Farm in Brown County, Wisconsin, infrasound was detected 6.2 miles away from the turbine, with complaints at 4.2 miles. The Shirley Wind Farm was designated a "human health hazard" in 2014 by the Brown County Board of Health. <https://www.michigancapitolconfidential.com/20690>.

Also, I am attaching a study on blade and ice throw that shows these throw distances can be up to 6500 ft. (Attachment B)

In August of 2017 I met Vicki May, who lives about an hour south of us in Nebraska. She lives 1 1/3 miles from the closest of 200 wind turbines. I have been to her place and in her home. I heard her testimony in front of the State of Nebraska Natural Resources Committee in September of 2017. (Attachments C and D) Early in 2018 I got a call from Jerome Powers who suffers from some symptoms of WTS. He lives well over a mile and a half from the Beethoven Wind Farm. It makes sense to me to listen to people that live in a wind farm and under these conditions than some computer model or highly educated person that has never lived near a wind farm. I do know certain people have ill effects up to 4.2 miles away (Shirley Wind Farm). It makes sense to me to error on the side of caution since the only recourse for a resident who suffers problems is to move from his home. Walworth County, South Dakota has a 2-mile setback.



- 2-2) Refer to the direct testimony of Mr. Richard James, Page 2, line 55. Is compliance with the Bon Homme County's noise regulation associated with wind energy systems achieved through a sound model based on predicted sound levels, or is compliance based on actual sound levels? Please explain.**

**RESPONSE:**

Reece Almond: Section 1741 of the Bon Homme County Zoning Ordinance addresses what a LWES must do in order to comply with the Ordinance. Section 1741 provides:

Noise level produced by the LWES shall not exceed forty five (45) dBA, average A-weighted sound pressure at the perimeter of occupied residences existing at the time the permit application is filed, unless a signed waiver or easement is obtained from the owner of the residence.

The permittees shall submit a report of predicted noise levels at habitable residential dwellings within one mile of proposed tower locations to the Board no less than forty five (45) days prior to commencing construction.

Based on this language and my interpretation thereof, the answer to the question in Data Request 2-2 is both.

Richard James: Models are, at best, approximations of what be expected if the project is constructed. Measurements are the only accurate method for assessing whether a project complies with a regulation. It is the developer's responsibility to understand the limitations of the models, and to apply appropriate safety factors to the design to accommodate the limitations of the model such that once operating, the measured sound levels do not exceed the regulatory limit. Models cannot substitute for measurements.

- 2-3) Refer to the direct testimony of Mr. Richard James, Page 3, lines 101, through Page 4, 105.**
- a) Have any U.S. counties or states adopted the Intervenor's recommended maximum sound level regulation for wind energy facilities of 35 dBA? Please provide documentation to support the response.**
  - b) Have any U.S. counties or states adopted the Intervenor's recommended sound level regulation for wind energy facilities of no more than 5 dBA louder than the pre-operational background sound levels? Please provide documentation to support the response.**

**RESPONSE:**

Gregg Hubner: Here are some setback distances used around the world, with examples both from residences and property lines:

[http://www.wiseenergy.org/Energy/Wind\\_Ordinance/Setbacks.pdf](http://www.wiseenergy.org/Energy/Wind_Ordinance/Setbacks.pdf).

Here are some decibel limits used around the world:  
[http://wiseenergy.org/Energy/Health/Acoustical\\_Limit.pdf](http://wiseenergy.org/Energy/Health/Acoustical_Limit.pdf).

Richard James: I do not maintain a comprehensive list of regulatory limits and documents. My response is thus an example of regulations in jurisdictions where I have had some involvement. First, it needs to be understood that a good regulatory limit to control noise in a community must address the characteristic of the noise source that is considered to be objectionable. For utility scale wind turbines those characteristics are amplitude modulation (fluctuations) of the sound pressure levels and tones particularly in the infrasonic and low frequency range. It is accepted in acoustics that fluctuating sounds are more annoying and more likely to cause sleep disturbance than steady sounds. The presence of audible tones also increase annoyance potential and sleep because the human auditory function is about 10 dB more sensitive to tones than to broadband sound. Thus, the ideal regulatory limit for wind turbines would be a not-to-exceed sound level measured with an instrument set to measure the current sound without any averaging. If the regulation is using a single number limit in dBA this would be expressed as dBA  $L_{MaxFast}$ . That is the maximum dBA level using the meter's fast response. However, many jurisdictions, and the wind industry have attempted to apply thresholds based on the long-term average sound level ( $L_{eq}$ ) which does not reflect the fluctuations that are present in wind turbine noise emissions. Long term normally means a measurement averaged over a period of ten minutes to one hour, but can also mean over periods of days and nights.

Field measurements of wind turbine sound has demonstrated that the  $L_{MaxFast}$  measurement will exceed the  $L_{eq}$  measurement by 10 dB or more under normal operating conditions. These conditions normally occur at night during the time when people are expecting quiet for sleep. Dr. Punch provides an example of this from the Michigan, Almer Township case where the US District court accepted that the ordinance limiting wind turbine noise to 45 dBA  $L_{MaxFast}$  was acceptable. The acoustician for the developer had filed statements saying that the equivalent average sound level ( $L_{eq}$ ) would need to be 11 dBA lower than this limit to comply. Since the primary adverse health impact from noise is sleep disturbance and studies have shown that fluctuating sounds outside a home when windows are open cause awakenings and delay return to sleep when they exceed 40 dBA  $L_{MaxFast}$  jurisdictions that are required to set thresholds to protect public health have variously adopted limits ranging from 35 dBA  $L_{eq}$  to 45 dBA  $L_{MaxFast}$ . All of them are roughly equivalent in terms of protection, but the  $L_{MaxFast}$  thresholds are more specific to the character of the sounds that need to be controlled.

This type of threshold is also easier to enforce. It is like how highway speeds are enforced. For example, if a driver on a road with a speed limit of 70 miles per hour averages 70 mph during the entire trip, but during part of the drive is exceeding that limit when a police radar tracks the car there is a violation. If the police officer was required to show that the driver's average speed exceeded 70 mph the limits would become unenforceable. They would need to follow the driver for long periods and the driver's knowledge of being under surveillance could lead to modified driving behavior. The same happens when a jurisdiction sets an average sound level ( $L_{eq}$ ) as the threshold. First, the measurements needed to confirm the exceedance become burdensome and subject to argument. Second, the applicant can raise all sorts of arguments about the period of time being averaged, length of the average, etc.. Thus, the use of limits set to control the maximum sound emissions are more direct and result in less burden on the local



government if or when complaints are filed. This line of reasoning has been applied in many jurisdictions who have re-written their wind turbine regulations to control the fluctuating character of wind turbine noise.

In response to part A of the question I refer back to Table 3 in my first statement's Exhibit "Noise: WindFarms." It shows that many countries where the wind industry has installed large projects have regulations set around the 35 dBA Leq threshold. Germany, Australia and New Zealand all have limits based on some form of 35 dBA average sound level and this has not prevented development of wind energy projects. In response to Part B regarding jurisdictions that use Background plus 5 dB method Table 3 shows this is also a common threshold. Some jurisdictions in the US also use background plus a constant (5, 6 or 10). For example, Oregon developed wind energy project sound limits in the early 2000s using a limit of 10 dB over the background sound as the goal. After doing a number of tests for background sound levels Oregon concluded that the background sound level in rural/wilderness locations where wind turbines were likely to be installed were about 25 dBA (L90). Thus, they adopted a limit 35 dBA (L50). New York's Noise Guidelines call for the new noise source to not increase the background sound levels by more than 6 dBA. Massachusetts uses 10 dBA but has some local rules using lower levels.

Tennessee recently adopted a state regulation of 35 dBA  $L_{MaxFast}$  at the receptor's dwelling and 45 dBA  $L_{MaxFast}$  at the property line.

In Michigan, regulations are set by counties, but each township has the right to set different limits under state law. Most of the wind turbines in Michigan are located in Huron County, which is the "thumb" region on the east side located between Saginaw Bay and Lake Huron. The County originally had limits of 50 dBA which attracted considerable development starting back in 2007. Because of the problems with complaints of annoyance and adverse health effects that have occurred in townships where the projects were located many of the remaining townships have adopted their own regulations setting not-to-exceed limits ranging from 30 to 45 dBA  $L_{MaxFast}$ . Those townships include:

**Townships in Huron County**

Almer	Effectively 45 $LA_{Max}$ at the non-participating property line (day), 39 $LA_{Max}$ (night)
Ellington	40 $LA_{Max}$ at non-participating property line
Denmark	Shall not exceed 35 dBA at property line
Merritt	40 dBA ( $LA_{Max}$ ) at property line
Sand Beach	35 dBA ( $LA_{Max}$ ) during day and 30 dBA at night
Marion	40 $LA_{Max}$ at non participating property line
Bridgehampton	40 $LA_{Max}$ at non-participating property line
Elmwood	40 $LA_{Max}$ at non-participating property line
Kingston	45 $LA_{Max}$ at non-participating property line
Greenwood	Shall not exceed 45 dB(A) at any property line adjacent to the wind energy system

**Other Michigan Townships and Counties (not exhaustive)**

Ingersoll Twp 45 LA<sub>Max</sub> at non-participating property line (day) 35 LA<sub>Max</sub> at property line (night) at same  
 Beaver Twp 45 LA<sub>Max</sub> at non-participating property line  
 Burnside Twp 45 LA<sub>Max</sub> at non-participating property line  
 Shiawassee 45 LA<sub>Max</sub> at non-participating property line

**Other Non-Michigan Jurisdictions**

Vermont 38 dBA Leq  
 New Hampshire 45 LA<sub>Max</sub> Day or 5 dB over background whichever is greater and 40 LA<sub>Max</sub> Night or 5 dB over background.  
 Sweetwater County, Wyoming 40 dBA (LA<sub>Max</sub>) and 50 dBC (LC<sub>Max</sub>) (this addresses the low frequency character of wind turbine sounds)

The link below shows a summary of some decibel limits used around the world:

[http://wiseenergy.org/Energy/Health/Acoustical\\_Limit.pdf](http://wiseenergy.org/Energy/Health/Acoustical_Limit.pdf).

- 2-4) **Refer to the direct testimony of Mr. Richard James, Page 3, lines 101 – 105, and Page 5, lines 158 – 163. If Mr. James recommends a maximum sound level of 35 dBA, and states the setback distance would be on the order of 3600 feet to meet the 35 dBA Leq limit, why does Mr. James calculate the setback to prevent annoyance during nighttime periods from multi-turbine projects would need to be 1.25 miles? Please explain.**

**RESPONSE:**

Richard James: The 3600-foot setback relates to the goal of limiting wind turbine noise to 35 dBA Leq, a point where annoyance will still occur, but high annoyance is limited to the more sensitive people. The 1.25-mile setback (roughly double the distance and thus about 6 dBA lower in sound level) is the distance needed to prevent high annoyance from audible sounds (infra sound will still be an issue for those sensitive to it). The predicted sound level at 1.25 miles is about 30 dBA Leq. High Annoyance is the descriptor for annoyance that results in health effects and threats of action. (See Health Canada study graph in first statement)

Since rural communities have nighttime sound levels of 25 dBA and often lower the sound of distant wind turbines is still audible even at the 1.25 mile distance.

Also, as revealed in the Health Canada study, the prevalence rates for health effects that are related to pulsating infra and low frequency sound, such as, tinnitus, dizziness, and migraines for people living 1.25 miles from the nearest wind turbine are still double that of the non-exposed population. These sounds may or may not be audible, but still have an impact on sensitive people through non-auditory processes. Thus, we cannot say that 1.25 miles represents a "safe" setback distance for all people.

- 2-5) **Refer to the direct testimony of Mr. Richard James, Page 5, lines 158 – 163, and the Intervenor's response to Staff Data Request 1-4. The Intervenor recommended a**

**condition that requires a 1,500 ft. setback from a property line, but Mr. James recommended a 1.25 mile setback from the property line. Please explain how the 1,500 ft. setback is consistent with Mr. James' testimony.**

**RESPONSE:**

Gregg Hubner: As stated before, I have always advocated for a 2-mile setback from a residence and a 1500 ft. setback from a property or right of way line.

The reason I advocate for 1500 ft. is that people often are near their fence lines, farming, putting up hay or hunting. The Vesta Owners Safety Manual for a 3.0 MW Turbine recommends people to stay 400 meters (1300 ft.) from the turbine unless it is necessary to be closer, and 500 meters away from a runaway turbine (attachment E) This is for a 3.0 MW, and Prevailing Winds is using 3.8 MW turbines. General Electric uses the following calculation for ice throw:  $1.5 \times \text{hub height plus blade diameter}$  ( $1.5 \times (361+449)$ ) = 1,215 foot setback from ROWs and property lines. (Attachment F)

The 2-mile setback for a non-participating resident and a 1500 ft. setback from a property or right of way line would be a good safe combination. It protects both homes and bare land, always considering people are not always in their home, they are across every acre of their land several times during the year.

Reece Almond: Mr. James' explanation for his 1.25-mile setback from a property line is explained on page 6, lines 178-185, of his pre-filed testimony.

- 2-6) Refer to the direct testimony of Prof. Mariana Alves-Pereira, Line 460:  
 "Appropriate zoning laws for industrial wind turbines should be considered."  
 Please provide Prof. Alves-Pereira recommendation for an appropriate zoning law  
 for industrial wind turbines to address her concerns regarding ILFN.**

**RESPONSE:**

Mariana Alves-Pereira: I am assuming the question posed above is: "Please request that Prof. Alves-Pereira provide recommendations for an appropriate zoning law for industrial wind turbines to address her concerns regarding ILFN."

Zoning laws were not conceived as legal entities to be solely based on economic convenience. In theory, zoning laws are founded on the idea of the protection of Public Health. In order to properly ascertain what are the 'safe-distances' for residential neighborhoods located in the vicinity of wind developments, then scientifically-valid studies must be undertaken by the appropriate authorities.

The possibility of such studies was briefly described in the subsequent Lines 463-466 of the same testimony:

463 epidemiological studies. Ideally, this would study relevant health endpoints *before* and  
 464 *after* installation of the industrial wind turbines. It would also include the quantification  
 465 of ILFN *before* and *after* the installations of the industrial wind turbines, with the same  
 466 wind speed and wind direction, and evaluated *inside* the affected homes.

There are currently no scientifically-valid studies providing numerical data on ‘safe-distances’ that can effectively protect families against ILFN-contaminated homes (whatever the source).

**2-7) Refer to the direct testimony of Prof. Mariana Alves-Pereira, Lines 460 – 462:  
 “However, in the absence of zoning laws based on scientific information, then the governmental agencies responsible for Public Health should step in to conduct appropriately designed epidemiological studies.” Which governmental agency in South Dakota is Prof. Alves-Pereira referring to?**

**RESPONSE:**

Mariana Alves-Pereira: I am unclear as to the question posed here. I understand that the word ‘governmental’ within the context of the State of South Dakota may be misleading. Perhaps, therefore, the word ‘governmental’ should be replaced by ‘federal and state,’:

“[I]n the absence of zoning laws based on scientific information, then *Federal and State agencies responsible for Public Health* should step in to conduct appropriately designed epidemiological studies.”

I am not familiar with the details of South Dakota State Government, but I imagine that there is some Health Department at the State level whose job description would include the protection of Public Health.

At the Federal level, I would imagine that agencies such as the CDC (Center for Disease Control), the ATSDR (Agency for Toxic Substances and Disease Registry) or the NIH (National Institutes of Health) would have the expertise and the mandate to undertake properly designed studies that would begin to ascertain ‘safe-distances’ between residential areas and wind developments.

The lack of properly determined ‘safe-distances’ is not an issue merely in South Dakota, or merely in the United States. Countries all over the world are faced with this quagmire that is leading to the onset of illness among entire families and neighborhoods, and consequently, to increased healthcare costs. Within this context, perhaps the scientific determination of ‘safe-distance’ should be under the auspices of larger regulatory bodies, such as the World Health Organization or the International Standards Organization.

**2-8) Refer to the direct testimony of Mr. Jerry Punch, Page 14, lines 396 – 402, and the direct testimony of Mr. Richard James, Page 3, line 101 through Page 4, line 105.**



**Mr. James recommends that “the maximum sound level for audible sounds should be 35 dBA (Leq) and 50 dBC, especially for nighttime wind turbine noise. We also limited the new noise source to be no more than 5 dBA louder than the pre-operational background sound level at night.”**

**Mr. Punch recommends that “the WHO recommendation of 40 dBA Leq (night,outside) should not be exceeded at any residence, particularly at non-participating households. To provide adequate protection from sleep disturbance, nighttime noise levels should be limited to 40 dB L<sub>Amax</sub>. A metric of dB L<sub>A10</sub>(night, outside), the noise level exceeded 10% during nighttime hours and measured at the façade of the residence, may be a reasonable substitute for L<sub>Amax</sub> if considered by acoustical experts to be easier to apply for the purpose of compliance.”**

**The recommendations between these two witnesses for the Intervenor’s appear inconsistent. Actually, Mr. James’ states that the use of a limit of 40 dBA is inadequate to prevent adverse effect (Direct testimony, Page 5, lines 143 – 149).**

**Will the Intervenor’s advocate for Mr. James’ recommendation or Mr. Punch’s recommendation for audible noise at the hearing? Please explain.**

#### **RESPONSE:**

Jerry Punch: The inconsistency of my recommendation with that of Mr. James is in question, and my response is that I stand by my statement that 40 dBA Leq(night, outside) should not be exceeded at any residence, but recognize that others, including Mr. James, may have reasons for recommending a lower level. For example, the WHO (2009)<sup>1</sup> notes that people complain of a sense of reduced well-being at an average noise level of 35 dBA Leq(night,outside), and that same level may be recommended to protect a higher percentage of residents from annoyance, which is known to be a major complaint of individuals living near wind turbines.

In the recent Health Canada study, for example, at least 10% of people in the area of a wind project area who were exposed to levels >35 dBA were extremely annoyed.<sup>2</sup> I am basing my recommendation to limit averaged nighttime, outside levels to 40 dBA on the WHO’s 2009 recommendation to protect human health. The above-referenced extensive list of levels of noise permitted nationally and internationally<sup>3</sup> indicates that levels as low as 30 dBA have been recommended or utilized at a number of wind projects.

In my direct testimony, (page 11, lines 306-307), I stated that “The WHO (2009) Night Guidelines suggest that a 40 dB L<sub>Amax</sub> level should be the maximum allowable level during nighttime hours.” In fact, the WHO (2009) states that some of the more subtle, physiologically

<sup>1</sup> World Health Organization (2009). Night Noise Guidelines for Europe, p. XIV.

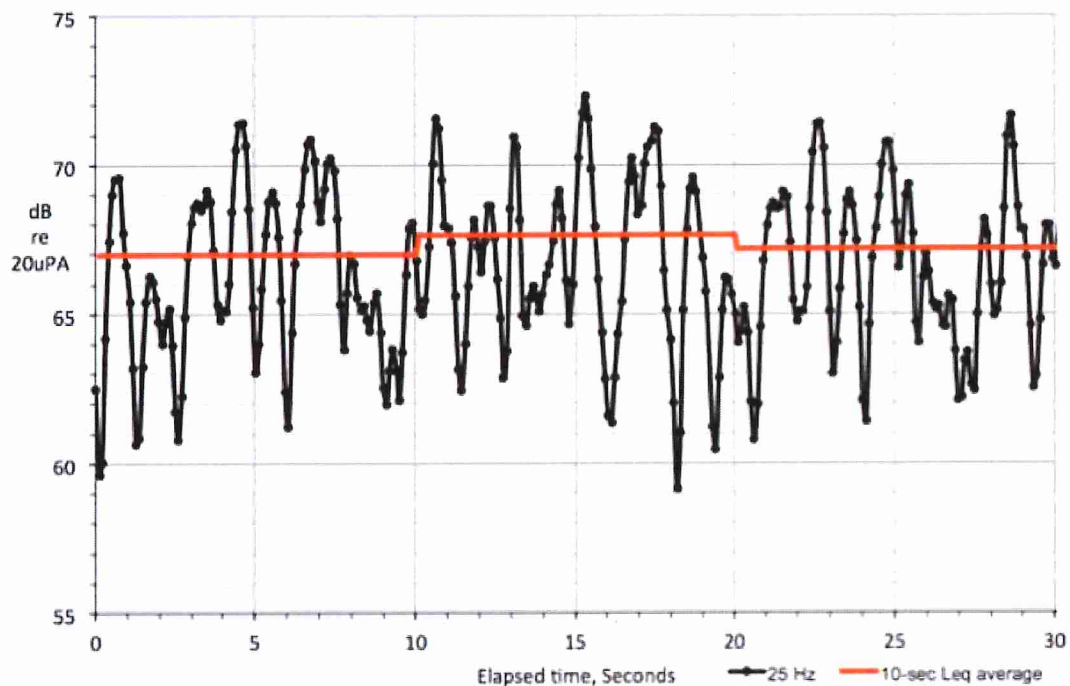
<sup>2</sup> Michaud, D. S., Feder, K., Keith, S.E., Voicescu, S. A., Marro, L., Than, J., et al. (2016). Exposure to wind turbine noise: Perceptual responses and reported health effects. Journal of the Acoustical Society of America, 139, 1443-1454.

<sup>3</sup> [http://wiseenergy.org/Energy/Health/Acoustical\\_Limit.pdf](http://wiseenergy.org/Energy/Health/Acoustical_Limit.pdf)

measurable, aspects of sleep disturbance occur at noise levels of 32-42 dB L<sub>Amax</sub>(night,inside). According to James,<sup>4</sup> the L<sub>Amax</sub> level is 10 dB above that of Leq, so a level of 40 dB L<sub>Amax</sub> corresponds to a level of 30 dBA Leq; note that is a peak level at night, inside a residence.

My professional opinion is based not only on the concerns expressed in the WHO Night Noise Guidelines for Europe and the WHO Guidelines for Community Noise (Berglund et al., 1999),<sup>5</sup> but also on the notions that wind turbine noise consists of rapid energy peaks and valleys and that nearby residents need to be protected from inaudible infrasound, as well as audible sound.

The chart below is a graphic illustration of the presence of the highly fluctuant nature of wind turbine noise, over short periods of time. The chart is from Robert Rand, well-known acoustician, and it shows noise fluctuations between about 60 dB SPL to about 72 dB SPL in the one-third octave band centered at 25 Hz. These fluctuations occurred within a time period of only 30 seconds, captured using a fast setting on the sound level meter. The fluctuations occur above and below the average noise level of approximately 67-68 dB Leq(10sec). The chart also illustrates why Leq measurements do not adequately depict the emissions experienced by receptors in real time.



**Figure 6.1. 25 Hz one-third octave band noise level, 2000-feet upwind, turbines 2 and 3 operating, Freedom, Maine (acquired 8Jan2010). 1/10 second sample (black), 10-second averages (red). R. Rand**

<sup>4</sup> James, R. (March 27, 2018). Recommended Amendments to Section 4.3.76 Shiawassee County Zoning Ordinance, Article 4, Specific Use Regulations Prepared On Behalf of: Regulated Wind of Shiawassee County (RWSC), p. 6.

<sup>5</sup> Berglund, B., Lindvall, T., & Schwela, D.H. (eds.) (1999). Guidelines for Community Noise. World Health Organization, April 1999.

With respect to the WHO guidelines, two primary considerations need to be taken into account. Together, they justify the necessity of establishing reasonably conservative noise exposure guidelines with respect to wind turbine noise. First, the WHO bases its recommended noise limits largely on transportation noises, which contain low-frequency energy, but substantially less infrasonic energy than wind turbine noise. Secondly, the WHO assumes that the outside-to-inside attenuation for transportation noises is about 15 dB. Neither of these assumptions can be applied to the infrasonic energy in wind turbine noise, which travels long distances and is not easily attenuated by traditional physical barriers. It is also true that people have a right to sleep with their bedroom windows open, and that should be especially true for those individuals who have chosen to live in an area where they can enjoy the peace and quiet of a rural community.

A case in Vermont<sup>6</sup> supports the contention that the outside-to inside attenuation of wind turbine noise is much less than 15 dB, and that it is almost negligible, when windows are open. Paul Brouha of Sutton, Vermont, lives 6,385 feet from the nearest turbine in the area of the Sheffield Wind project. Brouha filed his first noise complaint on Dec. 24, 2011, after the wind turbines began operating in October. The Vermont Public Service Board (PSB) dismissed his complaint. An earlier report by the wind project operator showed virtually no reduction (1 dBA) in the broadband sound of the loudspeaker between outdoors and indoors, a value much lower than normally expected, even for large open windows. Brouha hired a noise expert, Acentech, which found that instead of the 15 dB noise attenuation between outside and inside projected by wind project's experts, the home attenuated the noise by 25 dBA when Brouha's bedroom windows were closed, by 9 dBA when the windows were partially open and by only 3 dB when the windows were fully open. The indoor measurements in the Brouha bedroom (averaged across locations within the room) did not exceed the project criterion level of 30 dBA<sub>Leq</sub>(1hr) with the windows fully closed, but did exceed 30 dBA with the windows partially or fully open.

In the Brouha case, Acentech's measurements showed "multiple and frequent violations of the CPG noise criteria" adopted by the PSB, and the PSB ordered the Vermont Department of Public Service (DPS) to investigate the complaint early in 2014. DPS hired a consultant who conducted the same test on July 1, 2014. In January 2015, Brouha filed a nuisance lawsuit in superior court in Vermont. In September 2015, DPS reported to the PSB that Sheffield Wind exceeded interior noise standards 10 to 14 percent of the time. Because of PSB's laborious investigation and enforcement process, and the parties' noise experts' failure to agree on a new monitoring plan, his noise complaint had not been resolved as of February 2017, the time of the most recent report.

Justification for concern that LAmix be considered as an option (in addition to offering L10 as an option), stems from the following quotes from the 1999 WHO document, as well as the final quote, which is from the 2009 WHO Night Noise Guidelines:

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<sup>6</sup> Smith A, "The Kafkaesque world of windmill neighbors" (VTDigger [The Vermont Journalism Trust] Feb. 3, 2017), available at <<https://vtdigger.org/2017/02/03/annette-smith-kafkaesque-world-windmillneighbors/>>.

- “When the noise consists of a small number of discrete events, the A-weighted maximum level (LA<sub>max</sub>) is a better indicator of the disturbance to sleep and other activities.... Where there are no clear reasons for using other measures, it is recommended that LA<sub>eq,T</sub> be used to evaluate more-or-less continuous environmental noises. Where the noise is principally composed of a small number of discrete events, the additional use of LA<sub>max</sub> or SEL (sound exposure level) is recommended” (p. viii). *(I contend that whether the number of discrete events is small or large, the occurrence of discrete events that have their peak amplitudes during any nighttime period can be highly disturbing to sleep.)*
- “If negative effects on sleep are to be avoided the equivalent sound pressure level should not exceed 30 dBA indoors for continuous noise. If the noise is not continuous, sleep disturbance correlates best with LA<sub>max</sub> and effects have been observed at 45 dB or less. This is particularly true if the background level is low.” (p. 46)
- “When the background noise is low, noise exceeding 45 dB LA<sub>max</sub> should be limited, if possible, and for sensitive persons an even lower limit is preferred. Noise mitigation targeted to the first part of the night is believed to be an effective means for helping people fall asleep. It should be noted that the adverse effect of noise partly depends on the nature of the source. A special situation is for newborns in incubators, for which the noise can cause sleep disturbance and other health effects (p. xii).... The LA<sub>max</sub> of sound events during the night should not exceed 40 dB(A) indoors. For ward rooms in hospitals, the guideline values indoors are 30dB LA<sub>eq</sub>, together with 40 dB LA<sub>max</sub> during night.” (p. xiii)
- “L10 values have been widely used to measure road-traffic noise, but they are usually found to be highly correlated measures of the individual events, as are LA<sub>max</sub> and SEL.” (p. 23)
- “Where the noise consists of a small number of discrete events, the A-weighted maximum level (LA<sub>max</sub>) will be a better indicator of the disturbance to sleep and other activities.” (p. 29)
- “A large number of events lead to high levels of awakening once the threshold of LA<sub>max,inside</sub> is exceeded.” (p. 105)

Richard James: As I explained in my response to question 2-3) picking a regulatory limit should focus on the characteristic of the noise emitter that is most problematic. As Dr. Punch explains above the differences between our recommendations are mainly a result of which metric we are considering for limiting the intrusion. There are many different ways that limits can be set with the 35 dBA Leq or 45 dBA L<sub>Max</sub> being two examples. Any differences between Dr. Punch's suggestions and mine are likely resolved when considering these various options for metrics.

I support Dr. Punch's response.



**2-9) Refer to the direct testimony of Mr. Jerry Punch, Page 11, lines 303 – 314. Have any U.S. counties or states adopted the Intervenor’s recommended maximum nighttime noise level regulation for wind energy facilities of 40 dB LA max? Please provide documentation to support the response.**

**RESPONSE:**

Jerry Punch: In answer to the staff’s Question 2-9, it is understandable that few if any U.S. counties or states have adopted 40 L<sub>Amax</sub>, or the L<sub>Amax</sub> metric in general, as a means of quantifying maximum nighttime noise. L<sub>Amax</sub> has been discussed, however, as a recommended metric at some wind projects, but there is scant evidence that 40 dB L<sub>Amax</sub> has been adopted at any specific facility. I can point, though, to several communities where the concept of L<sub>Amax</sub> (sometimes referred to as L<sub>max</sub>) has been recommended as a legitimate metric for measuring the level of wind turbine noise, or where the refusal of a wind company to adopt L<sub>max</sub> was a partial basis for disapproval of a wind project.

According to Robert Chanaud,<sup>7</sup> who recently developed a document that serves as an update of the EPA’s Model Community Noise Control Ordinance, the Leq metric is part of the noise ordinances in Seattle, Washington, and Portland, Oregon. The Seattle ordinance stipulates that “...the L<sub>max</sub> must not be more than 15 dB over the Leq” (p. A-17). The same document states: “Set the maximum levels sufficiently high that it is unlikely for the ambient to exceed it. This approach requires either an arbitrary assumption or extensive measurements. It also does not satisfy the health and welfare goals of the community so no communities have taken it” (p. 6-3).

In Almer Township, Michigan, the local ordinance specified a noise limit of 45 dBA. The presiding judge interpreted the ordinance to mean that no sound should be allowed to exceed 45 dBA, and ruled that Tuscola Wind’s refusal to adopt L<sub>max</sub> as a means to comply with the ordinance was tantamount to its refusal to protect citizens from fluctuating wind turbine noise. In his final ruling, the judge stated: “...it is ORDERED that Defendant Almer Township Board’s denial of Plaintiff Tuscola Wind III, LLC’s, SLUP application is AFFIRMED” (p. 46). In footnote 12 of that document (p. 45), it is stated: “Tuscola has not demonstrated that it is entitled to deferential or economically favorable conditions. Perhaps application of an L<sub>max</sub> standard creates such an economic hardship that it constitutes de facto exclusionary zoning. But Tuscola’s conclusory briefing on this point falls far short of showing that to be true.”

Despite the low prevalence of the adoption of L<sub>Amax</sub> as a preferred metric in local zoning ordinances, the use of L<sub>Amax</sub> deserves to be explored by wind developers, as it offers an increased probability that the numerous complaints of annoyance and adverse effects related to wind turbine noise exposure can be substantially reduced.

In my direct testimony, I provided several alternative metrics as recommendations for determining the maximum allowable limits for wind turbine noise emissions. I have offered the above detailed explanation of my justification for including both an Leq level and L<sub>Amax</sub> level

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<sup>7</sup> Chanaud, R. C. (July 2014). Noise ordinances: Tools for enactment, modification and enforcement of a community noise ordinance.

because of a specific question raised regarding inconsistency between my recommendation and that of Mr. James.

Having given my rationale for recommending 40 dB LAmax as one such metric, it is the case that the use of LAmax could entail some rather complex measurement issues. It would be a relatively simple matter to determine whether a specific LAmax level has been exceeded in a given nighttime period of time, such as an 8-9 hour night, or nights over a one-week period. However, a decision would have to be made regarding how many discrete occurrences of that maximum level are allowable before the noise is ruled in noncompliance. While the WHO (2009, p. XV) states that a large number of events lead to high levels of awakening once the LAmax threshold is exceeded, it also indicates that there is no generally accepted way to count the number of relevant noise events, and that the options include the number of measured LAmax levels and the number exceeding a specific LAmax level (p. 8). For this reason, it is understandable that most wind projects have adopted the use of dBA Leq, which—despite its extreme limitations when applied to wind turbine noise—is a traditional metric around which there is a considerable body of data for comparison. Although resolution of these issues could be achieved with careful thought, it would require an effort the wind industry thus far has not been willing to expend.

Dated this 2<sup>nd</sup> day of October, 2018.

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CERTIFICATE OF SERVICE

The undersigned, one of the attorneys for Intervenor Gregg C. Hubner, Marsha Hubner, Paul M. Schoenfelder, and Lisa A. Schoenfelder, certifies that a true and correct copy of the **Intervenor's Responses to Staff's Second Set of Data Requests to Intervenor** was served on October 2<sup>d</sup>, 2018, via email, upon the following:

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should be spelled out in a local ordinance—were presented at the annual conference of the Institute of Noise Control Engineering/USA in 2008 and are posted on the Wind Turbine Syndrome website at [www.windturbinesyndrome.com/?p=925](http://www.windturbinesyndrome.com/?p=925). An important outcome of Kamperman and James's method is that as turbines get larger, setbacks will have to be greater.

The simple answer is: *Keep wind turbines at least 2 km (1¼ miles) away on the flat, and 3.2 km (2 miles) in mountains. These are minimum distances. Kamperman and James's methods will likely recommend larger setbacks, especially in rural areas that are very quiet at baseline.* Second, all wind turbine ordinances should hold developers responsible for a full price (pre-turbine) buyout of any family whose lives are ruined by turbines—to prod developers to follow realistic health-based rules and prevent the extreme economic loss of home abandonment.



A 2 km setback would have prevented this:<sup>3</sup>

My husband is seeing a doctor for depression. I have a daughter who is seeing a specialist for serious stomach problems. I have had endless sleepless nights since the wind turbines went up. I constantly have feelings of anxiety. My children have complained of headaches and not sleeping well.

Let me ask you, What would you do?

What would I do? I admit I'd be driven into doing what she has done:

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<sup>3</sup> Personal communication, April 6, 2009.

## RESEARCH ARTICLE

# Analysis of throw distances of detached objects from horizontal-axis wind turbines

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## ABSTRACT

This paper aims at predicting trajectories of the detached fragments from wind turbines, in order to better quantify consequences of wind turbine failures. The trajectories of thrown objects are attained using the solution to equations of motion and rotation, with the external loads and moments obtained using blade element approach. We have extended an earlier work by taking into account dynamic stall and wind variations due to shear, and investigated different scenarios of throw including throw of the entire or a part of blade, as well as throw of accumulated ice on the blade. Trajectories are simulated for modern wind turbines ranging in size from 2 to 20 MW using upscaling laws. Extensive parametric analyses are performed against initial release angle, tip speed ratio, detachment geometry, and blade pitch setting. It is found that, while at tip speeds of about 70 m/s (normal operating conditions), pieces of blade (with weights in the range of approximately 7–16 ton) would be thrown out less than 700 m for the entire range of wind turbines, and turbines operating at the extreme tip speed of 150 m/s may be subject to blade throw of up to 2 km from the turbine. For the ice throw cases, maximum distances of approximately 100 and 600 m are obtained for standstill and normal operating conditions of the wind turbine, respectively, with the ice pieces weighting from 0.4 to 6.5 kg. The simulations can be useful for revision of wind turbine setback standards, especially when combined with risk assessment studies. Copyright © 2015 John Wiley & Sons, Ltd.

## KEYWORDS

wind turbine accidents; blade element theory; blade detachment; ice throw; aerodynamic model; HAWT

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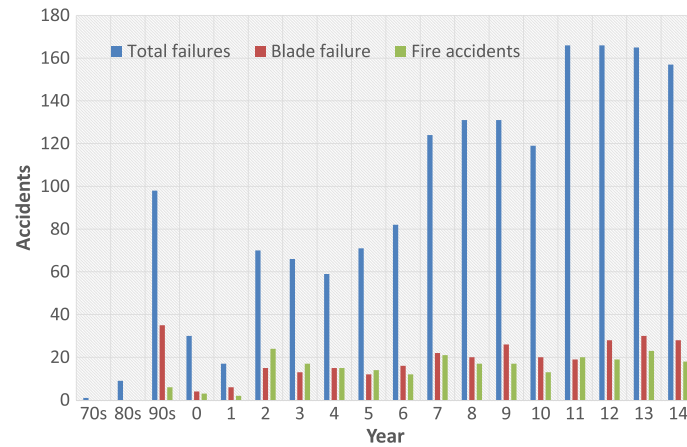
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## 1. INTRODUCTION

The ever-growing number of wind turbines installed near inhabited areas, buildings and community facilities, such as bridges, power installations or highways, has resulted in an increasing concern by authorities to determine risk levels associated with wind turbine blade failure. From a safety point of view, the most serious failure is associated with splintering of rotor blades and detachment of debris, which could be thrown over long distances and damage people or property. Ice-throw from wind turbines installed in cold climate is also of high concern, especially for wind turbines erected near highways where the ice pieces thrown from a wind turbine may strike a passing car, which in the worst case may cause a fatal accident.

Various types of hazards regarding operation of wind turbines have recently been reported by Durstwitz and the Caithness Windfarm Information Forum.<sup>2,3</sup> According to a recent survey by the Caithness Windfarm Information Forum, blade failures resulting in either whole blades or pieces of blades being thrown from the turbine are the most important causes of turbine accidents.<sup>3</sup> A comparative graph showing the growth of wind turbine accidents over the past four decades is shown in Figure 1, where the share of blade accidents and accidents due to fire, which may eventually cause throw of fire patches, are also presented. Due to such accident data, energy authorities all over the world have tried to enforce safety distances around wind turbines and wind farms. The safety distance is a distance within which it is not allowed to build human structures such as buildings and roads. Shown in Table I is an example of the safety distance standards defined by different authorities. It can be seen from the table the values of offset safety distances fall within an extensive range of



**Figure 1.** Comparison of wind turbine accidents and particularly blade failure data in a period from 1970s until 2014 (data taken from Caithness Windfarms<sup>3</sup>).

**Table I.** Safety distances of wind turbines from human structures as practiced in different regions of the world.<sup>17</sup>

Authority/source	Safety distance [m] (ft)
France	1609 (5280)
Germany	1609 (5280)
Rural Manitoba, Canada (1981)	(6500)
US National Research Council	762 (2500)
IL, USA	457 (1500)
Riverside County, CA, USA	<b>3218 (10560)</b>
MI, USA	<b>304 (1000)</b>

scales between 3.2km and 300m, and that the setback standards are not even similar in different regions of the same country. To standardize such safety guidelines, it is useful to employ mathematical models of the throw in various conditions and risk assessment tools to associate the probability of failure in each particular setting.

Motions of solid particles in fluids were first addressed analytically by Kirchhoff.<sup>4</sup> He showed that the equations of motion for a solid body in an ideal fluid reduce to a set of ordinary differential equations (ODE) based on Euler's equations. Further experimental investigations on falling objects revealed, despite originating from Euler's equations, various states of chaotic motion. It was also mathematically shown that Kirchhoff's equations had been prone to yield chaotic solutions [5]. Tanabe *et al.*<sup>6</sup> developed a set of two-dimensional equations of motion (including rotation) based on simple mechanics in which plates of zero thickness were subject to lift, friction and gravity forces. Based on those assumptions, they found five different falling patterns, ranging from a periodic movement to chaotic random motions depending on the density ratio between the solid and the surrounding fluid and on the length of the object. Pesavento and Wang<sup>7</sup> and Andersen *et al.*<sup>8</sup> performed more detailed studies to determine the motion of a falling two-dimensional elliptic object using direct numerical simulation of the Navier–Stokes equations. They took added mass and added moment of inertia into account and analyzed the transient motion and local jumps of the falling object thoroughly.

Due to complications in a real-life blade accidents (erratic motions, high Reynolds numbers, complex geometries etc.), the fundamental studies mentioned above could only partially help understanding the physics of wind turbine blade throw patterns. To cope with the wind turbine problems, simplified approaches were used. Macqueen *et al.*,<sup>9</sup> for instance, studied the problem of blade-throw from wind turbines, using classical ballistics and also assumption of constant lift and drag. A lift coefficient of  $Cl = 0.8$  and a drag coefficient of  $Cd = 0.4$  were used for the gliding simulations, with  $Cl = 0.0$  and  $Cd = 1.0$  for the tumbling motion. However, the probability that gliding would occur was deemed very small. Their maximum throw studies using simple ballistic analysis, that is, by neglecting aerodynamic forces, showed that in the extreme throw velocity of approximately 310m/s, the maximum throw length reaches 10km.

One of the first detailed studies on the aerodynamics of a detached wind turbine blade was performed by Sørensen<sup>1</sup> using a blade element approach. In this approach, the detached blade is divided into a number of sections and the aerodynamic loads are determined for each section. The total external aerodynamic load on the whole blade would then be determined as the summation of the individual forces on each section.



Recently, Rogers *et al.*<sup>10</sup> used a dynamic model employing quaternions instead of Euler angles and rotation vectors to form the orientation matrix and performed Monte Carlo simulations of a large set of initial conditions in order to obtain a range of the throw distances.

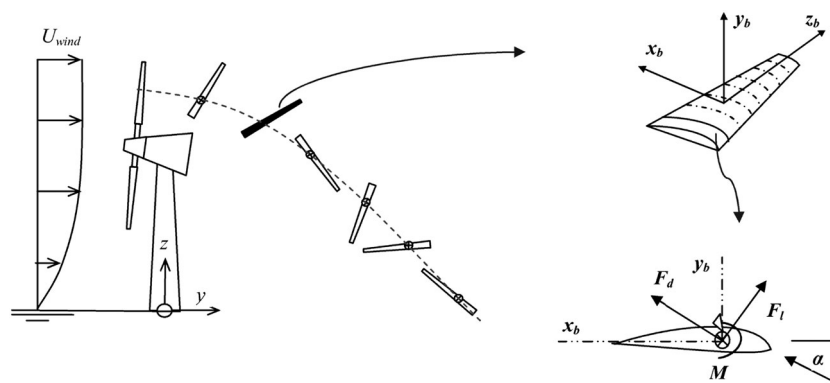
Ice throw has also been investigated, especially for the turbines erected in the cold climate. Seifert *et al.* measured ice-throw accidents together with a simple aerodynamic model and performed risk analysis of the ice fragments thrown from the blades.<sup>11</sup> Recently, a model of ice throw for a wind turbine in operation was presented by Biswas *et al.*,<sup>12</sup> in which calculations were carried out for ice pieces by neglecting lift and using a fixed drag coefficient of  $C_d = 1.0$ . It was also estimated that including the highest possible, lift increases the throw distance by approximately a factor of two.

The problem of blade/ice throw has also been investigated through the window of probabilistic methods. Such methods deal with risk levels and probabilities that a certain throw distance will occur. Such studies are typically performed together with a dynamic model for calculating the throw distances. Macqueen *et al.*,<sup>9</sup> Morgan,<sup>13</sup> Morgan and Bossanyi<sup>14</sup> and Rogers *et al.*<sup>10</sup> carried out risk analyses of ice throw to determine safety guidelines for wind developments in ice-prone areas. Sørensen<sup>15</sup> proposed a statistical model that determines risk levels of debris hitting people. Similarly, Carbone and Afferrante<sup>16</sup> performed a combined probabilistic and dynamic analyses to quantify hazards due to the blade throw.

In the present work, detailed aerodynamic analysis are performed for simulating flying debris. The cases include blade throw in which the blade together with its components is thrown, a case in which only a shell laminate is thrown and a case involving detachment of ice fragments. The governing equations of motion form a set of 18 ODEs responsible for the six degree-of-freedom motion. The resulting system of discretized equations are solved using an ordinary time integration method. Throw distances for four different turbine sizes ranging from 2.3 to 20 MW are compared, by employing simple upscaling rules. The computations are carried out for different wind and tip speeds.

## 2. MATHEMATICAL MODELING

The equations of motion for a detached blade include equations of translation and equations of rotation. These are obtained using Newton's second law and Euler's equations of motion, with the aerodynamic forces obtained from tabulated airfoil data. To be able to quantify the rotational motion of the detached blade, the moments of inertia around the rotation axes are calculated. This, however, cannot be calculated in a fixed coordinate system (i.e., an inertial system) since both the moments of inertia and the rotational speeds are varying and a solution would become very complicated. Instead, the equations are computed around the body-fixed principal axis, and the obtained values are subsequently transformed to the global (inertial) coordinate system to represent the absolute location and orientations. Two coordinate systems are defined here: a global coordinate system  $\mathbf{x} = (x, y, z)$  with the origin on the tower basement and orthonormal right-handed unit vectors  $(\vec{i}, \vec{j}, \vec{k})$ , with the  $y$ -axis in the wind direction and the  $z$ -axis in the upward direction. A body-fixed coordinate system  $\mathbf{b} = (x_b, y_b, z_b)$  is defined by an orthonormal right-handed unit vector  $(\vec{r}_1, \vec{r}_2, \vec{r}_3)$ , with the origin located at the center of gravity of the detached blade fragment and the third axis parallel to the length axis of the blade (Figure 2).



**Figure 2.** Sketch of the problem and definition of coordinate systems.

The orientation of the detached part is determined through a matrix  $\mathbf{R}$ , which gives the transformation from global coordinates to the body-fixed coordinates

$$\begin{bmatrix} \vec{r}_1 \\ \vec{r}_2 \\ \vec{r}_3 \end{bmatrix} = [\mathbf{R}] \begin{bmatrix} \vec{i} \\ \vec{j} \\ \vec{k} \end{bmatrix} = \begin{bmatrix} r_{11} & r_{12} & r_{13} \\ r_{21} & r_{22} & r_{23} \\ r_{31} & r_{32} & r_{33} \end{bmatrix} \begin{bmatrix} \vec{i} \\ \vec{j} \\ \vec{k} \end{bmatrix} \text{ and similarly, } \begin{bmatrix} \vec{i} \\ \vec{j} \\ \vec{k} \end{bmatrix} = [\mathbf{R}^{-1}] \begin{bmatrix} \vec{r}_1 \\ \vec{r}_2 \\ \vec{r}_3 \end{bmatrix} \quad (1)$$

Equation (1) holds for transformation of any variable between the two coordinate systems. This way of defining a vectorized rotation matrix (as opposed to Euler's scalar angles) ensures uniqueness of orientation angles and avoids the problem known as gimbal lock.

The full six degree-of-freedom motion is governed by Newton's second law of motion and Euler's equations of motion:

$$m\ddot{\underline{x}}_g = \underline{F} + m\underline{g} \quad (2)$$

$$\underline{I}\dot{\underline{\omega}}_b = \underline{\omega}_b \times (\underline{I}\underline{\omega}_b) = \underline{M} \quad (3)$$

where  $m$  is the mass of the blade,  $\underline{x}_g$  is the position vector of the center of gravity,  $\underline{F}$  is the aerodynamic force acting on the center of gravity,  $\underline{g}$  is the gravitational acceleration,  $\underline{I}$  is the moment of inertia tensor,  $\underline{\omega}$  is the angular velocity in the rotating frame of reference,  $\underline{M}$  is the aerodynamic force acting along the principal axis of the moment of inertia tensor and  $(\cdot)$  denotes differentiation with respect to time. To close the system, the following relationship between the motion of the unit vectors of the body (the blade fragment) and the angular velocity is used:

$$\dot{\underline{r}} = \underline{\omega} \times \underline{r} \quad (4)$$

where  $\underline{\omega}$  is the angular velocity of the blade fragment in the inertial coordinate system, which by equation (1) is transformed into the local body-fixed coordinate system. The total set of equations are solved using a fourth-order Runge–Kutta–Nystrom or a third-order Adams–Bashforth method. For more information about the mathematical and numerical treatment of the equations, readers are referred to the early work of Sørensen.<sup>1</sup>

## 2.1. Aerodynamic modeling

For the solution of the system of ODEs, a blade element approach is employed in which each blade is divided into  $n$  sections along the span. In each section, the external forces and moments are calculated from airfoil data based on the local wind speed and relative velocities.

The three-dimensional edge effects are to some extent considered through the finite aspect ratio assumption of the blade, and the aerodynamic coefficients of lift and drag are calculated for all angles of attack based on flat-plate theory. The induced velocities are, however, neglected, and the Reynolds-number dependence of the airfoil data is disregarded. Once the aerodynamic coefficients are found, the lift, drag and moments on the blade fragment are computed as

$$L_i = \frac{1}{2} \rho v_i^2 A_i C_{Li}, \quad D_i = \frac{1}{2} \rho v_i^2 A_i C_{Di} \quad (5)$$

where  $L_i$  and  $D_i$  are lift and drag forces on the  $i$ -th section,  $\rho$  is the air density,  $v_i$  is the local relative airspeed,  $A_i = c_i \Delta r_i$  is the local planform area where  $c_i$  and  $\Delta r_i$  are the local chord and the section lengths, and  $C_{Li}$  and  $C_{Di}$  are the sectional lift and drag coefficients at the desired angle of attack.

The static forces aerodynamic coefficients of the airfoil only depend on the angle of attack. Unsteady effects at high angles of attack are included by using the dynamic stall model of Øye.<sup>18</sup> In this model, the dynamic lift coefficient is obtained by interpolating between the lift coefficient of an airfoil in a fully attached flow and a lift coefficient of the airfoil when the flow around the airfoil is fully separated, i.e.,

$$C_{L,dyn} = f_s C_{L,inv}(\alpha) + (1 - f_s) C_{L,fs}(\alpha) \quad (6)$$

where  $C_{L,inv}$  is the lift coefficient for a fully attached flow (i.e., inviscid flow assumption) and  $C_{L,fs}$  is the lift coefficient for fully separated flow. The stall-changing rate is defined as

$$\frac{df_s}{dt} = \frac{f_s^{st} - f_s}{\tau} \quad (7)$$

where  $f_s$  is the time-dependent separation function, which can be thought of as the unsteady weighting function between the fully attached and the fully separated flow.  $f_s^{st}$  is a function of airfoil section,

$$f_s^{st}(\alpha) = \frac{C_{L,st}(\alpha) - C_{L,fs}(\alpha)}{C_{L,inv}(\alpha) - C_{L,fs}(\alpha)} \quad (8)$$



and  $\tau$  is an empirically determined time constant giving the time lag between the dynamic value of  $f_s$  and its static value. It follows from equation (7) that

$$f_s(t + \Delta t) = f_s^{st} + (f_s(t) - f_s^{st}) \exp\left(\frac{-\Delta t}{\tau}\right) \quad (9)$$

## 2.2. The atmospheric boundary layer effects

The inlet wind is included as a velocity profile corresponding to the Atmospheric Boundary Layer (ABL). As a result, in addition to simulating uniform inflow,<sup>1</sup> it is possible to simulate throw distances for blades thrown in wind fields following a power or logarithmic law, depending on the specific site information. The ABL wind profile as a function of height and atmospheric conditions reads

$$u_z = \frac{u_*}{\kappa} \left[ \ln\left(\frac{z}{z_0}\right) + \psi(z, z_0, L) \right] \quad (10)$$

where  $u_*$  is the friction velocity,  $\kappa$  is the von Karman constant ( $\sim 0.41$ ),  $z_0$  is the roughness length,  $\psi$  is a function of atmospheric stability and  $L$  is the Monin–Obukhov stability parameter (see Wyngaard<sup>19</sup> for more details).

If no data are available in a specific site, and neutral ABL is assumed, a power law  $u(z) = u_{hub}(z/z_{hub})^\alpha$ ,  $\alpha \sim 0.14$  will be used for the wind velocity at different heights having the wind velocity at hub height as an input. The power-law method is used for the parametric studies in this paper.

Using the mentioned wind profile and denoting the local position vector of a point  $p$  on the wing as  $\vec{r}_{pb}$ , the local relative wind velocity  $\vec{u}_{pb}$ , as seen by the blade fragment, is given as

$$\vec{u}_{pb} = [\mathbf{R}] \cdot (\vec{u}_{wind} - \vec{u}_g) - \vec{\omega}_b \times \vec{r}_{pb} \quad (11)$$

where the wind vector is assumed to be  $\vec{u}_{wind} = (0, u_y, 0)$ , neglecting the vertical and lateral components.

## 3. SIMULATION RESULTS

Simulations of both blade-throw and ice-throw distances are performed by solving the equations derived in the previous sections using the in-house aerodynamic code *Savbal*<sup>\*</sup>. The overall procedure for the solution consists of three stages, comprising coordinate transformation, aerodynamics load assessment and time integration. The initial position, orientation and velocities of the detached part are first evaluated at their local coordinates. Based on these values, an iterative procedure starts where the local velocities are evaluated, according to exerted aerodynamic loads, and integrated to give the location and orientation of the fragment in global coordinates until the fragment reaches the ground level.

For the blade-throw analysis, cases with different detached lengths and tip speeds are compared in two sub-cases: (1) the whole blade together with its sandwich structure is thrown and (2) only the shell layer of the blade is thrown. For ice-throw analysis, it turns out that the drag to mass ratio plays an important role for the magnitude of the throw distance. As a result, a few cases with different  $C_d A/m$  ratios (as discussed by Biswas *et al.*<sup>12</sup>) with both standstill and running turbine conditions are simulated. The analyses are performed for different wind turbine sizes.

### 3.1. Turbine upscaling laws

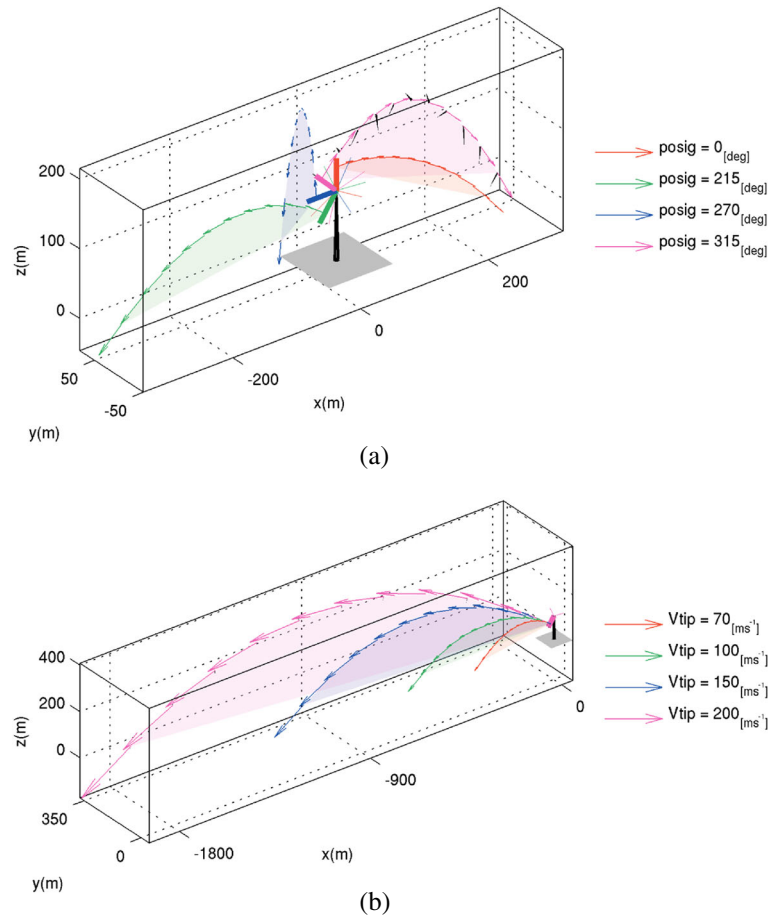
The throw distance analysis was initially performed for a 2.3 MW turbine using publicly available data. A series of empirical relations was then used to upscale the data for the larger turbines, and the analyses were performed for four different wind turbine sizes, i.e., 2.3, 5, 10 and 20 MW. The scale-up factors are first obtained for the blade length, which scales as the square root of the power ratio. Therefore, denoting the blade length, mass (applicable to both total sandwich structure and the shell laminate masses) and mass moment of inertia for the reference turbine with index  $a$ , i.e.,  $r_a$ ,  $m_a$  and  $\mathbf{I}_a$ , respectively, the corresponding values for the upscaled turbine, index  $b$ , can be obtained as

$$r_b = r_a \left( \frac{P_b}{P_a} \right)^{S_l}, \quad m_b = m_a \left( \frac{r_b}{r_a} \right)^{S_m}, \quad \mathbf{I}_b = \mathbf{I}_a \left( \frac{m_b}{m_a} \right) \left( \frac{r_b}{r_a} \right)^2 = \mathbf{I}_a \left( \frac{r_b}{r_a} \right)^{S_m+2} \quad (12)$$

<sup>\*</sup>The computing code *Savbal* will be available upon request for further studies on this field.

**Table II.** Characteristics of different turbine sizes considered in the throw analyses.

Size	$L^* = \frac{L}{R}$	$L$ (m)	$m$ (kg)	$I_x$ (kg·m <sup>2</sup> )	$I_y$ (kg·m <sup>2</sup> )	$I_z$ (kg·m <sup>2</sup> )
2.3 MW $R = 45$ m, $H = 100$ m	1.0	45	7.3E+3	0.1E+7	0.1E+7	0.3E+04
	0.5	22.5	2.4E+3	0.1E+6	0.1E+6	0.40E+03
	0.2	10	4.1E+2	0.4E+04	0.4E+04	0.2E+02
5 MW $R = 66$ m, $H = 147$ m	1.0	66	2.6E+04	0.9E+07	0.9E+07	0.2E+05
	0.5	33	8.2E+03	0.1E+07	0.1E+07	0.3E+04
	0.2	14	1.7E+3	0.3E+05	0.3E+05	0.2E+03
10 MW $R = 93$ m, $H = 208$ m	1.0	93	8.2E+04	0.5E+08	0.5E+08	0.1E+06
	0.5	46.5	2.7E+04	0.6E+07	0.6E+07	0.2E+05
	0.2	20	5.3E+3	0.2E+06	0.2E+06	0.1E+04
20 MW $R = 132$ m, $H = 294$ m	1.0	132	2.6E+05	0.3E+09	0.3E+09	0.9E+06
	0.5	66	8.7E+04	0.4E+08	0.4E+08	0.1E+06
	0.2	29	1.6E+04	0.1E+07	0.1E+07	0.8E+04

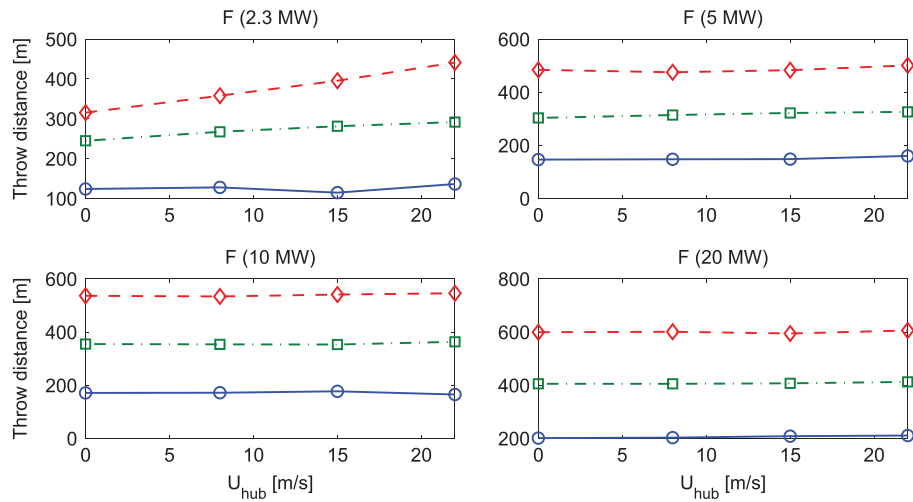
**Figure 3.** Schematic graphs of the throw distances for half-blade detachment changing (a) the initial release angles (upward-clockwise reference) and (b) the tip speed velocities for the 2.3 MW reference turbine.

where  $\mathbf{I} = (I_x, I_y, I_z)$ . In the previous relations,  $S_l = 1/2$  and  $S_m$  depends on actual scaling laws when increasing the size of the rotor. From simple upscaling rules,  $S_m$  would be equal to 3, but because of more elaborate rotor designs, this parameter is usually found to be somewhat smaller. In the present work, we employ  $S_m = 2.3$  (see UpWind<sup>20</sup> and TPI Composites<sup>21</sup> for more information on turbine scaling).

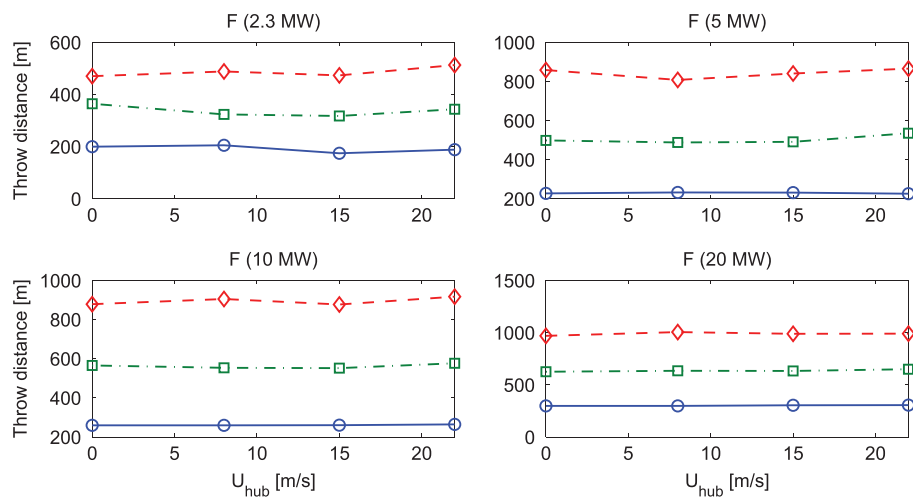
### 3.2. Full-blade throw analysis

In this section, the throw distance analyses are performed for four different turbine sizes based on the upscaling rules presented previously. Here, the term full blade refers to the case of blade shell including stiffening members (upper and lower shells, spar, etc.). The dimensions and other characteristics of each turbine size are reported in Table II. In accordance with the copyright policies of the turbine manufacturers, the data for the reference turbine (2.3 MW) do not correspond to an existing turbine but are chosen to mimic a real turbine.

The analysis included a parametric study, where the effects of the length of the detached parts, incoming wind speeds, blade tip speeds and wind turbine size on the blade-throw distances were investigated. The height of the tower is in all considered cases assumed to be equal to the rotor diameter. Figure 3 shows three-dimensional visualizations of the throw distances of a half-blade piece thrown of the 2.3 MW machine for different initial conditions. The small colored patches in the figure shows the instantaneous orientation of the detached part. For the sake of clarity, only some selected curves are shown in the figure. Figure 3(a) shows the effect of release angle on the throw distance, and Figure 3(b) shows the effect



**Figure 4.** Throw distance calculations of full blade with three different detached lengths for 2.3, 5, 10 and 20 MW turbines at the normal operating condition of  $V_{tip} = 70$  m/s. The horizontal axis shows the wind speed at the hub height and the vertical axis represents the throw distance.  $\diamond \diamond \diamond$ :  $L^* = 0.2$ ;  $\square \square \square$ :  $L^* = 0.5$ ; and  $\circ \circ \circ$ :  $L^* = 1$ .



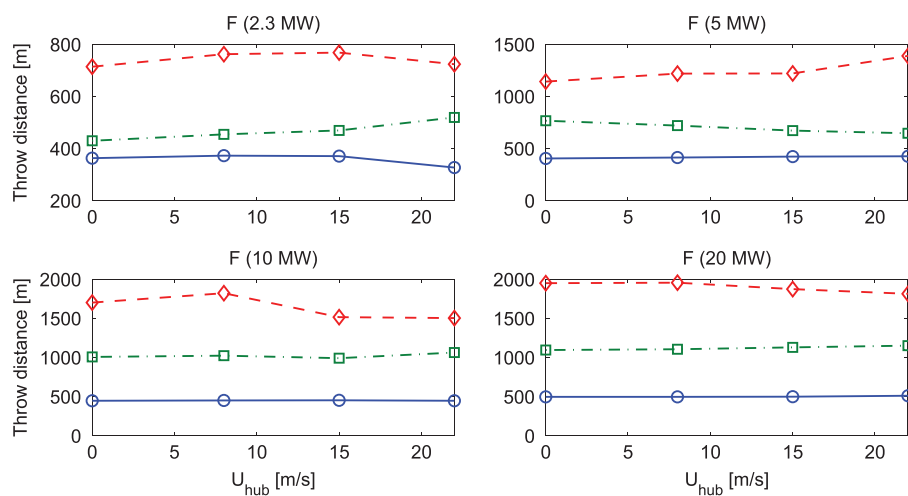
**Figure 5.** Throw distance calculations of full blade with three different detached lengths at a high tip speed of  $V_{tip} = 100$  m/s. Legends are similar to those in Figure 4.

of release tip velocity. As can be seen, the release tip speed is a very important factor influencing the maximum throw distances. Normal operating conditions with  $V_{tip} = 70$  m/s result in throw distances of about 500 m long, whereas a tip speed of  $V_{tip} = 150$  m/s may lead to throw distances up to 2 km.

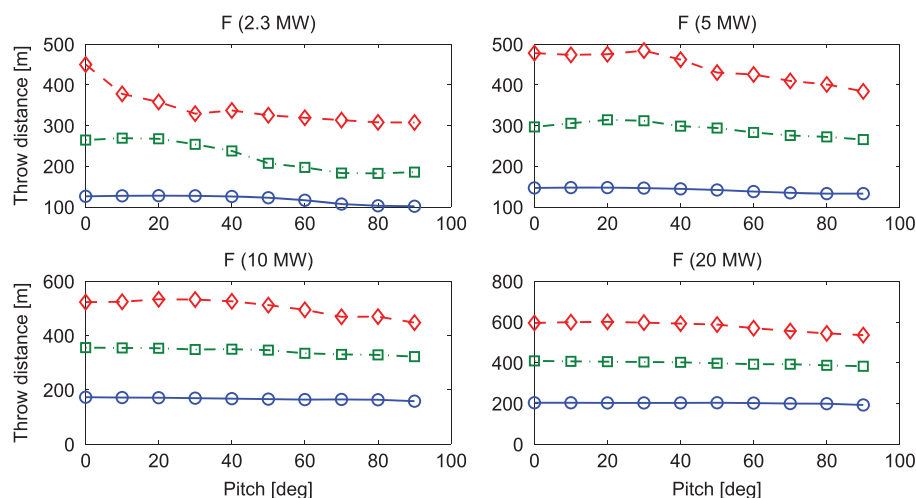
For the quantitative analysis performed in the next section, the fragments are thrown at a release angle of  $45^\circ$  from the horizon ( $225^\circ$  measured upward-clockwise) in all calculations. The full-blade and blade-shell throw calculations are performed using flat-plate assumption for the aerodynamic coefficients.

Figures 4, 5 and 6 show the throw distances for three different fragments of the full blade for a combination of three blade tip speeds ( $v_{tip} = 70, 100, 150$  m/s) and four different incoming wind velocities (with power-law profiles) ranging between 0 and 22 m/s at hub height.

The figures are divided into three groups, the first group (Figure 4) shows the throw distances, relative to the tower position, for different incoming wind speeds (shown on the horizontal axis) and different detachment lengths at a tip speed of  $V_{tip} = 70$  m/s. The detachment length  $L^*$ , shown with markers, is the length of the detached piece, measured from the blade tip and normalized by the blade length. The throw distances are calculated and plotted for the four considered wind turbine sizes ranging from 2.3 to 20 MW. As can be seen, except for the 2.3 MW machine, the effect of the incoming wind on the throw distance is almost negligible. Similarly, the effect of turbine size on the throw distance is minimal and the main



**Figure 6.** Throw distance calculations of full blade with three different detached lengths at an extreme tip speed of  $V_{tip} = 150$  m/s. Legends are similar to those in Figure 4.

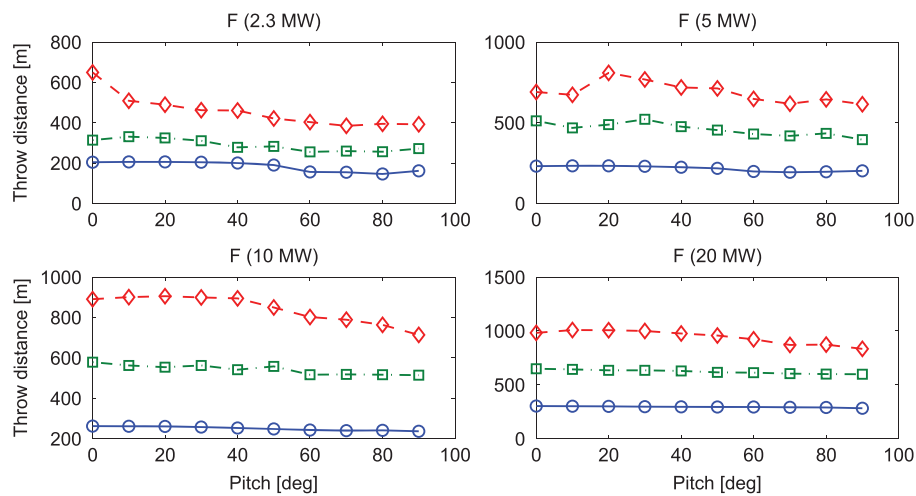


**Figure 7.** Sensitivity of throw distances of full blade to the initial pitch setting for 2.3, 5, 10 and 20 MW turbines operating at  $V_{tip} = 70$  m/s.  $\diamond \diamond \diamond$ :  $L^* = 0.2$ ;  $\square \square \square$ :  $L^* = 0.5$ ; and  $\circ \circ \circ$ :  $L^* = 1$ .

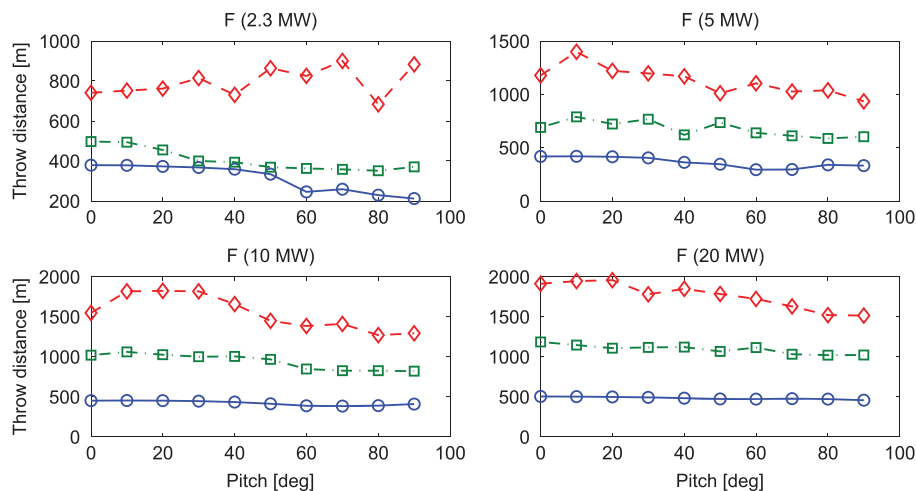
parameter governing the throw distance is the detachment length. The minimum throw distance is obtained for the heaviest fragment ( $L^* = 0.2$ ) thrown from the 2.3 MW turbine, while the maximum throw distance of all cases at  $V_{tip} = 70$  m/s is around 600 m for the lightest fragment ( $L^* = 0.2$ ).

Figure 5 shows the same graphs for the higher tip speed of  $V_{tip} = 100$  m/s, where the maximum throw distances for the smallest and largest turbines are about 500 and 1000 m, respectively, while the minimum throw distance is reached for a full-blade throw ( $L^* = 1$ ) of a 2.3 MW turbine. Also, it is clear that the effect of the hub-height wind velocity is still very small. Figure 6 shows the same plots for the most extreme case considered, i.e., using a tip speed of  $V_{tip} = 150$  m/s. Here, the thrown pieces reach throw distances ranging from approximately 350 m for the full-blade throw for a 2.3 MW turbine to about 2000 m for the lightest fragment thrown from the 20 MW turbine.

As can be seen from the red curve in Figure 6 for the 10 MW turbine (bottom-left), the throw distance has unexpectedly decreased when increasing the wind speed from 10 to 15 m/s. This behavior is somehow repeated to a smaller extent in other cases, especially at higher tip velocities. The unexpected results can happen because of the fact that a small change in the initial conditions can change the force/moment distributions on the fragments, thereby changing the trajectory drastically. To investigate the erratic motion further, the effect of initial pitch setting on the trajectory is analyzed in the next section.



**Figure 8.** Sensitivity of throw distances of full blade to the initial pitch setting at  $V_{tip} = 100$  m/s. Legends are similar to those in Figure 7.



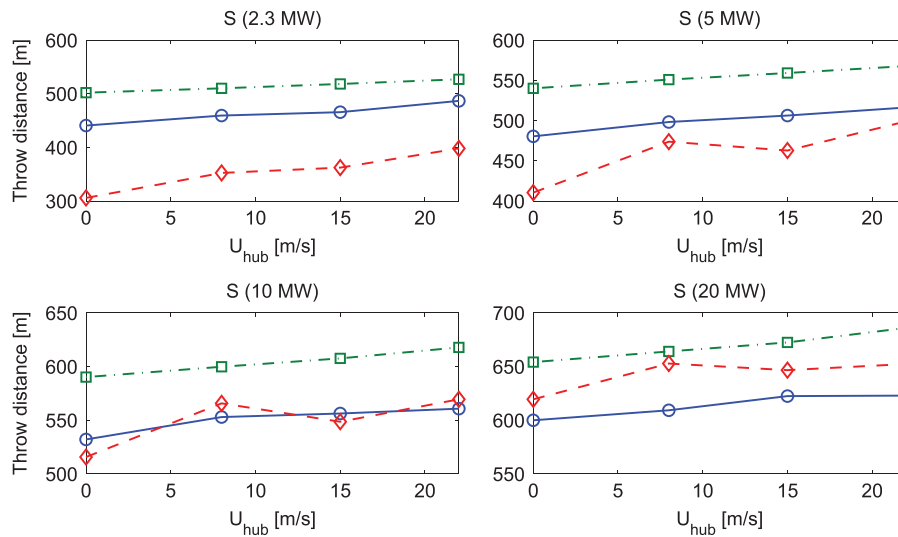
**Figure 9.** Sensitivity of throw distances of full blade to the initial pitch setting at  $V_{tip} = 150$  m/s. Legends are similar to those in Figure 7.

### 3.2.1. Effect of initial pitch settings.

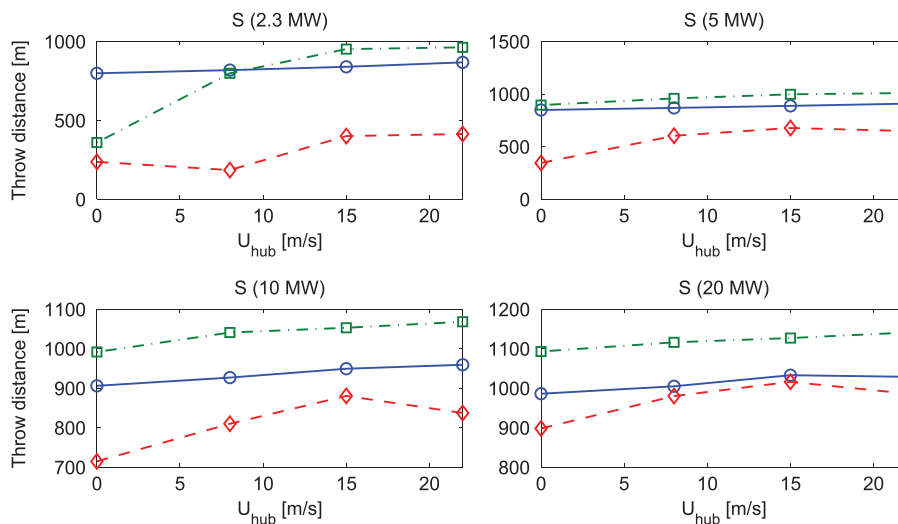
As explained earlier, analyses of the throw trajectories show that the throw distance for a particular wind turbine sometimes exhibits an erratic behavior going from one dominant solution to another with only a slight change in the initial conditions.

**Table III.** Aspect ratios, reference chord length  $C_{ref}$  and detached mass  $m$  of the blade shells ( $\rho_{shell} = 1700 \text{ kg/m}^3$ ) used for throw simulation from turbines of different sizes.

Cases – AR	2.3 MW		5 MW		10 MW		20 MW	
	$C_{ref}$ (m)	$m$ (kg)	$C_{ref}$ (m)	$m$ (kg)	$C_{ref}$ (m)	$m$ (kg)	$C_{ref}$ (m)	$m$ (kg)
AR = 1	1	34	1.5	83	2.1	184	3	408
AR = 5		170		415		920		2040
AR = 10		340		830		1840		4080



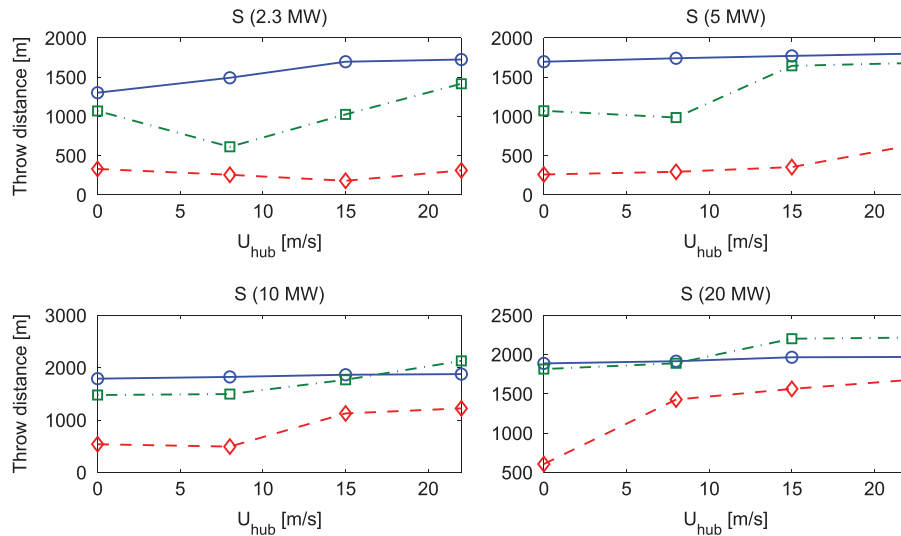
**Figure 10.** Throw distance calculations of blade shell with three different aspect ratios (invariant chord length for each turbine) for 2.3, 5, 10 and 20 MW turbines at a normal operating condition of  $V_{tip} = 70 \text{ m/s}$ .  $\diamond \diamond \diamond$  AR = 1;  $\square \square \square$  AR = 5; and  $\circ \circ \circ$  AR = 10.



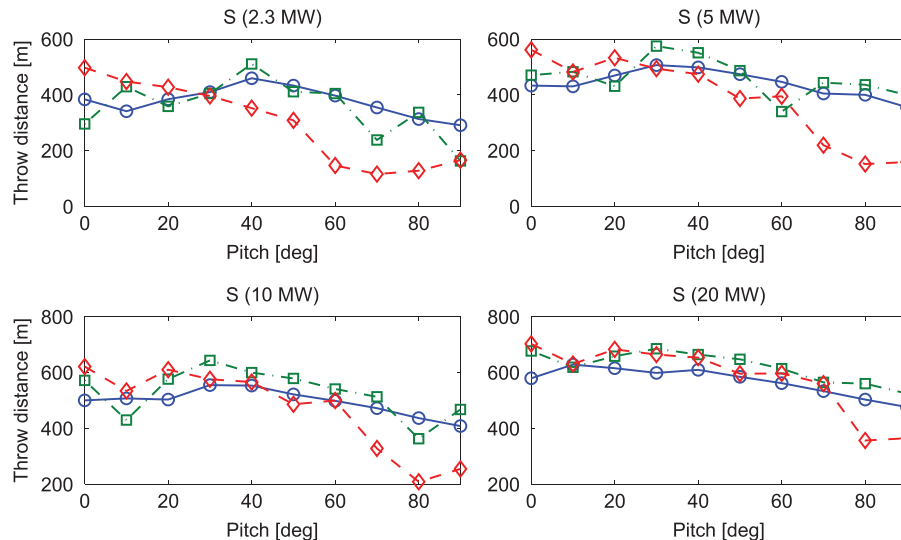
**Figure 11.** Throw distance calculations of blade shell at high tip speed of  $V_{tip} = 100 \text{ m/s}$ . Legends are similar to those in Figure 10.



To understand this behavior, a sensitivity study is performed to investigate the effects of the initial pitch settings on the trajectory. Figures 7–9 demonstrate the pitch angle dependence of the full-blade throw distances for different turbine sizes and tip speeds, where the throw distances are obtained for release pitch angles ranging from  $0^\circ$  to  $90^\circ$ . As can be seen, the pitch setting has a substantial impact especially for the lighter parts. In general, higher throw distances are achieved using fragments thrown at lower pitch angles, which are due to the reduced drag. The effect of pitch angle on the heavier pieces (green and blue curves) is, however, smaller. The reason for this is that the aerodynamics plays a less significant role for the heavy parts in the throw distance calculation and the distance is mainly governed by the inertial forces. For the extreme tip velocity, and especially for the 2.3 MW turbine, increasing the pitch angle produces erratic throw distances for the lightest fragments. The exact reason for such erratic behavior has not been yet understood, but it is most likely explained by the physics of the problem, as explained earlier.



**Figure 12.** Throw distance calculations of blade shell at an extreme tip speed of  $V_{tip} = 150$  m/s. Legends are similar to those in Figure 10.

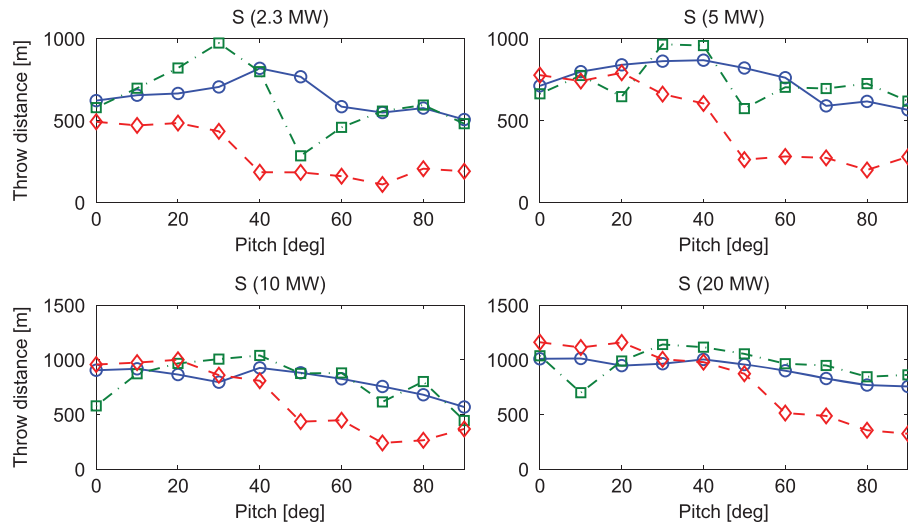


**Figure 13.** Sensitivity of throw distances of blade shell to the initial pitch setting at  $V_{tip} = 70$  m/s. Legends are the same as in Figure 10.

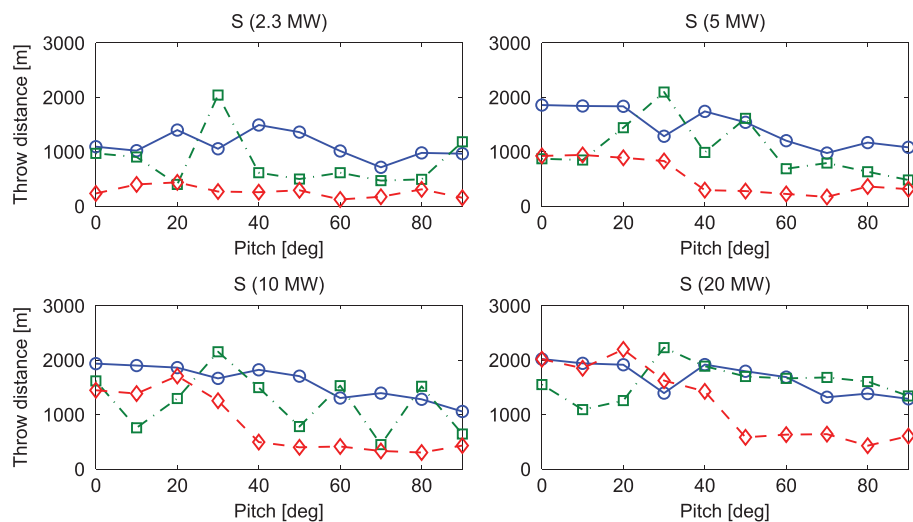
### 3.3. Blade-shell throw analysis

An analysis of available data from blade failure accidents shows that depending on the manufacturing method and the structural integrity of the blade, it might first shatter into lighter parts, with the consequence that the shell layer is most likely to be thrown away. Three cases of different aspect ratios are considered for the shell throw analyses. For the reference case of 2.3 MW turbine, an average chord of 1 m and a shell thickness of 2 cm are chosen, and three aspect ratios (where  $AR$  is defined as the ratio of span to average chord) of 1, 5 and 10 are investigated. Then keeping the same  $AR$ , the analysis is repeated for each of the turbines introduced in the preceding sections. The density of the shell, consisting of fiber and glass, is assumed to be  $1700 \text{ kg/m}^3$ . Table III shows the test cases used for blade shell throw simulations.

Throw distances for the four different turbine sizes with the same working conditions as those for the full-blade case are plotted in Figures 10–12. Here, the non-dimensional length is replaced by the aspect ratio of the blade shell and three different aspect ratios are considered. As can be seen, increasing the hub-height wind speed and the turbine size generally results in larger throw distance. Nevertheless, an erratic behavior, as mentioned in the previous section, appears in the



**Figure 14.** Sensitivity of throw distances of blade shell to the initial pitch setting at  $V_{tip} = 100 \text{ m/s}$ . Legends are the same as in Figure 10.



**Figure 15.** Sensitivity of throw distances of blade shell to the initial pitch setting at  $V_{tip} = 150 \text{ m/s}$ . Legends are the same as in Figure 10.

simulation results. By comparing the shell-throw graphs with the corresponding figures from the full-blade analysis, the throwing range of the blade shells and that of the full-blade structure are seen to be of the same order of magnitude. That is, the range is between 300 m for the 2.3 MW turbine operating at  $V_{tip} = 70$  m/s and a maximum of 2200 m obtained for the 20 MW turbine in the extreme case of  $V_{tip} = 150$  m/s. However, unlike the full-blade throw cases, the case with the smallest length ( $AR = 1$ ) reaches the least throw distance, whereas for the full blade, the smallest fragment reaches the highest distance. This is most probably due to the fact that the small shell object is lighter and the corresponding inertial force is relatively small as compared with the drag forces.

As a comparison, the throw distances obtained for the ballistic motion of an equivalent particle in vacuum was also performed (results not shown), in which case there is no aerodynamic forcing on the objects. The results revealed that the ballistic throw distances are the most extreme cases in terms of throw distance.

### 3.3.1. Effect of initial pitch settings.

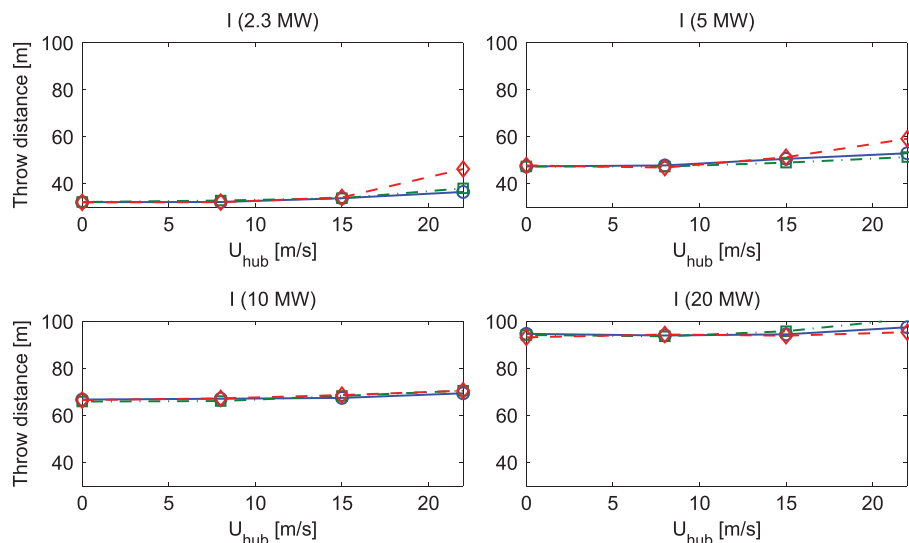
Similar to Section 3.2.1, the role of initial pitch setting on the trajectory of thrown blade-shell debris is assessed. Figures 13–15 show the pitch angle dependence of the throw distances for different turbine sizes and tip speeds for the blade-shell cases. Similar to the full-blade throw cases, the pitch setting has a substantial impact on the throw distance of thrown blade-shell structures. One major difference with the full-blade cases is, however, that the effect of the shell aspect ratios on the throw distance is much less significant and all of the cases show similar behavior with  $AR = 1$  cases (red diamonds), predicting smaller throw distances in general.

### 3.4. Ice throw

For the analysis of the ice throw, the same procedure as for the blade throw is applied except that the throw analysis is not performed for the extreme tip speed conditions but only for the standstill where the tip speed is zero, and the running conditions, where the turbine is assumed to rotate in its normal operational mode at a tip speed of 70 m/s. For the icing case,

**Table IV.** Aspect ratios, reference chord length  $C_{ref}$  and detached mass  $m$  of the ice fragments ( $\rho_{ice} = 0.7$  kg/m<sup>3</sup>) used for throw simulation of turbines of different sizes.

Cases – $AR$	2.3 MW		5 MW		10 MW		20 MW	
	$C_{ref}$ (m)	$m$ (kg)	$C_{ref}$ (m)	$m$ (kg)	$C_{ref}$ (m)	$m$ (kg)	$C_{ref}$ (m)	$m$ (kg)
$AR = 1$		0.18		0.43		0.97		2.16
$AR = 2$	0.1	0.36	0.15	0.87	0.2	1.95	0.3	4.33
$AR = 3$		0.54		1.31		2.94		6.49



**Figure 16.** Throw distance calculations of ice fragments for three different aspect ratios for 2.3, 5, 10 and 20 MW turbines in standstill operation ( $V_{tip} = 0$  m/s).  $\diamond \diamond \diamond$ :  $AR = 1$ ;  $\square \square \square$ :  $AR = 2$ ; and  $\circ \circ \circ$ :  $AR = 3$ .

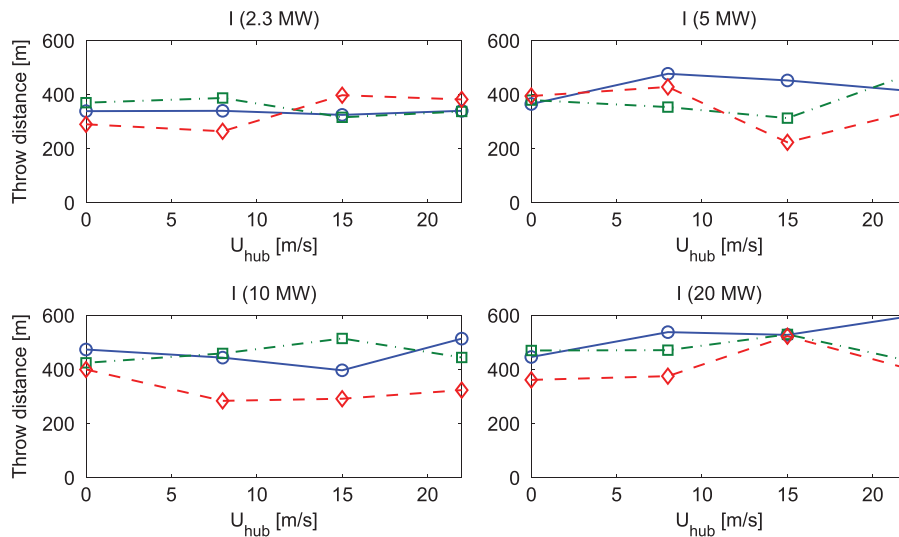
a density of  $700 \text{ kg/m}^3$  is used (see also Seifert *et al.*<sup>11</sup>). The dimensions of the tested ice fragments and corresponding turbine sizes are shown in Table IV. According to field studies performed by, e.g., Cattin *et al.*,<sup>22</sup> most of the ice fragments thrown away from turbine are broken into objects that typically are smaller than 1 kg. However, fragments as heavy as up to 1.8 kg have also been observed. Because the pieces are so light, the throw distance of an ice piece is mainly governed by the drag forces applied on it (which are only functions of mass–area ratio) and the incoming wind.

Similar to the previous section, studies of the effects of different parameters on throw distances are performed and plotted in Figures 16 and 17 with the graphs structured in the same way as in the previous sections.

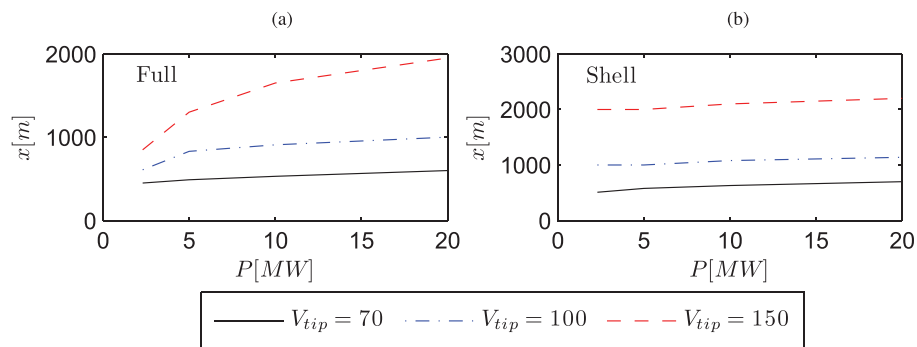
For the simulations, no lift is considered and the drag coefficient according to the flat-plate assumption is used. Figure 16 shows that the throw distances of the standstill case range from 30 to 100 m for different turbine sizes and incoming wind speeds. For the running conditions however, the fragments can reach distances up to 600 m. It is also clear from the figure that in many cases the aspect ratio does not play a significant role in the determination of throw distances.

### 3.5. Maximum throw distances

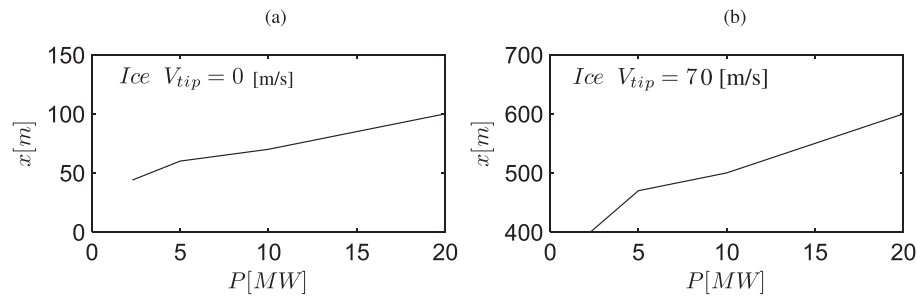
This section presents a summary of the previous results in terms of maximum throw distances. The maximum throw distances are obtained from the entire set of previous simulations regardless of the size and upcoming wind speed and plotted in Figure 18 for the full-blade and blade-shell cases and in Figure 19 for the ice-throw cases, respectively. In all



**Figure 17.** Throw distance calculations of ice fragments for three different aspect ratios for turbines in normal operation ( $V_{tip} = 70 \text{ m/s}$ ). Legends are the same as in Figure 16.



**Figure 18.** Maximum throw distances obtained for (a) full blade and (b) blade shell in different operating conditions. Blue line:  $V_{tip} = 70 \text{ m/s}$  as a function of turbines power.



**Figure 19.** Maximum throw distances obtained for the ice throw in (a) standstill operation, i.e.,  $V_{tip} = 0$  m/s and (b) normal operating condition, i.e.,  $V_{tip} = 70$  m/s as a function of turbines power.

figures, the horizontal axis shows the turbine capacity and the vertical axis represents the maximum throw distance. It can be concluded that, in general, the tip speed has a large impact on the throw distances. From Figure 18(a), the turbine size does not affect the throw distances drastically for the lower tip speeds, whereas throw distances at high tip speeds experience a significant growth with increasing turbine size. Figure 18(b), on the other hand, shows that the effect of turbine size on the throw distance for the shell parts is almost negligible.

#### 4. CONCLUDING REMARKS

Trajectory analysis of detached parts of blades and ice fragments thrown from horizontal-axis wind turbines was studied extensively using Newton's and Euler's equations of motion and rotation, employing a blade element approach for the aerodynamics. Full-blade and blade-shell analyses were performed for turbines running under different tip velocities. Turbine upscaling laws were derived, and simulations of throw distances were performed for four different turbine sizes, ranging from existing 2.3 MW machines to future 20 MW turbines.

In some cases, erratic behavior was observed in the computations, where a small change in one parameter could influence throw distance drastically. The behavior was believed to depend highly on the initial conditions. A likely explanation is that a small change in positioning and velocity components in some cases alters the distribution of forces on the detached objects and causes significant changes in the trajectory.

Maximum throw distances obtained at different tip speeds and detachment sizes were analyzed, and it was shown that the tip speed plays the most important role in the throw distance. From the full-blade throw analysis, it was shown that, when released at extreme tip speeds, throw distance picks up more rapidly with the tip speed rather than throw at lower tip speeds (looking at the absolute throw distances). The considered [thrown] full-blade pieces reached approximately 700, 900 and 2000 m at tip speeds of 70, 100 and 150 m/s, respectively. For the blade shell, throw distances were found to be approximately constant as turbine size escalates, and of the same order of magnitude as in the full-blade throw. Throw calculations were also obtained at the tip speeds of  $V_{tip} = 0$  and  $V_{tip} = 70$  m/s for ice pieces of three different aspect ratios and it was seen that the maximum throw distances scaled almost linearly with the turbine size irrespective of the tip speed. The ice-throw distances reached about 100 and 600 m in standstill  $V_{tip} = 0$  m/s and normal operating conditions  $V_{tip} = 70$  m/s, respectively. The throw distances presented by this study were obtained with respect to a set of initial parameters without taking into account their probabilities of occurrence. The authors are extending the current study to include the risk levels associated with each of the cases.

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Natural Resources Committee  
September 22, 2017

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VICKIE MAY: Thank you. Good afternoon, Senators. I'm going to try. I have nothing prepared. I'm just going to speak to you from my heart. I know we're not allowed to ask questions, but I'd like to ask how many of you live by an industrial wind complex? [LR125]

SENATOR HUGHES: Ma'am, could you spell your name for the record? [LR125]

VICKIE MAY: Vickie May, V-i-c-k-i-e M-a-y. [LR125]

SENATOR HUGHES: Thank you. [LR125]

VICKIE MAY: (Exhibit 20) I live in northern Holt County, home to the currently BHE's largest operating wind turbine complex. I don't know where to start. It has ruined our life. Our property rights have been stripped. There are nights we're up fully dressed at 3:00 in the morning because the sound from those turbines penetrate our home and we are a mile and one-third from the closest turbine. When the project originally came in, we were told...my husband is on planning and zoning in our county. The project developer looked him in the eye and said, Keith, you have nothing to worry about. There will be no turbines within four to five miles of you. From our south corner we look at 72 wind turbines. They tell you that they don't make any more sound than your dishwasher. I tell you people if you had a dishwasher that was that noisy you would immediately replace it. Besides that, the dishwasher isn't mounted 425 foot up in the air and there aren't 72 of them outside your home. It is like a jet plane revving up to take off but the plane never leaves. That sound is constantly with you. When the wind gets to a current...a certain speed, then you get a thumping like you're drying boots in a dryer when that blade deflects past that base. And it's always when we're on the downwind side when we have a southeast, east-southeast, south wind, southwest wind, which as you know in the state in Nebraska that is the prevailing wind nine months of the year. My husband and I tried to go through the proper channels to get this alleviated. We first contacted...when they first started, when we first heard bulldozers coming in, we knew our view scape had changed forever. We thought maybe we could get used to that. When the turbines became fully operational in October of last year, we had prayed daily that we wouldn't be able to hear them. That was certainly dashed. On the 20th of December last year, we contacted the site manager. He said, I'll come up to your place. When we got out of his pickup you could tell he was surprised at what he was hearing. He apologized

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to us. He said, I didn't realize you were here because since we're a mile outside of the project, we're not considered in the project. He said, I'll see what I can do for you. We'll see what we can do to alleviate this problem. Two weeks later he was let go of his position. I e-mailed him and tried to get some information, but they placed a gag order on him. We've called the project manager more times than I care to even and I've got records. So we were forced to buy an expensive decibel meter at our home and these are logs of decibels that we take on a daily basis: what it sounds like, what direction the wind is from, and what the decibel ratings are. Holt County granted the CUP on 50 decibels, which I don't know if any of you have studied sound. I have learned. I had to and if you can tell me the difference between 35 decibels and 45 decibels. You think, well, that's ten decibels more. No, in sound that is ten times more decibels. So every time you jump up five decibels, it's five times more decibels. I've been in the project taking decibel readings. You can't get anything close to 50. Usually they're around 70 up to 98. At our property, they put out a slick binder that tells you the projections of what you should be hearing and not hearing. They're only projections until those turbines are built. They don't take into consideration how peaceful it was before, the atmospheric conditions, the topography. It's all based on projections. At our home, they had us projected to not hear more than 30-39. You're welcome to my studies but it's always over that. We rarely get anything other than that when the wind's not blowing. Our decibel meter also rates it on a C scale. The wind turbine people, all their studies are done on an A-rated scale which only takes in the midline sounds--nothing high, nothing low. C rating is also low sounds which I'm very susceptible to. I can actually in the winter when there's less ambient sounds, no tractors in the fields, very little traffic, no leaves on the trees, I can feel the pulsing of those turbines in my chest. As I stated earlier, we get very little sleep. Everybody says the health concerns are debunked, but I don't care to go into my health issues today. But I am having problems that I have never had in my life before. And I thank you for your consideration and your time. And if you ever have the chance to live by one, run. I didn't have the opportunity and it breaks my heart to think that everything we have worked our whole life for we may have to abandon or we may have to sell out. Thank you. [LR125]

SENATOR HUGHES: Thank you, Ms. May. Are there questions? [LR125]

VICKIE MAY: Are there any questions? [LR125]

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SENATOR WALZ: I was wondering if we could get a copy of that information. [LR125]

VICKIE MAY: Yes. It's a lot of pages and I can sure get it to you. [LR125]

SENATOR HUGHES: Okay. Any other questions? Senator Albrecht. [LR125]

SENATOR ALBRECHT: I thank you so much for sharing what you have because you are living it. They...the others that are here might not want to live it, but they already know what's coming. And, you know, I've just jotted down some notes from the previous folks, too, and I'm just probably airing my frustrations right now. So your husband served on the Planning Commission. [LR125]

VICKIE MAY: Yes. [LR125]

SENATOR ALBRECHT: And they promised you, somebody did, either at the county level or the planning level that it's okay, you're only going to be at 35-39 decibels. But if you have that documentation that it is much higher, you know, people don't want to have to spend their hard-earned dollars to sue somebody. But I'm sorry, I think we do have a responsibility in this room to be able to look into these type of things, because to have a gag order on somebody who's part of a project and I've already read the book. So I get all that you're talking about and I probably would have asked the other gentleman a few more questions. But in the time constraints that we have, I'm just wanting you to understand that planning and zoning have a huge say in whether something comes or goes. But if you're telling me that these projects come without the planning and zoning's approval or their county board's approval, and some places don't have planning boards, so if you had one that's a great thing. But there is documentation just like we have here today that they told you what you should expect and shouldn't expect. So with that, that might be one place to go is back to your county or your planning board... [LR125]

VICKIE MAY: We've tried. [LR125]

SENATOR ALBRECHT: ...whether it was your husband sitting there or not, but... [LR125]

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September 22, 2017

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VICKIE MAY: We've tried. [LR125]

SENATOR ALBRECHT: But it's wrong, and you know what, as a state legislator, I'm really disturbed with what I'm hearing. And I'm even more disturbed if the public power has the ability to come in and put these lines down, whether the project is approved or not. Yours might have already been. Maybe they kissed the paper and there it went. [LR125]

VICKIE MAY: There's nothing to help us, but I want to help anybody else I can. And something I didn't get to is we also contacted Alicia Knapp, the project manager, Tom Budler who I think gave a presentation at noon to you people today. They've been to my home. And the conclusion of what they told me, I asked if we could have an independent sound study--absolutely not. [LR125]

SENATOR ALBRECHT: Why not? [LR125]

VICKIE MAY: They would use the people that they have always used. I asked them. I said, would you please provide me with that information so I can research them and see if I will get a fair shake out of this deal. That was on June 9 they were at my house. I am waiting yet today to get that information they promised me. And at the conclusion of that meeting, Alicia Knapp looked me in the eye and I said, just be honest with me here. What are we to do? She said you are to put up and you are to shut up. My own county commissioner told my husband and I that we are the collateral damage for the good of Holt County. That does little to help you get to sleep at night when those turbines are thumping. We've been back to our zoning administrator. We have asked for meetings. I don't know how many times we get shot down, every time. We can't change the regulations. We know they're going to come back for more turbines. We want to get the setback set back further. The wind company will tell you those turbines will slough ice up to a half a mile. Our county road setbacks are only have the diameter of one blade which is 90 feet. Do you want to be the one driving down the road when that thing decides to let go? There's someone else who's going to talk about how the fire departments are not able to go on to that property to fight a fire. They have to stay on the road. That does little good when there's grassland all to the south of me and I'm living to the north of that and that fire is coming at me. There are so many things that we need responsible setbacks. We need responsible decibels. But

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we let big wind come in and tell us how it's going to be. They wine and dine our county officials and they have what they call Windmill Wednesdays up there in Holt County where they have coffee and donuts on Wednesdays and they wine and dine them. They give them jackets with their names embroidered on them and stuff. When we do have meetings, our local officials sit with the wind turbine people. They don't sit with their constituents. So I'm here today just to ask any help that you can be because you would not want anyone in your family up to have to live like this. We were hoping to pass our land on to our children and grandchildren, but I don't know if we'll be able to stay. At what point should we have to make the decisions because my neighbor. And I believe in personal property rights and I'm a private person and I'm living, minding my own business. But you don't know how bad I wished I would have stuck my nose in a little bit further. [LR125]

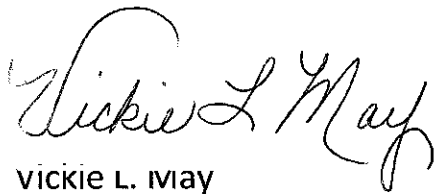
SENATOR ALBRECHT: I appreciate your testimony. [LR125]

VICKIE MAY: Thank you. [LR125]

March 25, 2018

To Whom It May Concern;

September 22, 2017 I testified at a public hearing before the Natural Resources Committee in Lincoln Nebraska. I give my permission to read or reproduce this testimony.

A handwritten signature in cursive script that reads "Vickie L. May". The signature is written in black ink and is positioned above the printed name.

vickie L. May

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Lynch NE, 68746

402-569-2130



# ATTACHMENT 1

## WIND TURBINE SAFETY CONSIDERATIONS

Vestas is one of the leading wind turbine manufacturers, with approximately 70% market share worldwide. Based on its prominence in the world market, the Vestas Safety Manual (32 pages) is a credible source of safety information. Nordex is another well known manufacturer of wind turbines. Its Safety Manual (130 pages) likewise is considered a credible source of information on the subject of safety.

On page 3 of the Vestas Safety Regulations for Operators and Technicians Manual, point # 2. – Stay and Traffic by the Turbine, Vestas personnel are instructed to stay away from a turbine by 400 m (1312 ft) unless it is necessary. Taken in context, this distance would apply to normal operating conditions. (See Exhibit 1)

Under abnormal operating conditions, Vestas expands this distance in consideration of the safety of its employees. This is evidenced by the Vestas Confidential Health and Safety Instruction manual for a Falmouth MA wind farm. Page 10 of this manual addresses the situation of a free spinning “runaway turbine”. In that manual, instructions are for no one to be allowed within a 1640 feet (500 m) radius. (See Exhibit 2)

The Nordex Safety Manual also addresses safety in the context of a fire. On page 52, under section 9.3 Fire, it states:

***DANGER FALLING TURBINE PARTS*** *In case of a fire in the nacelle or on the rotor, parts may fall off the wind turbine. In case of a fire, nobody is permitted within a radius of 500 m from the turbine. (See Exhibit 3)*

Given that these standards apply to employees who are familiar with the safety implications of wind turbines and are equipped to deal with abnormal conditions, it is indefensible, from a safety perspective alone, to specify in a wind ordinance designed to protect the public health, safety and welfare a setback that is less than 1640 feet.

Item no.: 960314.R5 Date 2006-09-11

Issued by: Technology Class: II

Type: MAN Page 3 of 32

Safety Regulations for Operators and Technicians

V90 – 3.0MW/V100 – 2.75MW

Vestas Wind Systems A/S · Alsvej 21 · 8900 Randers · Denmark · www.vestas.com

# 1. Introduction

A turbine connected to the grid implies certain elements of danger if it is handled without exercising proper caution.

For safety reasons, at least two persons have to be present during a work procedure.

The work must be properly carried out in accordance with this manual and other related manuals. This implies, among other things that personnel must be instructed in and familiar with relevant parts of this manual.

Furthermore, personnel must be familiar with the contents of the “Substances and Materials” regulations.

Caution must especially be exerted in situations where measurement and work is done in junction boxes that can be connected to power.

Consequently the following safety regulations must be observed.

# 2. Stay and Traffic by the Turbine

*Do not stay within a radius of 400m (1300ft) from the turbine unless it is necessary.* If you have to inspect an operating turbine from the ground, do not stay under the rotor plane but observe the rotor from the front.

Make sure that children do not stay by or play nearby the turbine. If necessary, fence the foundation. The access door to the turbine must be locked in order to prevent unauthorized persons from stopping or damaging the turbine due to mal-operation of the controller.

# 3. Address and Phone Number of the Turbine

Note the address and the access road of the turbine in case an emergency situation should arise. The

address of the turbine can often be found in the service reports in the ring binders next to the ground

controller. Find the phone number of the local life-saving service.

WKI 1000 711-04 EN Issued by: Technology Type: Work Instruction	<b>Vestas Confidential - Falmouth</b> <b>Health &amp; Safety Instruction</b>	Date: 2008-11-08 Class: II <b>Page 10 of 65</b>
<b>2.6.1 Special vehicles</b>		
<i><b>Important:</b> Protect the environment: stop engines when vehicles are not in use.</i>		
<ul style="list-style-type: none"> <li>• Drivers of special vehicles, such as extra wide or high vehicles, must only drive onto the site with prior agreement with the supervisor/site manager who will advise as to the preferred route and possible site risks.</li> <li>• The supervisor/site manager will also arrange for auxiliary vehicles, if necessary.</li> </ul>		
<b>2.7 In Case of Runaway Operation</b>		
A runaway operation is almost impossible, as it would require several circumstances to happen at the same time		
<ul style="list-style-type: none"> <li>• If a runaway operation should occur, the plant must be evacuated immediately by running upwind, and access to the surrounding area in a radius of at least 500 metres must be restricted.</li> </ul>		

**Vestas** advises to “**evacuate by running upwind ...access to the surrounding area in a radius of at least 500 meters [1640 ft.] must be restricted.**”

The WT itself is adequately protected against damage by comprehensive lightning protection measures. However, persons inside or in the proximity of a WT are still at risk. ■ Initially, proceed as in a grid failure ■ Leave and lock the WT ■ Wait at a safe distance from the WT until the thunderstorm has passed Do not re-enter the WT until the thunderstorm has passed.

## 9.3 Fire

### **DANGER**

#### **FALLING TURBINE PARTS**

*In case of a fire in the nacelle or on the rotor, parts may fall off the wind turbine. In case of a fire, nobody is permitted within a radius of 500 m from the turbine.*

**NOTE** The WT is equipped with ABC powder fire extinguishers for fighting incipient fires. At least one fire extinguisher is located in the tower base near the door and another in the nacelle near the Topbox. This makes it possible to extinguish burning solids and liquids, as well as fires in electrical systems of up to 1,000 V. These fire extinguishers are not suitable for extinguishing a fire on the high-voltage elements, see Chapter 9.3.2 "Fire in medium-voltage switchgear or transformer".

### 9.3.1 Fire in the WT

■ Remove any persons from the danger area ■ If possible, disconnect the burning object from the grid ■ Fight the fire with available means if there is any chance of success ■ If the fire cannot be extinguished or if there is no chance of success, call the fire department ■ Inform the responsible Remote Monitoring

# Ice Shedding and Ice Throw – Risk and Mitigation

**David Wahl**  
**Philippe Giguere**  
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# Ice Shedding and Ice Throw – Risk and Mitigation

## Introduction

As with any structure, wind turbines can accumulate ice under certain atmospheric conditions, such as ambient temperatures near freezing (0°C) combined with high relative humidity, freezing rain, or sleet. Since weather conditions may then cause this ice to be shed, there are safety concerns that must be considered during project development and operation. The intent of this paper is to share knowledge and recommendations in order to mitigate risk.

## The Risk

The accumulation of ice is highly dependent on local weather conditions and the turbine's operational state.<sup>[2,4]</sup> Any ice that is accumulated may be shed from the turbine due to both gravity and the mechanical forces of the rotating blades. An increase in ambient temperature, wind, or solar radiation may cause sheets or fragments of ice to loosen and fall, making the area directly under the rotor subject to the greatest risks<sup>[1]</sup>. In addition, rotating turbine blades may propel ice fragments some distance from the turbine—up to several hundred meters if conditions are right.<sup>[1,2,3]</sup> Falling ice may cause damage to structures and vehicles, and injury to site personnel and the general public, unless adequate measures are put in place for protection.

## Risk Mitigation

The risk of ice throw must be taken into account during both project planning and wind farm operation. GE suggests that the following actions, which are based on recognized industry practices, be considered when siting turbines to mitigate risk for ice-prone project locations:

- **Turbine Siting:** Locating turbines a safe distance from any occupied structure, road, or public use area. Some consultant groups have the capability to provide risk assessment based on site-specific conditions that will lead to suggestions for turbine locations. In the absence of such an assessment, other guidelines may be used. Wind Energy Production in Cold Climate<sup>[6]</sup> provides the following formula for calculating a safe distance:

$$1.5 * (\text{hub height} + \text{rotor diameter})$$

While this guideline is recommended by the certifying agency Germanischer Lloyd as well as the Deutsches Windenergie-

Institut (DEWI), it should be noted that the actual distance is dependant upon turbine dimensions, rotational speed and many other potential factors. Please refer to the *References* for more resources.

- **Physical and Visual Warnings:** Placing fences and warning signs as appropriate for the protection of site personnel and the public.<sup>[4]</sup>
- **Turbine Deactivation:** Remotely switching off the turbine when site personnel detect ice accumulation. Additionally there are several scenarios which could lead to an automatic shutdown of the turbine:
  - Detection of ice by a nacelle-mounted ice sensor which is available for some models (with current sensor technology, ice detection is not highly reliable)
  - Detection of rotor imbalance caused by blade ice formation by a shaft vibration sensor; note, however, that it is possible for ice to build in a symmetric manner on all blades and not trigger the sensor<sup>[2]</sup>
  - Anemometer icing that leads to a measured wind speed below cut-in
- **Operator Safety:** Restricting access to turbines by site personnel while ice remains on the turbine structure. If site personnel absolutely must access the turbine while iced, safety precautions may include remotely shutting down the turbine, yawing to place the rotor on the opposite side of the tower door, parking vehicles at a distance of at least 100 m from the tower, and restarting the turbine remotely when work is complete. As always, standard protective gear should be worn.



## References

The following are informative papers that address the topic of wind turbine icing and safety. These papers are created and maintained by other public and private organizations. GE does not control or guarantee the accuracy, relevance, timeliness, or completeness of this outside information. Further, the order of the references is not intended to reflect their importance, nor is it intended to endorse any views expressed or products or services offered by the authors of the references.

- [1] *Wind Turbine Icing and Public Safety – a Quantifiable Risk?:* Colin Morgan and Ervin Bossanyi of Garrad Hassan, 1996.
- [2] *Assessment of Safety Risks Arising From Wind Turbine Icing:* Colin Morgan and Ervin Bossanyi of Garrad Hassan, and Henry Seifert of DEWI, 1998.
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EUROPE

# NIGHT NOISE GUIDELINES FOR EUROPE

55

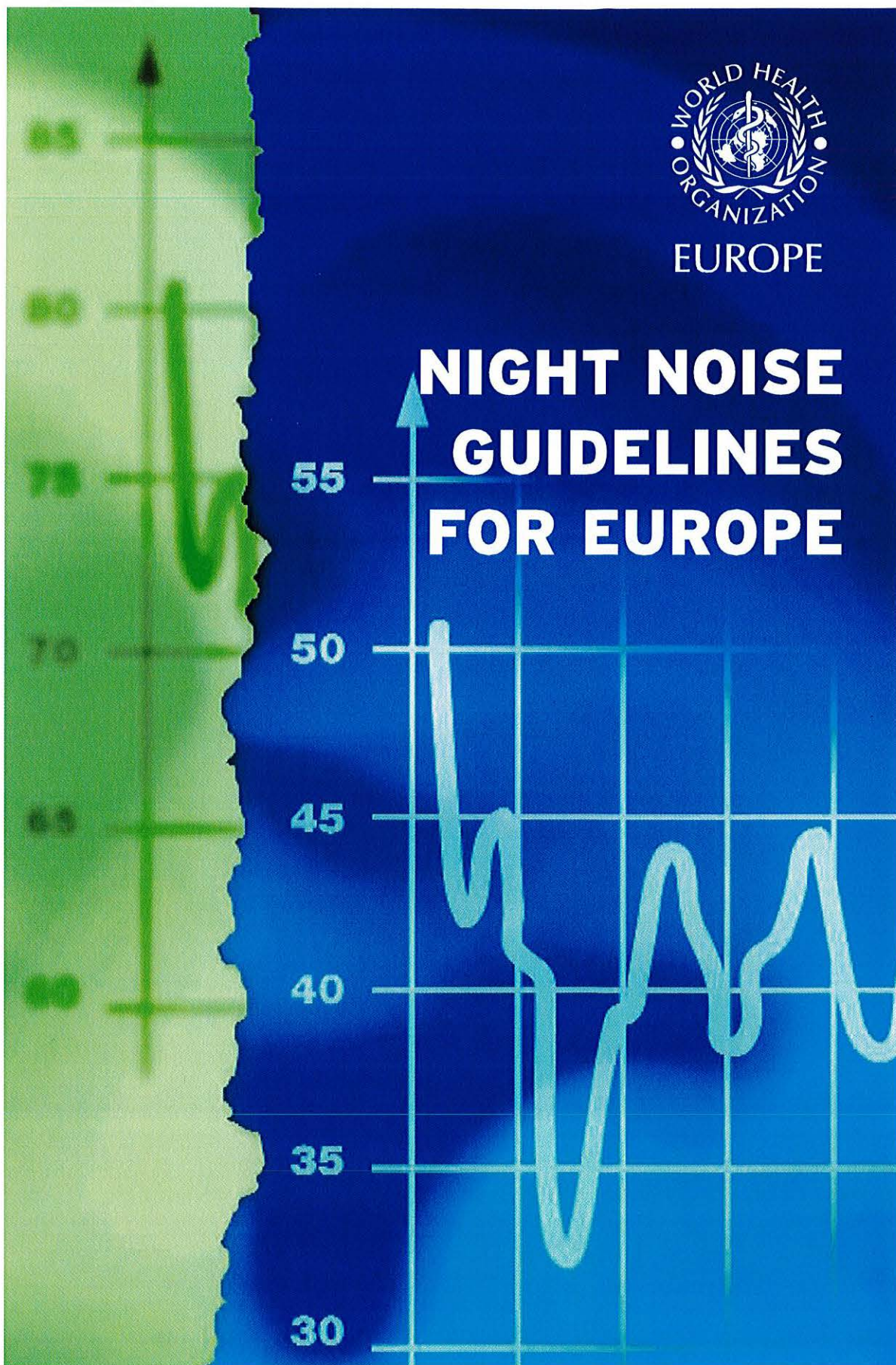
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# **NIGHT NOISE GUIDELINES FOR EUROPE**



**Keywords**

**NOISE - ADVERSE EFFECTS - PREVENTION AND CONTROL**

**SLEEP DEPRIVATION - ETIOLOGY**

**SLEEP DISORDERS - PREVENTION AND CONTROL**

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**GUIDELINES**

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Edited by Charlotte Hurlley, Layout by Dagmar Bengs



ABSTRACT	VI
FOREWORD	VII
LIST OF CONTRIBUTORS	VIII
EXECUTIVE SUMMARY	IX

## CHAPTER 1 INTRODUCTION: METHODS AND CRITERIA

1.1 Introduction: methods and criteria	1
1.1.1 Existing policy documents for night-time noise	1
1.1.2 General model	2
1.1.3 Process of developing guidelines	3
1.2 Strength of evidence	4
1.2.1 Basic concepts	4
1.2.2 Risk assessment and risk control	5
1.2.3 Cause-effect chain	5
1.2.4 Procedure for deriving guidelines	6
1.3 Considerations with regard to night-time noise indicators	7
1.3.1 Length of night	7
1.3.2 Event or long-term descriptor	7
1.3.3 Number of events	8
1.3.4 Conversion between indicators	8
1.3.5 Inside/outside differences	10
1.3.6 Background level	12
1.3.7 Choice of indicators for regulatory purposes	12
1.4 Exposure in the population	13
1.4.1 Noise levels	13
1.4.2 Reported night-time noise disturbance	13
1.5 Conclusions	14

## CHAPTER 2 THE RELATION BETWEEN SLEEP AND HEALTH

2.1 Sleep, normal sleep, definitions of sleep disturbance, characteristics, mechanisms, the insomnia model	15
2.1.1 Normal sleep (objective measurements)	15
2.1.2 Definitions of disturbed sleep	18
2.1.3 Conclusions	20
2.2 Long-term health risk mediated by sleep disturbances	20
2.2.1 Stressors, neurobehavioural data and functional neuroimaging	20
2.2.2 Signals mediated by subcortical area (the amygdala), the role of stress hormones in sleep disturbance and their health consequences	21
2.2.3 Sleep restriction, environmental stressors (noise) and behavioural, medical and social health consequences of insufficient sleep: risk of morbidity and mortality	22
2.3 Risk groups	25
2.3.1 Health effects of disturbed sleep in children	25
2.3.2 Basic individual factors: gender and age	33
2.3.3 Persons exposed to stressors as a risk group	34
2.3.4 Shift work as a risk factor for sleep disturbance and health effects	36
2.3.5 Conclusion	41
2.4 Accidents related to sleep quality	41
2.5 Animal studies	42
2.6 Conclusions	42

**CHAPTER 3 EFFECTS OF NIGHT-TIME NOISE ON SLEEP**

3.1 Short-term effects of transportation noise on sleep with specific attention to mechanisms and possible health impact	45
3.1.1 Introduction	45
3.1.2 How noise influences normal sleep	45
3.1.3 Mechanisms	46
3.1.4 EEG response	47
3.1.5 Cardiovascular response	48
3.1.6 Body movement	49
3.1.7 Behavioural awakening in adults	50
3.1.8 Dose-effect relations for body movements during sleep	51
3.1.9 Individual sensitivity	53
3.1.10 Use of instantaneous effects in predictions over a longer time period	53
3.2 Chronic effects: chronic increase in motility	54
3.3 Conclusions	55

**CHAPTER 4 EFFECTS OF NIGHT-TIME NOISE ON HEALTH AND WELL-BEING**

4.1 Introduction	57
4.2 Self-reported (chronic) sleep disturbances	57
4.3 Complaints	59
4.4 Neighbourhood noise and noise from neighbours	59
4.5 Cardiovascular effects of noise – findings from epidemiological studies	61
4.5.1 Introduction	61
4.5.2 Noise and stress–reaction model	62
4.5.3 Previous reviews on environmental noise and cardiovascular risk	63
4.5.4 Updated review of epidemiological studies	64
4.5.5 Mean BP	65
4.5.6 Hypertension	66
4.5.7 IHD	66
4.5.8 Medication and drug consumption	67
4.5.9 Evaluation of studies	68
4.5.10 Dose–response curve: meta-analysis	72
4.5.11 Effect modification	73
4.5.12 Exposure during the night	74
4.5.13 Risk groups	75
4.5.14 Risk evaluation	76
4.5.15 Conclusions	77
4.6 Insomnia	79
4.7 Effects on performance	80
4.7.1 Cognition and SWS	80
4.7.2 Comparing daytime and night-time noise exposure	80
4.7.3 Comparing children and adults	81
4.7.4 Noise and after-effects	81
4.8 Effects on psychic disorders	81
4.8.1 Transportation noise and mental health	82
4.8.2 Noise exposure and mental hospital admission rates	84
4.8.3 Noise exposure and psychiatric morbidity in the community	84
4.8.4 Aircraft noise exposure and mental health in children	86

4.8.5	Neighbourhood noise and mental health	86
4.8.6	Mechanisms for causal links between noise and mental health	87
4.8.7	Habituation to noise and mental health	88
4.8.8	Risk groups for mental health effects from noise	88
4.8.9	Population groups at risk for mental health effects from noise	88
4.8.10	Noise sensitivity	88
4.8.11	Mental health consequences of insomnia	90
4.8.12	Insomnia as a mental health symptom	91
4.8.13	Depressive episode and anxiety disorders	91
4.8.14	Associations between insomnia and psychiatric disorders	92
4.8.15	Conclusions: associations between noise and psychiatric disorders	93
4.9	The severity of self-reported sleep disturbance	93
4.9.1	Introduction	93
4.9.2	An assessment of disability weights	94
4.9.3	Comparison between insomnia and self-reported sleep disturbance	94
4.9.4	Conclusions	96
4.10	Discussion: can chronic short-term effects cause long-term effects on health?	97

## CHAPTER 5 GUIDELINES AND RECOMMENDATIONS

5.1	Assessment	101
5.2	Thresholds for observed effects	102
5.3	Relations with $L_{\text{night, outside}}$	102
5.4	Dealing with situations exceeding the thresholds	105
5.5	Protection measures and control	107
5.6	Recommendations for health protection	108
5.7	Relation with the guidelines for community noise (1999)	110

## REFERENCES 111

Appendix 1.	Glossary of terms and acronyms	135
Appendix 2.	Relations between $L_{\text{night}}$ and instantaneous effects	137
Appendix 3.	Animal studies on stress and mortality	138
Appendix 4.	Noise and sleep in children	154

## ABSTRACT

The WHO Regional Office for Europe set up a working group of experts to provide scientific advice to the Member States for the development of future legislation and policy action in the area of assessment and control of night noise exposure. The working group reviewed available scientific evidence on the health effects of night noise, and derived health-based guideline values. In December 2006, the working group and stakeholders from industry, government and nongovernmental organizations reviewed and reached general agreement on the guideline values and key texts for the final document of the *Night noise guidelines for Europe*.

Considering the scientific evidence on the thresholds of night noise exposure indicated by  $L_{\text{night, outside}}$  as defined in the Environmental Noise Directive (2002/49/EC), an  $L_{\text{night, outside}}$  of 40 dB should be the target of the night noise guideline (NNG) to protect the public, including the most vulnerable groups such as children, the chronically ill and the elderly.  $L_{\text{night, outside}}$  value of 55 dB is recommended as an interim target for the countries where the NNG cannot be achieved in the short term for various reasons, and where policy-makers choose to adopt a stepwise approach. These guidelines are applicable to the Member States of the European Region, and may be considered as an extension to, as well as an update of, the previous WHO *Guidelines for community noise* (1999).



WHO defines health as a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity, and recognizes the enjoyment of the highest attainable standard of health as one of the fundamental rights of every human being. Environmental noise is a threat to public health, having negative impacts on human health and well-being. In order to support the efforts of the Member States in protecting the population's health from the harmful levels of noise, WHO issued *Guidelines for community noise* in 1999, which includes guideline values for community noise in various settings based on the scientific evidence available. The evidence on health impacts of night noise has been accumulated since then.

In the WHO European Region, environmental noise emerged as the leading environmental nuisance triggering one of the most common public complaints in many Member States. The European Union tackled the problem of environmental noise with an international law on the assessment and management of environmental noise. The WHO Regional Office for Europe developed the *Night noise guidelines for Europe* to provide expertise and scientific advice to the Member States in developing future legislations in the area of night noise exposure control and surveillance, with the support of the European Commission. This guidelines document reviews the health effects of night time noise exposure, examines exposure-effects relations, and presents guideline values of night noise exposure to prevent harmful effects of night noise in Europe. Although these guidelines are neither standards nor legally binding criteria, they are designed to offer guidance in reducing the health impacts of night noise based on expert evaluation of scientific evidence in Europe.

The review of scientific evidence and the derivation of guideline values were conducted by outstanding scientists. The contents of the document were peer reviewed and discussed for a consensus among the experts and the stakeholders from industry, government and nongovernmental organizations. We at WHO are thankful for those who contributed to the development and presentation of this guidelines and believe that this work will contribute to improving the health of the people in the Region.

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## INTRODUCTION

The aim of this document is to present the conclusions of the WHO working group responsible for preparing guidelines for exposure to noise during sleep. This document can be seen as an extension of the WHO *Guidelines for community noise* (1999). The need for “health-based” guidelines originated in part from the European Union Directive 2002/49/EC relating to the assessment and management of environmental noise (commonly known as the Environmental Noise Directive and abbreviated as END) which compels European Union Member States to produce noise maps and data about night exposure from mid-2007. The work was made possible by a grant from the European Commission and contributions from the Swiss and German governments.

Although a number of countries do have legislation directed at controlling night noise exposure, there is little information on actual exposure and its subsequent effects on the population. Estimates made in some countries of the number of people highly disturbed by noise during sleep (see Fig. 1 for the Netherlands as an example) indicate that a substantial part of the population could be exposed to levels that might risk their health and well-being.

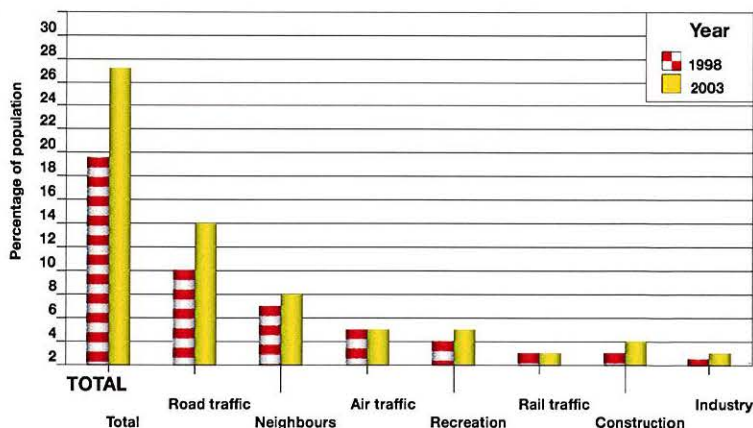


Fig. 1.  
Percentage of  
population highly  
disturbed by noise  
during sleep in the  
Netherlands:  
survey results for  
1998 and 2003

As direct evidence concerning the effects of night noise on health is rarely available, these guidelines also use indirect evidence: the effects of noise on sleep and the relations between sleep and health. The advantage of this approach is that a lot of medical evidence is available on the relation between sleep and health, and detailed information also exists on sleep disturbance by noise.

## PROCESS OF DEVELOPING GUIDELINES

In 2003, the WHO Regional Office for Europe set up a working group of experts to provide scientific advice to the European Commission and to its Member States for the development of future legislation and policy action in the area of control and surveillance of night noise exposure. The review of available scientific evidence on the health effects of night noise was carried out by an interdisciplinary team who set out to derive health-based guideline values. The contributions from the experts were reviewed by the team and integrated into draft reports following discussion at four technical meetings of the working group. In 2006, all the draft reports were compiled into a draft document on guidelines for exposure to noise at night, which was reviewed and commented on by a number of stakeholders and experts.

At the final conference in Bonn, Germany, on 14 December 2006, representatives from the working group and stakeholders from industry, government and non-governmental organizations reviewed the contents of the draft document chapter by chapter, discussed several fundamental issues and reached general agreement on the guideline values and related texts to be presented as conclusions of the final WHO *Night noise guidelines for Europe*.

## NOISE INDICATORS

From the scientific point of view the best criterion for choosing a noise indicator is its ability to predict an effect. Therefore, for different health end points, different indicators could be chosen. Long-term effects such as cardiovascular disorders are more correlated with indicators summarizing the acoustic situation over a long time period, such as yearly average of night noise level outside at the facade ( $L_{\text{night, outside}}$ )<sup>1</sup>, while instantaneous effects such as sleep disturbance are better with the maximum level per event ( $L_{\text{Amax}}$ ), such as passage of a lorry, aeroplane or train.

From a practical point of view, indicators should be easy to explain to the public so that they can be understood intuitively. Indicators should be consistent with existing practices in the legislation to enable quick and easy application and enforcement.  $L_{\text{night, outside}}$ , adopted by the END, is an indicator of choice for both scientific and practical use. Among currently used indicators for regulatory purposes,  $L_{\text{Aeq}}$  (A-weighted equivalent sound pressure level) and  $L_{\text{Amax}}$  are useful to predict short-term or instantaneous health effects.

## SLEEP TIME

Time use studies, such as that undertaken by the Centre for Time Use Research, 2006 ([www.timeuse.org/access/](http://www.timeuse.org/access/)), show that the average time adult people are in bed is around 7.5 hours, so the real average sleeping time is somewhat shorter. Due to personal factors like age and genetic make-up there is considerable variation in sleeping time and in beginning and end times. For these reasons, a fixed interval of 8 hours is a minimal choice for night protection.

Though results vary from one country to another, data show (see Fig. 2 as an example) that an 8-hour interval protects around 50% of the population and that it would take a period of 10 hours to protect 80%. On Sundays, sleeping time is consistently 1 hour longer, probably due to people recovering from sleep debt incurred during the week. It should also be borne in mind that (young) children have longer sleeping times.

<sup>1</sup>  $L_{\text{night}}$  is defined in the END as the outside level. In order to avoid any doubt, the suffix "outside" is added in this document.



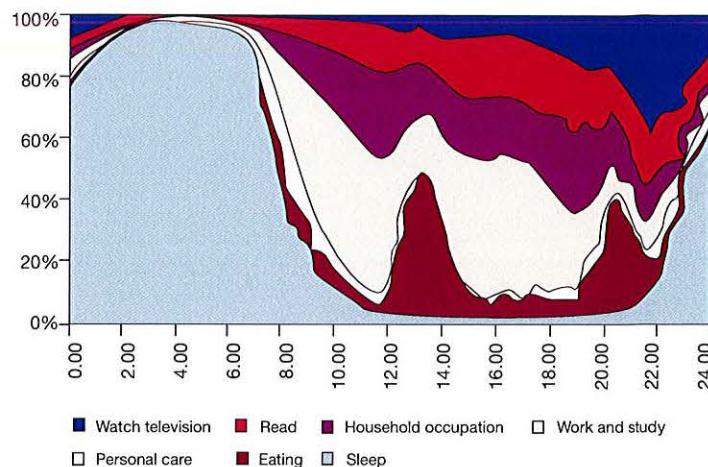


Fig. 2  
Percentage of  
time that the  
Portuguese  
population spend  
asleep or in  
different  
activities

Source: <http://www.ine.pt/prodseu/destaque/arquivo.asp>,  
based on a study by the Instituto Nacional de Estatística Portugal, 1999.

## NOISE, SLEEP AND HEALTH

There is plenty of evidence that sleep is a biological necessity, and disturbed sleep is associated with a number of health problems. Studies of sleep disturbance in children and in shift workers clearly show the adverse effects.

Noise disturbs sleep by a number of direct and indirect pathways. Even at very low levels physiological reactions (increase in heart rate, body movements and arousals) can be reliably measured. Also, it was shown that awakening reactions are relatively rare, occurring at a much higher level than the physiological reactions.

### DEFINITION OF "SUFFICIENT" AND "LIMITED" EVIDENCE

**Sufficient evidence:** A causal relation has been established between exposure to night noise and a health effect. In studies where coincidence, bias and distortion could reasonably be excluded, the relation could be observed. The biological plausibility of the noise leading to the health effect is also well established.

**Limited evidence:** A relation between the noise and the health effect has not been observed directly, but there is available evidence of good quality supporting the causal association. Indirect evidence is often abundant, linking noise exposure to an intermediate effect of physiological changes which lead to the adverse health effects.

The working group agreed that there is sufficient evidence that night noise is related to self-reported sleep disturbance, use of pharmaceuticals, self-reported health problems and insomnia-like symptoms. These effects can lead to a considerable burden of disease in the population. For other effects (hypertension, myocardial infarctions, depression and others), limited evidence was found: although the studies were few or not conclusive, a biologically plausible pathway could be constructed from the evidence.

## **XII EXECUTIVE SUMMARY**

An example of a health effect with limited evidence is myocardial infarction. Although evidence for increased risk of myocardial infarction related to  $L_{\text{day}}$  is sufficient according to an updated meta-analysis, the evidence in relation to  $L_{\text{night, outside}}$  was considered limited. This is because  $L_{\text{night, outside}}$  is a relatively new exposure indicator, and few field studies have focused on night noise when considering cardiovascular outcomes. Nevertheless, there is evidence from animal and human studies supporting a hypothesis that night noise exposure might be more strongly associated with cardiovascular effects than daytime exposure, highlighting the need for future epidemiological studies on this topic.

The review of available evidence leads to the following conclusions.

- Sleep is a biological necessity and disturbed sleep is associated with a number of adverse impacts on health.
- There is sufficient evidence for biological effects of noise during sleep: increase in heart rate, arousals, sleep stage changes and awakening.
- There is sufficient evidence that night noise exposure causes self-reported sleep disturbance, increase in medicine use, increase in body movements and (environmental) insomnia.
- While noise-induced sleep disturbance is viewed as a health problem in itself (environmental insomnia), it also leads to further consequences for health and well-being.
- There is limited evidence that disturbed sleep causes fatigue, accidents and reduced performance.
- There is limited evidence that noise at night causes hormone level changes and clinical conditions such as cardiovascular illness, depression and other mental illness. It should be stressed that a plausible biological model is available with sufficient evidence for the elements of the causal chain.

### **VULNERABLE GROUPS**

Children have a higher awakening threshold than adults and therefore are often seen to be less sensitive to night noise. For other effects, however, children seem to be equally or more reactive than adults. As children also spend more time in bed they are exposed more to night noise levels. For these reasons children are considered a risk group.

Since with age the sleep structure becomes more fragmented, elderly people are more vulnerable to disturbance. This also happens in pregnant women and people with ill health, so they too are a group at risk.

Finally, shift workers are at risk because their sleep structure is under stress due to the adaptations of their circadian rhythm.

## THRESHOLDS FOR OBSERVED EFFECTS

The no observed adverse effect level (NOAEL) is a concept from toxicology, and is defined as the greatest concentration which causes no detectable adverse alteration of morphology, functional capacity, growth, development or lifespan of the target organism. For the topic of night noise (where the adversity of effects is not always clear) this concept is less useful. Instead, the observed effect thresholds are provided: the level above which an effect starts to occur or shows itself to be dependent on the exposure level. It can also be a serious pathological effect, such as myocardial infarctions, or a changed physiological effect, such as increased body movement.

Threshold levels of noise exposure are important milestones in the process of evaluating the health consequences of environmental exposure. The threshold levels also delimit the study area, which may lead to a better insight into overall consequences. In Tables 1 and 2, all effects are summarized for which *sufficient and limited evidence* exists. For these effects, the threshold levels are usually well known, and for some the dose-effect relations over a range of exposures could also be established.

Effect	Indicator	Threshold, dB
Biological effects	Change in cardiovascular activity	*
	EEG awakening	$L_{Amax,inside}$ 35
	Motility, onset of motility	$L_{Amax,inside}$ 32
	Changes in duration of various stages of sleep, in sleep structure and fragmentation of sleep	$L_{Amax,inside}$ 35
	Waking up in the night and/or too early in the morning	$L_{Amax,inside}$ 42
Sleep quality	Prolongation of the sleep inception period, difficulty getting to sleep	* *
	Sleep fragmentation, reduced sleeping time	* *
Well-being	Increased average motility when sleeping	$L_{night,outside}$ 42
	Self-reported sleep disturbance	$L_{night,outside}$ 42
	Use of somnifacient drugs and sedatives	$L_{night,outside}$ 40
Medical conditions	Environmental insomnia**	$L_{night,outside}$ 42

**Table 1**  
Summary of effects and threshold levels for effects where *sufficient evidence* is available

\* Although the effect has been shown to occur or a plausible biological pathway could be constructed, indicators or threshold levels could not be determined.

\*\*Note that "environmental insomnia" is the result of diagnosis by a medical professional whilst "self-reported sleep disturbance" is essentially the same, but reported in the context of a social survey. Number of questions and exact wording may differ.



## XIV EXECUTIVE SUMMARY

**Table 2**  
**Summary of effects**  
**and threshold levels**  
**for effects where**  
**limited evidence is**  
**available\*\***

Effect	Indicator	Estimated threshold, dB
Biological effects	Changes in (stress) hormone levels	*
Well-being	Drowsiness/tiredness during the day and evening	*
	Increased daytime irritability	*
	Impaired social contacts	*
	Complaints	$L_{night, outside}$ 35
	Impaired cognitive performance	*
Medical conditions	Insomnia	*
	Hypertension	$L_{night, outside}$ 50
	Obesity	*
	Depression (in women)	*
	Myocardial infarction	$L_{night, outside}$ 50
	Reduction in life expectancy (premature mortality)	*
	Psychic disorders	$L_{night, outside}$ 60
	(Occupational) accidents	*

\* Although the effect has been shown to occur or a plausible biological pathway could be constructed, indicators or threshold levels could not be determined.

\*\* Note that as the evidence for the effects in this table is limited, the threshold levels also have a limited weight. In general they are based on expert judgement of the evidence.

## RELATIONS WITH $L_{NIGHT, OUTSIDE}$

Over the next few years, the END will require that night 'noise' exposures are reported in  $L_{night, outside}$ . It is, therefore, interesting to look into the relation between  $L_{night, outside}$  and adverse health effects. The relation between the effects and  $L_{night, outside}$  is, however, not straightforward. Short-term effects are mainly related to maximum levels per event inside the bedroom:  $L_{Amax, inside}$ . In order to express the (expected) effects in relation to the single European Union indicator, some calculation needs to be done. The calculation for the total number of effects from reaction data on events (arousals, body movements and awakenings) needs a number of assumptions. The first that needs to be made is independence: although there is evidence that the order of events of different loudness strongly influences the reactions, the calculation is nearly impossible to carry out if this is taken into consideration. Secondly, the reactions per event are known in relation to levels at the ear of the sleeper, so an assumption for an average insulation value must be made. In the report a value of 21 dB has been selected. This value is, however, subject to national and cultural differences. One thing that stands out is the desire of a large part of the population to sleep with windows (slightly) open. The relatively low value of 21 dB takes this into account already. If noise levels increase, people do indeed close their windows, but obviously reluctantly, as complaints about bad air then increase and sleep disturbance remains high. This was already pointed out in the WHO *Guidelines for community noise* (1999).



From source to source the number of separate events varies considerably. Road traffic noise is characterized by relatively low levels per event and high numbers, while air and rail traffic are characterized by high levels per event and low numbers. For two typical situations estimates have been made and presented in graphical form. The first is an average urban road (600 motor vehicles per night, which corresponds roughly to a 24-hour use of 8000 motor vehicles, or 3 million per year, the lower boundary the END sets) and the second case is for an average situation of air traffic exposure (8 flights per night, nearly 3000 per year).

Fig. 3 shows how effects increase with an increase of  $L_{\text{night, outside}}$  values for the typical road traffic situation (urban road). A large number of events lead to high levels of awakening once the threshold of  $L_{\text{Amax, inside}}$  is exceeded. To illustrate this in practical terms: values over 60 dB  $L_{\text{night, outside}}$  occur at less than 5 metres from the centre of the road.

In Fig. 4 the same graph is presented for the typical airport situation. Due to a lower number of events there are fewer awakenings than in the road traffic case (Fig. 3), but the same or more health effects. In these examples the worst case figures can be factors higher: the maximum number of awakenings for an  $L_{\text{night, outside}}$  of 60–65 dB is around 300 per year.

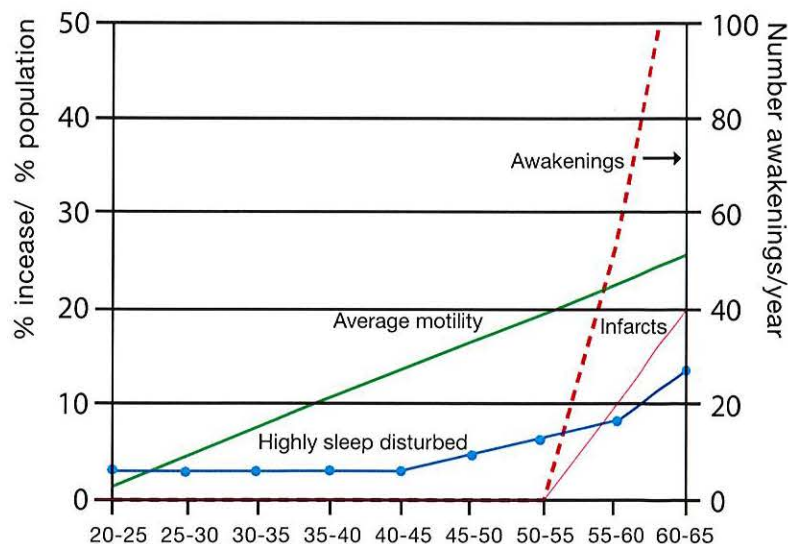


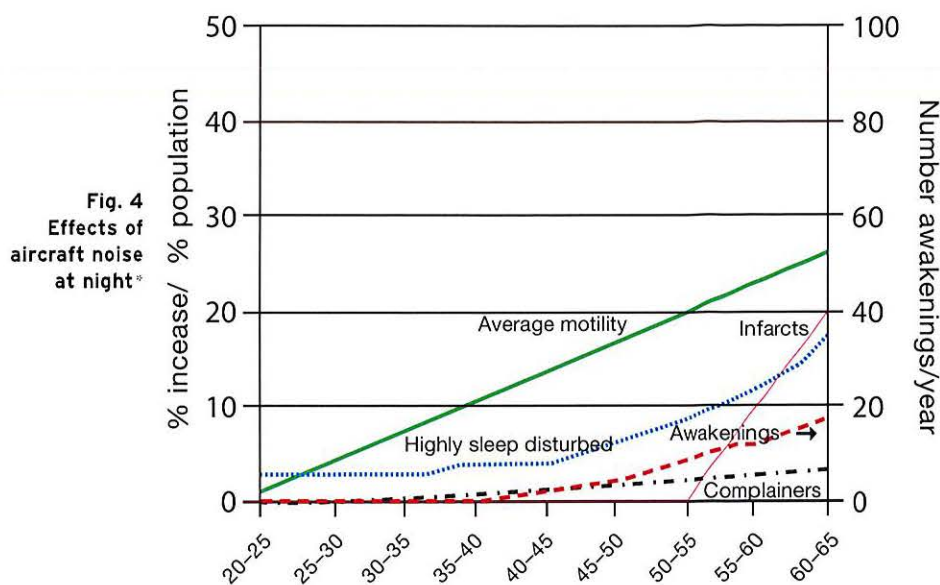
Fig. 3  
Effects  
of road traffic  
noise at night\*

\*Average motility and infarcts are expressed in percent increase (compared to baseline number); the number of highly sleep disturbed people is expressed as a percent of the population; awakenings are expressed in number of additional awakenings per year.

A recent study suggests that high background levels of noise (from motorways) with a low number of separate events can cause high levels of average motility.

Therefore, by using the  $L_{\text{night, outside}}$  as a single indicator, a relation between effects and indicator can be established. For some effects, however, the relation can be

## XVI EXECUTIVE SUMMARY



\*Average motility and infarcts are expressed in percent increase (compared to baseline number); the number of highly sleep disturbed people is expressed as a percent of the population; complainers are expressed as a % of the neighbourhood population; awakenings are expressed in number of additional awakenings per year.

source dependent. Although  $L_{\text{night}}$  gives a good relation for most effects, there is a difference between sources for some. Train noise gives fewer awakenings, for instance. Once source is accounted for, the relations are reasonably accurate.

## RECOMMENDATIONS FOR HEALTH PROTECTION

Based on the systematic review of evidence produced by epidemiological and experimental studies, the relationship between night noise exposure and health effects can be summarized as below. (Table 3)

Below the level of 30 dB  $L_{\text{night, outside}}$ , no effects on sleep are observed except for a slight increase in the frequency of body movements during sleep due to night noise. There is no sufficient evidence that the biological effects observed at the level below 40 dB  $L_{\text{night, outside}}$  are harmful to health. However, adverse health effects are observed at the level above 40 dB  $L_{\text{night, outside}}$ , such as self-reported sleep disturbance, environmental insomnia, and increased use of somnifacient drugs and sedatives.

Therefore, 40 dB  $L_{\text{night, outside}}$  is equivalent to the lowest observed adverse effect level (LOAEL) for night noise. Above 55 dB the cardiovascular effects become the major public health concern, which are likely to be less dependent on the nature of the noise. Closer examination of the precise impact will be necessary in the range between 30 dB and 55 dB as much will depend on the detailed circumstances of each case.

Average night noise level over a year  
 $L_{\text{night, outside}}$

Health effects observed in the population

Up to 30 dB	Although individual sensitivities and circumstances may differ, it appears that up to this level no substantial biological effects are observed. $L_{\text{night, outside}}$ of 30 dB is equivalent to the no observed effect level (NOEL) for night noise.
30 to 40 dB	A number of effects on sleep are observed from this range: body movements, awakening, self-reported sleep disturbance, arousals. The intensity of the effect depends on the nature of the source and the number of events. Vulnerable groups (for example children, the chronically ill and the elderly) are more susceptible. However, even in the worst cases the effects seem modest. $L_{\text{night, outside}}$ of 40 dB is equivalent to the lowest observed adverse effect level (LOAEL) for night noise.
40 to 55 dB	Adverse health effects are observed among the exposed population. Many people have to adapt their lives to cope with the noise at night. Vulnerable groups are more severely affected.
Above 55 dB	The situation is considered increasingly dangerous for public health. Adverse health effects occur frequently, a sizeable proportion of the population is highly annoyed and sleep-disturbed. There is evidence that the risk of cardiovascular disease increases.

**Table 3**  
**Effects of different levels of night noise on the population's health**

A number of instantaneous effects are connected to threshold levels expressed in  $L_{\text{Amax}}$ . The health relevance of these effects cannot be easily established. It can be safely assumed, however, that an increase in the number of such events over the baseline may constitute a subclinical adverse health effect by itself leading to significant clinical health outcomes.

Based on the exposure-effects relationship summarized in Table 3, the night noise guideline values are recommended for the protection of public health from night noise as below.

Night noise guideline (NNG)	$L_{\text{night, outside}} = 40 \text{ dB}$
Interim target (IT)	$L_{\text{night, outside}} = 55 \text{ dB}$

**Table 4**  
**Recommended night noise guidelines for Europe**

<sup>1</sup>  $L_{\text{night, outside}}$  is the night-time noise indicator ( $L_{\text{night}}$ ) of Directive 2002/49/EC of 25 June 2002: the A-weighted long-term average sound level as defined in ISO 1996-2: 1987, determined over all the night periods of a year; in which: the night is eight hours (usually 23.00 – 07.00 local time), a year is a relevant year as regards the emission of sound and an average year as regards the meteorological circumstances, the incident sound is considered, the assessment point is the same as for  $L_{\text{den}}$ . See *Official Journal of the European Communities*, 18.7.2002, for more details.



## **XVIII EXECUTIVE SUMMARY**

For the primary prevention of subclinical adverse health effects related to night noise in the population, it is recommended that the population should not be exposed to night noise levels greater than 40 dB of  $L_{\text{night, outside}}$  during the part of the night when most people are in bed. The LOAEL of night noise, 40 dB  $L_{\text{night, outside}}$  can be considered a health-based limit value of the night noise guidelines (NNG) necessary to protect the public, including most of the vulnerable groups such as children, the chronically ill and the elderly, from the adverse health effects of night noise.

An interim target (IT) of 55 dB  $L_{\text{night, outside}}$  is recommended in the situations where the achievement of NNG is not feasible in the short run for various reasons. It should be emphasized that IT is not a health-based limit value by itself. Vulnerable groups cannot be protected at this level. Therefore, IT should be considered only as a feasibility-based intermediate target which can be temporarily considered by policy-makers for exceptional local situations.

### **RELATION WITH THE GUIDELINES FOR COMMUNITY NOISE (1999)**

Impact of night-time exposure to noise and sleep disturbance is indeed covered in the 1999 guidelines, as below (WHO, 1999):

“If negative effects on sleep are to be avoided the equivalent sound pressure level should not exceed 30 dBA indoors for continuous noise. If the noise is not continuous, sleep disturbance correlates best with  $L_{\text{Amax}}$  and effects have been observed at 45 dB or less. This is particularly true if the background level is low. Noise events exceeding 45 dBA should therefore be limited if possible. For sensitive people an even lower limit would be preferred. It should be noted that it should be possible to sleep with a bedroom window slightly open (a reduction from outside to inside of 15 dB). To prevent sleep disturbances, one should thus consider the equivalent sound pressure level and the number and level of sound events. Mitigation targeted to the first part of the night is believed to be effective for the ability to fall asleep.”

The 1999 guidelines are based on studies carried out up to 1995 (and a few meta-analyses some years later). Important new studies (Passchier-Vermeer et al., 2002; Basner et al., 2004) have become available since then, together with new insights into normal and disturbed sleep. New information has made more precise assessment of exposure-effect relationship. The thresholds are now known to be lower than  $L_{\text{Amax}}$  of 45 dB for a number of effects. The last three sentences still stand: there are good reasons for people to sleep with their windows open, and to prevent sleep disturbances one should consider the equivalent sound pressure level and the number of sound events. The present guidelines allow responsible authorities and stakeholders to do this. Viewed in this way, the *night noise guidelines for Europe* are complementary to the 1999 guidelines. This means that the recommendations on government policy framework on noise management elaborated in the 1999 guidelines should be considered valid and relevant for the Member States to achieve the guideline values of this document.

# CHAPTER 1

## INTRODUCTION: METHODS AND CRITERIA

*With regard to sleep and waking, we must consider what they are: whether they are peculiar to soul or to body, or common to both; and if common, to what part of soul or body they appertain: further, from what cause it arises that they are attributes of animals, and whether all animals share in them both, or some partake of the one only, others of the other only, or some partake of neither and some of both.*

*(Aristotle, On sleep and sleeplessness, 350 BC)*

### 1.1 INTRODUCTION

#### 1.1.1 EXISTING POLICY DOCUMENTS FOR NIGHT-TIME NOISE

The aim of this document is to present guidance for exposure to noise during sleep. What is already available?

There are three related documents at the international level:

- *Guidelines for community noise* (WHO, 1999)
- *Directive 2002/49/EC relating to the assessment and management of environmental noise* (European Commission, 2002b)
- *Position Paper on dose-effect relationships for night-time noise* (European Commission, 2004).

In Chapter 5 the relation with the *Guidelines for community noise* (1999) will be explained.

The European Union (EU) Directive relating to the assessment and management of environmental noise (or, as it is commonly known, the Environmental Noise Directive – END), establishes that Member States should create noise maps (2007) and action plans (2008) for parts of their territory. The noise maps should present noise levels expressed in the harmonized indicators  $L_{den}$  and  $L_{night}$ . Although in the first round only between 20% and 30% of the population will be covered, it is expected that through the use of harmonized methods and indicators a deeper insight will be gained into the exposure of the population to noise. The END does not, however, set any limit values: on the basis of the subsidiarity principle this is left to the Member States. The Directive does, however, require Member States to report on their limit values and express them in the standard indicators. On the CIRCA web site (Communication and Information Resource Centre Administrator, European Commission, 2006) an overview of the data reported to the Commission can be found. Out of the 25 Member States, 10 reported on the  $L_{night}$  limits. In Table 1.1 some of these data are summarized.

Due to differences in legal systems it is hard to predict what the actual effect of a certain limit value will be. It could be a relatively high value but rigidly enforced, or a very low value with no legal binding whatsoever.

The *Position Paper* on dose-effect relationships for night-time noise is foreseen in the END (Annex III) and aims to give the competent authorities a tool to evaluate the

## 2 METHODS AND CRITERIA

impact on the population. However, it neither provides limit values nor guidelines. The same information that was used in the *Position Paper* also plays a role in these guidelines.

**Table 1.1**  
Reported  $L_{\text{night}}$  limit values  
for road traffic noise in new  
residential areas

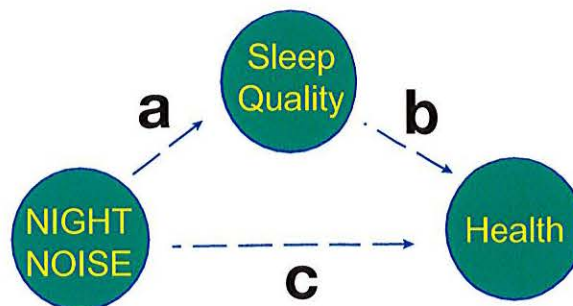
EU Member State	$L_{\text{night, outside}}$
France	62
Germany	49
Spain	45
Netherlands	40
Austria	50
Sweden	51
	(converted from $L_{Aeq}$ limit 30 dB(A) inside bedroom)
Finland	46
Hungary	55
Latvia	40
Estonia	45
Switzerland	50

Source: European Commission, 2006.

### 1.1.2 GENERAL MODEL

There is no doubt that a relation exists between sleep and health and well-being, as most of us know from personal experience. That does not mean, however, that this relation is simple. People who do not sleep well may not feel well the day after, but the reverse is also true: unfit people may have a disturbed sleep. Untangling the relations between health and disturbed sleep (night-time noise is only one of many causes) proved difficult, and Fig. 2.1 at the end of Chapter 2 shows why.

**Fig. 1.1.**  
General structure of the  
report on the effects of  
night noise



The general structure of the report is given in Fig. 1.1: evidence for the effects of night-time noise on health (c) is supported by evidence on the indirect route via (a) and (b). In Chapter 2 the relations between sleep and health are examined (relation (b) in Fig. 1.1), and this involves clinical evidence from sleep laboratories, but also evidence from animal experiments. In Chapter 3 it is shown how noise disturbs sleep from the basic, autonomous level up to conscious awakenings: relation (a). Chapter 4 presents the evidence between night-time noise and health and well-being: relation (c) in Fig. 1.1. The last chapter, Chapter 5, then provides guidance on reducing health impacts caused by night-time noise exposure.



### 1.1.3 PROCESS OF DEVELOPING GUIDELINES

The WHO Regional Office for Europe started the night noise guidelines (NNGL) project with a grant from the European Commission's Directorate-General for Health and Consumer Affairs. In 2003, the WHO Regional Office for Europe set up a working group of experts to provide scientific advice for the development of guidelines for future legislation and policy action in the area of control and surveillance of night noise exposure. The review of available scientific evidence on the health effects of night noise was carried out by the working group to derive health-based guideline values. The contributions from the experts were reviewed by the team and integrated into draft reports following discussion at four technical meetings of the working group.

The first meeting of the working group was held in Bonn, June 2004. It was agreed that the experts would produce background papers on a number of topics identified and assigned at the meeting.

The second meeting in Geneva, December 2004, concentrated on such technical issues as exposure assessment, metrics, health effects and guideline set-up. The topic-specific experts presented the first drafts for the identified topics for detailed discussions at the meeting. The discussions concentrated on central issues such as exposure assessment and guideline derivation.

The third meeting in Lisbon, April 2005, reviewed the revised background papers, and discussed in detail the overall structure of the guidelines document, and the process of consensus building among the working group and stakeholders.

At the workshop of acoustics experts in The Hague, September 2005, a consensus was made on the use of  $L_{\text{night}}$  as the single indicator for guideline values as it effectively combines the information on the number of events and the maximum sound levels per event over a year.

In 2006, all the draft reports collected at previous meetings were compiled by Mr. Martin van den Berg into a coherent document on guidelines for exposure to noise at night. The latter was revised according to the comments collected through a peer-review by the working group experts.

At the concluding meeting in Bonn, December 2006, the working group and stakeholders from industry, government and nongovernmental organizations reviewed the contents of the draft document chapter by chapter, discussed several fundamental issues and reached general consensus on the guideline values. The final implementation report of NNGL project was submitted to the EU in early 2007.

The following countries and institutes contributed to the development of *Night noise guidelines for Europe* as project partners.

AUSTRIA:	Institute of Hygiene and Social Medicine, University of Innsbruck
CZECH REPUBLIC:	Charles University in Prague
DENMARK:	National Institute of Public Health
FRANCE:	INRETS/LTE-Laboratoire Transports et Environnement CNRS-Centre National de Recherche Scientifique
GERMANY:	Umweltbundesamt-Federal Environmental Agency Landesgesundheitsamt Baden-Württemberg

## 4 METHODS AND CRITERIA

ITALY:	ARPAT – Environmental Protection Agency, Tuscany Region University of Rome “La Sapienza” – Center for Pediatric Sleep Disorders
NETHERLANDS:	TNO – Netherlands Organisation for Applied Scientific Research RIVM – National Institute of Public Health and the Environment
POLAND:	University of Warsaw, Clinic of Psychiatry of the Medical Academy
PORTUGAL:	IST – Instituto Superior Técnico
SLOVENIA:	Institute of Public Health of the Republic of Slovenia
SWEDEN:	University of Gävle, Centre for Built Environment
UNITED KINGDOM:	Queen Mary and Westfield College, University of London

In addition, WHO received advice and support from a number of national experts who participated in the working group. The affiliations of these additional expert advisers include:

CANADA:	Health Canada
GERMANY:	Forschungs- und Beratungsbüro Maschke
SWITZERLAND:	Bundesamt für Umwelt, Wald und Landschaft Universität St. Gallen, Institut für Wirtschaft und Ökologie
NETHERLANDS:	Ministry of Housing, Spatial Planning and Environment
UNITED KINGDOM:	Casella Stanger Environmental Consultants

Since the project report was published on the EU web site, various comments were received from experts who have not participated in the working group. The most critical points were regarding the achievability of guideline values in practice. Responding to these feedbacks, the WHO Regional Office for Europe, prepared a revision of guidelines and recommendations, and consulted with international experts and stakeholders including the EU. As of late 2008, it was agreed that the guideline should be based on the lowest observed adverse effects level (LOAEL) rather than the no observed effects level (NOEL). Interim target was also introduced as a feasibility-based level.

## 1.2 STRENGTH OF EVIDENCE

### 1.2.1 BASIC CONCEPTS

This document uses well-established practices from other disciplines and policy fields. Of main interest here are evidence-based medicine, the use of epidemiological evidence for environmental risk assessment and experiences with – principally – air quality guidelines.

The concept of “evidence” is further formalized, as variations in wording and scope are currently in use.

### 1.2.2 RISK ASSESSMENT AND RISK CONTROL

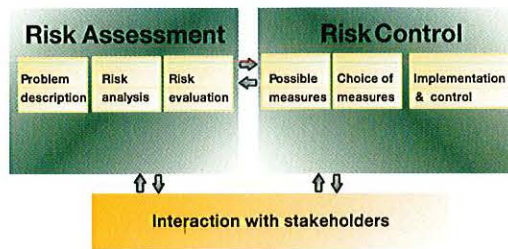


Fig. 1.2  
Elements of risk control

Source:  
Health Council of the  
Netherlands, 2004.

Fig. 1.2 outlines a general approach for risk assessment and control. This approach consists of the following steps:

1. problem description: assessing the impact on the population
2. risk analysis: evaluation of impact
3. risk evaluation: assessing impact considered undesirable
4. assessment of options to avoid or reduce impact
5. cost-benefit analysis of the options or of the mix of options
6. assessment of the preferred option
7. implementation and control.

It is important to observe that guideline values can be an input to, as well as an output of this process. At lower levels of decision (a particular infrastructure project, for instance) a preset guideline value reduces – intentionally – the degrees of freedom in the process. At the highest national or international level a guideline value is the outcome. As the scope of this document is to present the health consequences of night-time noise exposure (and not so much the economic outcomes of the choice of a certain value) it concentrates on the first three elements in the risk assessment block.

The following questions need to be addressed.

- What is the strength of the available evidence – what are the uncertainties?
- What is the health significance for the effects found?
- How serious is the impact on health?
- Does every instance of exposure lead to an effect and how are they related?
- How can the number of affected people be established?

### 1.2.3 CAUSE-EFFECT CHAIN

Underlying this approach is the notion of a cause-effect chain between environmental factors and health, symbolically simplified in Fig. 1.3.

Fig. 1.3  
Cause-effect chain



Source: Health Council of the Netherlands, 2004.



## 6 METHODS AND CRITERIA

There are important questions that need to be asked.

- Is there a causal relation between one link in the chain and the next?
- What are the intervening factors in that relation?
- How strong is the evidence for the relations?

The last question is the hardest to answer, as “strength of evidence” is not easy to express in simple numbers or labels. There are two forms of uncertainty: uncertainty because of variability of outcomes and uncertainty due to a lack of knowledge.

For the purpose of this document the following classification will be used, largely based on the IARC (International Agency for Research on Cancer) criteria accessible at <http://monographs.iarc.fr/ENG/Preamble/currentb6evalrationale0706.php> (see Table 1.2).

**Table 1.2**  
**Classification of**  
**evidence**

Grade of evidence	Criteria
Sufficient evidence	A causal relation has been established between exposure to night-time noise and an effect. In studies where coincidence, bias and distortion could reasonably be excluded, the relation could be observed and it is plausible that the effect is (also) caused by the exposure.
Limited evidence	A relation was observed between exposure to night-time noise and an effect in studies where coincidence, bias and distortion could not reasonably be excluded. The relation is, however, plausible. A direct relation between cause and effect has not been observed, but there is indirect evidence of good quality and the relation is plausible. Indirect evidence is assumed if exposure leads to an intermediate effect and other studies prove that the intermediate effect leads to the effect.
Insufficient evidence	Available studies are of low quality and lack significance to allow conclusions about causality of the relation between exposure and effect. Plausibility of the relation is limited or absent.

### 1.2.4 PROCEDURE FOR DERIVING GUIDELINES

The following procedure was followed in order to derive an ordering of guideline values:

1. collection of relevant data
2. evaluation of data in terms of strength of evidence
3. evaluation of data in terms of biological effects, health and well-being
4. ranking of guideline values.

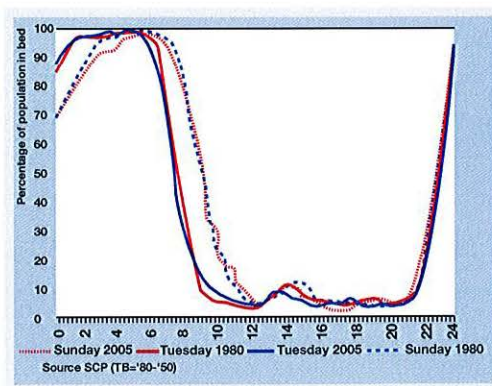
This procedure is essentially the same as in other guideline documents, although steps are more explicitly formalized. A major difference is that sound is a natural environmental quality, which makes defining a no-effect level a futile exercise. Therefore the choice was made for a series of levels with increasing severity of effects.

### 1.3 CONSIDERATIONS WITH REGARD TO NIGHT-TIME NOISE INDICATORS

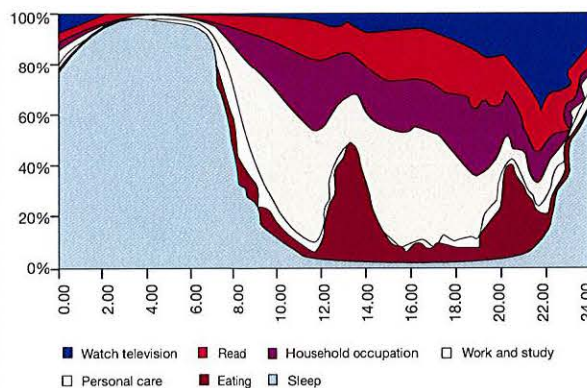
Briefly, the fundamental choices of night-time noise indicators with respect to length of night, use of single event descriptors and long-term average are commented on to assist the reader in understanding the relations presented in later chapters.

#### 1.3.1 LENGTH OF NIGHT

Time use studies (Centre for Time Use Research, 2006) show that the average time adult people are in bed is around 7.5 hours, so the real average sleeping time is somewhat shorter. Due to personal factors such as age and genetic factors there is considerable variation in sleeping time and in beginning and end times. For these reasons, a fixed interval of 8 hours is a minimal choice for night-time protection. From Fig. 1.4 it can be noted that around 50% of the population is protected with an interval of 8 hours and it would take a period of 10 hours to protect 80%. On Sundays, sleeping time is consistently one hour longer, probably due to people recovering from sleep debt incurred during the week. Data for other countries are readily available but this is the only study covering a long period in a consistent way. Fig. 1.5 (from a time use study in Portugal) shows that the stable pattern found in the Netherlands (Fig. 1.4) is not only typical for northern Europe, but also for the southern part. The pattern, however, seems to have shifted slightly. These figures stress that sleep times might be biologically fixed in humans, and culture has almost no influence.



**Fig. 1.4**  
Sleep pattern of Dutch population on weekdays and Sundays, 1980-2005



**Fig. 1.5**  
Percentage of time that the Portuguese population spend asleep or in different activities

Source: <http://www.ine.pt/prodser/destaque/arquivo.asp>, based on a study by the Instituto Nacional de Estatística Portugal, 1999

#### 1.3.2 EVENT OR LONG-TERM DESCRIPTOR

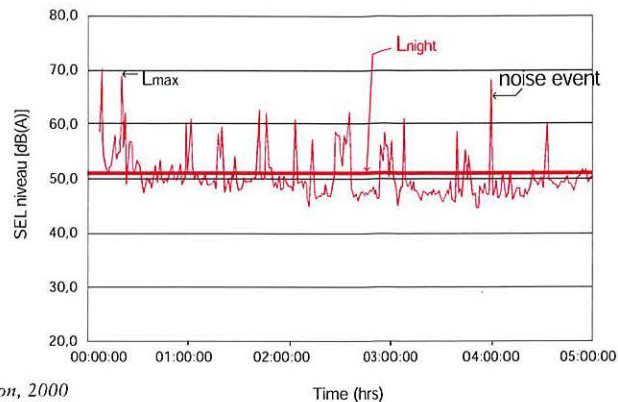
Much attention has been paid to the use of single event descriptors such as  $L_{Amax}$  (maximum outdoor sound pressure level) and SEL (sound exposure level). As the *Position Paper* on EU noise indicators (European Commission, 2000) points out, this is an important laboratory tool to describe instantaneous reactions to noise. But when it comes to long-term protection, the number of events is equally important. The possibility of predicting after-effects like sleepiness, reaction time, sleeping pill



## 8 METHODS AND CRITERIA

use and health complaints, in particular, requires a combination of a number of events and their level instead of just the average  $L_{Amax}$  or average SEL. For events with a similar time pattern there is a relatively simple relation between  $L_{Amax}$  and SEL, and therefore between  $L_{Amax}$  and  $L_{night}$  (night-time noise indicator as defined

**Fig. 1.6**  
Relation between  $L_{night}$ ,  
 $L_{Amax}$  and SEL



Source: European Commission, 2000

by the END – see paragraph 1.3.4 below). Appendix 2 describes this in detail. For now let it suffice to say that a choice for an  $L_{night}$  level ties the  $L_{Amax}$  related effects to a maximum and therefore allows for a protective/conservative approach.

Fig. 1.6 is based on a sound recording in a bedroom for one night. The top of the peaks are the  $L_{Amax}$  levels, the total energy is the  $L_{night}$  (thick horizontal line). The sound energy in one event is the SEL (not represented). In reality the  $L_{night}$  is the average over all nights in one year. This reasoning applies also to the issue of long-term average. A value for an arbitrary single night will, except in extreme cases, bear no relationship to an individual's long-term health status, whereas a sustained sufficiently high level over a long period may.

### 1.3.3 NUMBER OF EVENTS

There is no generally accepted way to count the number of (relevant) noise events. Proposals range from the number of measured  $L_{Amax}$ , the number of units (vehicles, aeroplanes, trains) passing by, to the number exceeding a certain  $L_{Amax}$  level (commonly indicated by  $NA_{xx}$ ;  $NA_{70}$  is the number of events higher than 70 dB).

### 1.3.4 CONVERSION BETWEEN INDICATORS

#### 1.3.4.1 Introduction

$L_{night}$  is defined as the 1 year  $L_{Aeq}$  (exposure to noise) over 8 hours outside at the most exposed façade. For the purpose of strategic noise mapping and reporting the height is fixed at 4 metres. As  $L_{night}$  is a relatively new definition and because the studies rarely cover such a long period, the research data are rarely expressed in  $L_{night}$ . The most frequently used noise descriptor in sleep research is the  $L_{Amax}$  or SEL near the sleeper. This means that a considerable amount of conversion work needs to be done if relations are to be expressed in  $L_{night}$ . There are four issues:

- conversion between SEL and  $L_{Amax}$
- conversion from instantaneous to long-term
- conversion from inside to outside
- conversion from (outside) bedroom level to most exposed façade.



Further background information on these issues is provided in section 1.3.5. This section details the conversions that are actually carried out.

#### 1.3.4.2 SEL to $L_{Amax}$

SEL is only used for aircraft noise in this report and, according to Ollerhead et al. (1992) from ground-based measurements, the following relation was found:

$$SEL = 23.9 + 0.81 * L_{Amax} \quad [1].$$

A more general approach can be used to estimate SEL for transportation noise.

If the shape of the time pattern of the sound level can be approximated by a block form, then  $SEL \approx L_{Amax} + 10 \lg t$ , where  $t$  (in seconds) is the duration of the noise event. This rule can be used, inter alia, for a long freight train that passes at a short distance. When  $t$  is in the range from 3 to 30 seconds, then SEL is 5–15 dB higher than  $L_{Amax}$ . For most passages of aircraft, road vehicles or trains, the shape of the time pattern of the sound level can be better approximated with a triangle. If the sound level increases with rate  $a$  (in dB per second), and thereafter is at its maximum for a short duration before it decreases with rate  $-a$ , then  $SEL \approx L_{Amax} - 10 \lg(a) + 9.4$ . Depending on the distance to the source, for most dwellings near transportation sources the rate of increase is in the order of a few dB per second up to 5 dB per second. When  $(a)$  is in the range from 9 dB to 1 dB per second, then SEL is 0–9 dB higher than  $L_{Amax}$ .

#### 1.3.4.3 Events to long-term

When the SEL values are known (if necessary after converting from  $L_{Amax}$ ) they can be converted to  $L_{night}$ . In general terms, the relation between  $L_{night}$  and SEL is:  
 $L_{night} = 10 * \lg \sum_i 10^{SEL_i/10} - 10 * \lg (T)$ .

If all (N) events have approximately the same SEL level, this may be reduced to:

$$L_{night} = SEL + 10 * \lg(N) - 70.2 \quad [2],$$

in which:

N = the number of events occurring in period T;

T = time during which the events occur in seconds. For a (night) year  $10 \lg(T)$  is 70.2.

The notation adheres to the END where the  $L_{night}$  is defined as a year average at the most exposed facade. Any reference to an inside level is noted as such, that is, as  $L_{night,inside}$ . In order to avoid any doubt the notation  $L_{night,outside}$  may be used, for instance in tables where both occur.

#### 1.3.4.4 Inside to outside

As the  $L_{night}$  is a year value, the insulation value is also to be expressed as such. This means that if the insulation value is 30 dB with windows closed and 15 dB with windows open, the resulting value is 18 dB if the window is open 50% of the time. If these windows are closed only 10% of the time, the result is little more than 15 dB. The issue is complicated by the fact that closing behaviour is, to a certain extent, dependent on noise level. When results about effects are expressed with indoor (that is, inside bedrooms) exposure levels, they need to be converted to  $L_{night}$ , in accordance with the END definition. The most important assumption is the correction for inside levels to outside levels. An average level difference of 21 dB has been chosen, as this takes into account that even in well-insulated houses windows may be open a large part of the year. In general:

$$L_{\text{night}} = L_{\text{night,inside}} + Y \text{ dB} \quad [3].$$

Y is the year average insulation value of the (bedroom) facade. In this report a default value of 21 dB is used (see also section 1.3.5). It should be stressed that this conversion is thought to be highly dependent on local building habits, climate and window opening behaviour.

#### 1.3.4.5 Most exposed facade

If an inside level is converted to an outside level with [3], it is assumed that this is equivalent to an  $L_{\text{night}}$  value on the most exposed facade. No information is available on bedroom position and use, so no explicit conversion factor can be given in this report.

This means that the effect estimated on the basis of  $L_{\text{night}}$  corresponds to an upper limit, because part of the bedrooms will be on a less exposed facade. If an estimate of the exposed population is based on a relation derived with [3], the actual prevalence will be less. From a practical point of view the most exposed facade safeguards protection in cases where there is a possibility that rooms can be swapped.

It should be pointed out that the above does not apply if a relation is based on  $L_{\text{night}}$  values which are directly measured or computed. These relations will show a large variation because of a misclassification effect, but they give a "correct" estimate of the prevalence of effects in the population. In other words, in some cases a low effect may be attributed to a high  $L_{\text{night}}$  because the bedroom is on the quiet side.

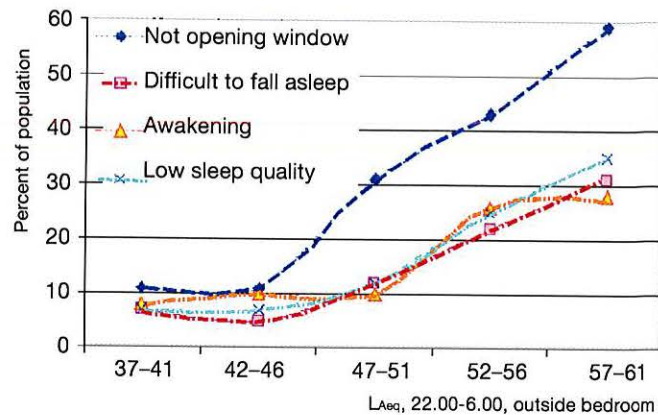
### 1.3.5 INSIDE/OUTSIDE DIFFERENCES

Night-time environmental noise affects residents mainly inside their homes. In order to protect residents inside their homes from noise from outside sources, attention should be focused on windows since they are generally the weakest points in the sound propagation path. Roofs must also be considered with regard to aircraft noise.

There are many types of window in the EU, varying from single thin panes within frames without additional insulation, to four-pane windows within insulated frames. The simplest types of facade have a sound reduction (from outside to inside) of usually less than 24 dB, and the most elaborate facades (built to cope with cold climates, for example), have sound reductions of more than 45 dB. In central Europe, most windows are double-glazed, mounted in a rigid and well-insulated frame. Their range of sound reduction is between 30 dB and 35 dB when closed.

When night-time environmental noise reaches high levels, residents tend to close their bedroom windows (cf. Langdon and Buller, 1977; Scharnberg et al., 1982; Schreckenberg et al., 1999; Diaz et al., 2001). The studies by Scharnberg et al. and Schreckenberg et al. found that more than 50% of bedroom windows are closed when outside road traffic noise levels exceed 55 dB ( $L_{\text{Aeq}}$ ). These findings have been replicated in Sweden, according to recent results from the Swedish soundscape research programme on road traffic noise (Fig. 1.7). Nevertheless, while residents with closed windows reported a reduction of sleep disturbances due to noise, they also reported an increase in sleep disturbances due to poor ventilation. Schreckenberg et al. (1999) report a much steeper increase in the incidence of closed windows when road traffic noise reaches high levels than is the case with increased levels of railway noise. Even when night-time noise levels reach 55 B, only 35% of the residents exposed to railway noise reported that they closed their windows at night.





**Fig. 1.7**  
Results from Swedish  
soundscape research  
programme on road  
traffic noise

Source: Öhrström, in European Commission, 2002a.

When windows are slightly open, outside sound levels are usually reduced by 10–15 dB. It should be kept in mind that most European residents want to keep their bedroom windows slightly open at night in order to provide proper ventilation (Scharnberg et al., 1982; Lambert and Plouhinec, 1985; Lambert and Vallet, 1994), and the WHO paper on community noise (WHO, 1999) also recommends that people should be able to sleep with their bedroom windows open.

Passchier-Vermeer et al. (2002) carried out detailed noise measurements inside and outside the bedroom and at the same time measured window position with sensors. The results (Table 1.3) showed that windows are fully closed only in 25% of the nights.

Window position	% nights	<b>Table 1.3</b> <b>Window positions during</b> <b>research period</b> <b>(April–November)</b>
Closed	25	
Slightly open	43	
Hand width	23	
Half open	5	
Fully open	4	

This results in average inside/outside differences of around 21 dB, with there being only a slight difference between single- and double-glazed windows (Table 1.4). The survey did not include dwellings which had been specifically insulated against noise. Nevertheless, there was a large variation in insulation values.

	Single-glazed window	Double-glazed window	<b>Table 1.4</b> <b>Average inside/outside</b> <b>differences in dB</b>
Average difference at night	21.3	22.2	

It should be stressed that this figure only applies to facades that have not been fitted with special appliances to reduce noise impact. To give an extreme example of where this general finding does not apply, rooms may be equipped with air conditioning so that windows can stay closed or could even be sealed. Less drastic provisions are sound-attenuated ventilation openings. Little is known, however, about the inhabitants' experiences (long-term use, appreciation) of these and other solutions. For example, sound-attenuated ventilation openings are sometimes blocked in order to cut out draughts.

### 1.3.6 BACKGROUND LEVEL

A simple definition of background level or “ambient noise” level is the noise that is not targeted for measurement or calculation. Background noise can interfere with the target noise in a number of ways. It can:

- mask the signal
- interact physically
- interact psychologically.

As this report is often dealing with low-level target noise, masking is an important issue. The other two interactions are more important in the domain of annoyance. Masking, however, is a complex process. The human auditory system is uncannily good at separating signals from “background”. Microphones (and the software behind them) have been slow to catch up, as the unsatisfactory results show when it comes to automatically recognizing aircraft in long-term unmanned measuring stations.

The rule of thumb that a noise can be considered masked if the signal is 10 dB below the background is only valid if the noises have the same frequency composition and if they actually occur at the same time. This is particularly important to stress where  $L_{Aeq}$  levels are compared: even a relatively continuous motorway of 50 dB cannot mask aircraft noise of 30 dB, because this may be composed of five aircraft arriving at an  $L_{Amax}$  of 57 dB. Neither can birdsong, because the frequency domains do not overlap.

Another factor relevant for this report is that background levels are lower at night-time than they are in the daytime. This is true for most man-made noises, but also for the natural background levels as wind speeds at night slow down.

Most levels mentioned in this report do not take background levels into account – explicitly. Where long-term  $L_{Aeq}$  levels are related to effects like hypertension and self-reported sleep disturbance, background levels are ignored, but they could obscure the effect at the lower end of the scale. This then influences the lowest level where an effect starts to occur.

In sleep laboratory studies the background level is kept as low as possible, around 30 dB. The background of the instrumentation is 20 dB.

In semi-field experiments it has been found that background noise levels inside bedrooms are very low, partly because people tend to choose their bedrooms on the quiet side of the building. This may have the side-effect of exposing children to higher levels.

### 1.3.7 CHOICE OF INDICATORS FOR REGULATORY PURPOSES

From the scientific point of view the correct choice for a noise indicator is its performance in predicting the effect. There are, however, a number of additional criteria which may influence the choice. Firstly, for different health end points different indicators could be suitable. Further considerations are of a more political nature, as mentioned in the *Position Paper* on EU noise indicators (European Commission, 2000). Indicators should also be easy to explain to the public – intuitively understandable, avoiding unnecessary breaks with current practice and enforceable. This is probably why in many countries  $L_{Amax}$  is a popular indicator: it has undeniable qualities in these areas.

This is also the case for  $L_{Aeq}$  indicators for short periods of, for example, one or a few hours in the middle of the night. Other fashionable indicators are those looking at numbers above a threshold.

For these indicators the relation between health end points and their values is either not well established, or the correlation between them and current indicators is high, or the correlation between the indicator and an effect is low.

## 1.4 EXPOSURE IN THE POPULATION

### 1.4.1 NOISE LEVELS

Surprisingly little information is available on the exposure of houses to night-time noise. It is possible that, in a few years time, the END will lead to the creation of a substantial database on these levels, but up till now only two countries have detailed data available (Table 1.5).

Country	$L_{night}$ in dB					Table 1.5 Percentage of dwellings per noise class of $L_{night}$ in dB
	40–45	46–50	51–55	56–60	61–65+	
Switzerland (Müller-Wenk, 2002)	–	24%	14%	7%	2%	
Netherlands (Nijland and Jabben, 2004)	25%	31%	19%	6%	1%	

Notwithstanding the obvious differences between these two countries, the data show a remarkable similarity.

A first result of the END (see Table 1.6) comes from a study into night regulations for (large) airports (Wubben and Busink, 2004).

Airport	Number of inhabitants	Number of night operations per year	Night operations as percentage of daytime operations	Table 1.6 Number of inhabitants within 45 $L_{night}$ contour
Amsterdam	21 863	23 462	5.8%	
Frankfurt	134 651	46 662	10.1%	
London	477 289	26 465	5.7%	
Paris	180 184	51 683	10.3%	

### 1.4.2 REPORTED NIGHT-TIME NOISE DISTURBANCE

Complaints about night-time exposure to noise are widespread and not exactly new: Roman writers used to complain about the racket in the streets at night (Juvenal, 160). Surprisingly, little detailed information is available today.

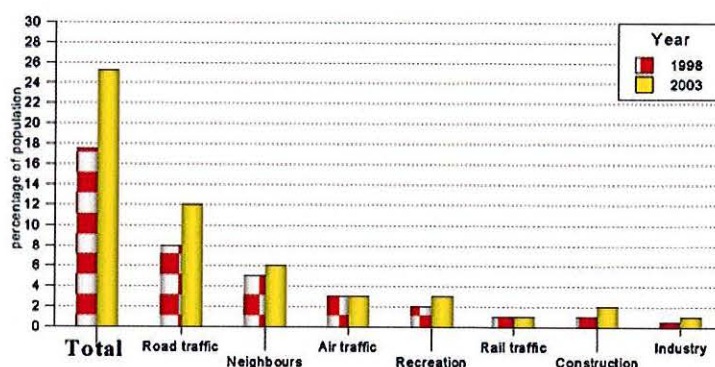
Nevertheless, data collected from a few Member States can help to give an impression of the order of magnitude of effects.



Fig. 1.8 shows the relative contributions to overall sleep disturbance caused by noise from different sources in the Netherlands. These data were derived from surveys in 1998 and 2003 (van Dongen et al., 2004) in which 4000 and 2000 people, randomly selected, were asked: "To what extent is your sleep disturbed by noise from [source mentioned]..." on a scale from 1 to 10. People recording the three highest points in the scale were considered "highly disturbed", according to an international convention. The totals are calculated from the number of people reporting serious sleep disturbance from one or more sources.

Unfortunately, comparable research data from other countries or regions is not available, and there is reason to believe that there may be considerable differences in the figures. Since this study is based on a survey conducted in the Netherlands, it is not representative for other Member States in the EU. General (not specific for night-time) annoyance data from Germany and the United Kingdom give an indication that similar numbers of people are affected.

**Fig. 1.8**  
Percentage of  
population highly  
disturbed by noise  
during sleep in the  
Netherlands



However, the fact that other noise nuisances may contribute significantly to overall sleep disturbance should not be overlooked. Further research on this topic is needed in order to gain an insight into the contribution of various noise sources to sleep disturbance.

## 1.5 CONCLUSIONS

The methods and criteria for deriving guidelines rest on well-established procedures from epidemiology. To relate the effects to the dose, standard metrics will be used wherever available. If possible, the values found in literature will be converted to avoid confusion. Most of the conversions are relatively straightforward and depend on physical laws; others, in particular the conversion between outside and inside levels, depend on local factors and should be used only if no other information is available.

Information about night-time noise exposure is relatively scarce, despite 10 EU Member States having limit values for night-time noise. The END could substantially increase this information (large-scale noise mapping is foreseen in 2007), increasing the demand for guidance.



## CHAPTER 2

# THE RELATION BETWEEN SLEEP AND HEALTH

*A night of quiet and repose in the profound silence of Dingley Dell, and an hour's breathing of its fresh and fragrant air on the ensuing morning, completely recovered Mr Pickwick from the effects of his late fatigue of body and anxiety of mind.*

*(Charles Dickens, The Pickwick Papers, 1836)*

## 2.1 SLEEP, NORMAL SLEEP, DEFINITIONS OF SLEEP DISTURBANCE, CHARACTERISTICS MECHANISMS, THE INSOMNIA MODEL

### 2.1.1 NORMAL SLEEP (OBJECTIVE MEASUREMENTS)

Sleep is part of living and, along with being awake, forms an inherent biological rhythm (Cooper, 1994). Normal sleep can be defined in an objective or subjective manner. The objective criteria are defined using a polysomnographic recording (PSG) of sleep, the method that measures different physiological functions during sleep. Minimal polygraphic requirements to measure sleep adequately include two channels of electroencephalography (EEG), one channel for the electrooculogram (EOG), and one channel for the submental electromyography (EMG). In routine PSG, additional channels are used to assess respiration, leg movements, oxygenation and cardiac rhythm (Ebersole and Pedley, 2003).

Scoring of sleep stages is usually done on an epoch-by-epoch basis, with a 30-second length used as a standard. Epochs are scored according to the guidelines of Rechtschaffen and Kales (1968). Each epoch is scored as the stage that occupies more than 50% of that epoch. Sleep can be divided into the following stages.

- Arousal is not a uniform concept and has been defined differently by different researchers. Commonly, the occurrence of alpha rhythms is required for EEG arousal. Depending on the additional requirements and on the length of time that the slower cortical rhythms are interrupted, arousals have been called, for instance, micro-arousal, minor arousal, EEG awakening or transient activation phases. The American Sleep Disorders Association (1992, 1997) devised a scoring system, taking sequences of 3–15 seconds into account for transient arousals which are not transferred to macroscopic behavioural awakening. Eleven further criteria must be met (see also Chapter 3, section 3.1.2).
- Vegetative arousals are activations of the sympathetic nervous system.
- Stage W corresponds to the waking stage and is characterized by alpha activity or low-voltage, mixed-frequency EEG activity. Rapid eye movements (REMs), eye blinks, and tonic EMG activity are usually present.
- Stage 1 is scored when more than 50% of an epoch is low-voltage, 2–7 Hertz (Hz) activity. Vertex waves may occur in late stage 1. Slow rolling eye movements lasting several seconds are routinely seen early in stage 1, but K complexes and sleep spindles are absent by definition. Tonic EMG activity is usually less than that of relaxed wakefulness.

- **Stage 2** requires the presence of sleep spindles or K complexes, and less than 20% of the epoch contains delta activity. Bursts of sleep spindles must last at least 0.5 seconds before they can be scored. K complexes are defined as biphasic vertex sharp waves with a total duration of greater than 0.5 seconds.
- **Stage 3** is scored when 20–50% of an epoch consists of delta activity that is 2 Hz or slower and is greater than 75  $\mu$ V in amplitude. Sleep spindles may or may not be present.
- **Stage 4** is scored when more than 50% of an epoch consists of delta activity that is 2 Hz or slower and is more than 75  $\mu$ V in amplitude. Reliable differentiation of stage 3 and stage 4 sleep is difficult by visual inspection, and most laboratories combine stages 3 and 4 into a single determination of slow-wave sleep (SWS).
- **Stage REM** is characterized by relatively low-voltage, mixed-frequency EEG activity with episodic REMs and absent or markedly reduced axial EMG activity. Phasic EMG activity may occur, but tonic activity must be at a level that is as low as, or lower than, that during any other time in the study. Sleep spindles and K complexes are absent. Series of 2- to 5- Hz vertex-negative “saw-tooth waves” occur, particularly just before phasic REM activity. The requirements to score sleep as REM sleep are: REMs, low or absent axial EMG, and typical mixed-frequency EEG recording that does not preclude the scoring of REM.

Movement time is scored when more than 50% of an epoch is obscured by movement artefact. Movement time must be preceded or followed by sleep and is thus distinguished from movement occurring during wakefulness.

Additional sleep values are determined from each sleep study and contribute to the clinical interpretation of the study. These additional variables include the following.

- **Recording time** is the time elapsed between “lights out” and “lights on” at the end of the study.
- **Total sleep time (TST)** is the total time occupied by stage 1, stage 2, SWS and REM sleep.
- **Sleep efficiency (SE)** is defined as total sleep time divided by recording time and is expressed as a percentage.
- **Sleep latency (SL)** is the time from “lights off” to the first epoch scored as sleep. Some authors prefer to use the first epoch of stage 2 in order to be more confident about identifying the onset of sustained sleep. However, when sleep is very disrupted, there may be an extended interval from recognition of stage 1 until an epoch that can be scored as stage 2.
- **REM latency** is the time from sleep onset (as described earlier) to the first time period scored as REM, minus any intervening epochs as wakefulness.
- **Sleep stage percentages** (% in stage 1, stage 2, SWS and REM sleep) are determined by dividing time recorded in each sleep stage by total sleep time.
- **Wake after sleep onset (WASO)** is time spent awake after sleep onset.



The objective criteria defining normal sleep are based on: sleep latency, total sleep time, sleep efficiency and the number of awakenings, including cortical arousals. However, all these parameters are age-related, sometimes also gender-related, and may vary from one individual to another.

Normal sleep has a clearly defined architecture that is relatively stable. Predictable changes in sleep architecture occur with age. Beginning in middle age, SWS becomes less prominent, the number of awakenings increase, and sleep efficiency decreases. Published information on normal sleep can serve as an outline for normal values in PSG (Williams, Karacan and Hirsch, 1974; see also Table 2.1), but each laboratory must study control subjects to identify any significant effects on sleep that result from differences in technique or environment (Ebersole and Pedley, 2003).

Sleep parameter (normal values)	20–29 years	40–49 years	60–69 years
TST (min)	419	389	407
Sleep efficiency (TST/TIB <sup>a</sup> )	95%	91%	90%
WASO	1%	6%	8%
Stage 1 (% of TST)	4%	8%	10%
Stage 2 (% of TST)	46%	55%	57%
SWS (% of TST)	21%	8%	2%
REM (% of TST)	28%	23%	23%
Sleep latency (min)	15	10	8

<sup>a</sup> Time in bed

Source: Williams, Karacan and Hirsch, 1974.

**Table 2.1**  
Average normal values for  
adults of different ages

Passchier-Vermeer (2003a) reports that subjects not exposed to loud night noise typically report waking up one and a half to two times during an average sleep period, while the number of EEG awakenings including cortical arousals averages 10–12 per night (Table 2.2).

Subjects not exposed to loud night noise	Subjective report of number of awakenings	Number of EEG awakenings
Normal adult subjects	1.5–2	10–12

**Table 2.2**  
Parameters of normal  
sleep

Source: Passchier-Vermeer, 2003a.

Night arousals result in fragmented sleep, which in turn leads to excessive daytime sleepiness (EDS). The gold standard for the assessment of EDS is the multiple sleep latency test (MSLT) (see Table 2.3), which provides an objective quantification of “sleepiness”. The preceding night’s sleep requires the PSG to ensure adequate sleep and to exclude sleep disruption. During the day, four or five nap times are scheduled every two hours. For each scheduled nap time the patient lies down and assumes a comfortable sleep position with the technician’s instructions to “close your eyes and attempt to sleep”. Each nap is terminated 20 minutes after the nap time started if no sleep occurred; or after 15 minutes of continuous sleep as long as sleep onset (SO) criteria are met before the end of 20 minutes; or after 20 minutes if the patient awakens, even if the patient has been asleep less than 15 minutes. The patient is instructed to stay awake between the nap periods.

**Table 2.3**  
Mean sleep latency

Group	MSLT (min)	No REM SO (% of group)	1 REM SO (% of group)	2 or more REM SO (% of group)
Narcoleptics	2.9 ± 2.7	2	2	96
EDS (non-narcoleptic, non-sleep apnoeic)	8.7 ± 4.9	92	8	0
Controls	13.4 ± 4.3	100	0	0

Source: Ebersole and Pedley, 2003.

## 2.1.2 DEFINITIONS OF DISTURBED SLEEP

Sleep disorders are described and classified in the International Classification of Sleep Disorders (ICSD) (American Academy of Sleep Medicine, 2005).

When sleep is permanently disturbed and becomes a sleep disorder, it is classified in the ICSD 2005 as “environmental sleep disorder”. Environmental sleep disorder (of which noise-induced sleep disturbance is an example) is a sleep disturbance due to a disturbing environmental factor that causes a complaint of either insomnia or daytime fatigue and somnolence. Secondary deficits may result, including deficits in concentration, attention and cognitive performance, reduced vigilance, daytime fatigue, malaise, depressed mood and irritability. The exact prevalence is not known. Fewer than 5% of patients seen at sleep disorder centres receive this diagnosis. The sex ratio is not known. The disorder may occur at any age, although the elderly are at more risk for developing this condition (American Academy of Sleep Medicine, 2005).

### 2.1.2.1 Insomnia

In the ICSD 2005 the section on insomnia includes a group of sleep disorders all of which have in common the complaint of insomnia (adjustment insomnia, psychophysiological insomnia, paradoxical insomnia, idiopathic insomnia, etc.), defined as repeated difficulty with sleep initiation, duration, consolidation or quality that occurs despite adequate time and opportunity for sleep and results in some form of daytime impairment. Insomnia is a symptom that often arises from primary medical illness, mental disorders and other sleep disorders, but may also arise from abuse or exposure. However, the general criteria for insomnia are the same for all subgroups of insomnias.

### 2.1.2.2 General criteria for insomnia

- A. A complaint is made concerning difficulty initiating sleep, difficulty maintaining sleep, waking up too early or sleep that is chronically non-restorative or poor in quality. In children, the sleep difficulty is often reported by the carer and may consist of observed bedtime resistance or inability to sleep independently.
- B. The above sleep difficulty occurs despite adequate opportunity and circumstances for sleep.
- C. At least one of the following forms of daytime impairment related to the night-time sleep difficulty is reported by the patient:
  - fatigue or malaise
  - attention, concentration, or memory impairment
  - social or vocational dysfunction or poor school performance
  - mood disturbance or irritability



- daytime sleepiness
- motivation, energy, or initiative reduction
- proneness to errors or accidents at work or while driving
- tension, headaches, or gastrointestinal symptoms in response to sleep loss
- concerns or worries about sleep.

Defining the cause of a sleep/wake disturbance in an insomnia patient is a complex task since it is often multifactorial. In fact, a confluence of factors that support multiple insomnia diagnoses may be judged important in many patients with insomnia. Although selection of a single diagnosis is preferable and this selection may be appropriate, such a selection should not necessarily imply the absence of a subset of factors relevant to an alternate diagnosis. When criteria for multiple insomnia diagnosis are met, all relevant diagnosis should be assigned.

### 2.1.2.3 *Environmental sleep disorder*

In the ICSD 2005, environmental sleep disorder is listed in the category of “other sleep disorders”. Noise-induced sleep disturbance is one of the disturbing environmental factors that cause a complaint of either insomnia or daytime fatigue and somnolence.

The diagnostic criteria for environmental sleep disorder are the following.

- A. The patient complains of insomnia, daytime fatigue or a parasomnia. In cases where daytime fatigue is present, the daytime fatigue may occur as a result of the accompanying insomnia or as a result of poor quality of nocturnal sleep.
- B. The complaint is temporally associated with the introduction of a physically measurable stimulus or environmental circumstance that disturbs sleep.
- C. It is the physical properties, rather than the psychological meaning of the environmental factor, that accounts for the complaint.
- D. The sleep disturbance is not better explained by another sleep disorder, medical or neurological disorder, mental disorder, medication use or substance use disorder.

The prevalence of environmental sleep disorder is not known. Fewer than 5% of patients seen at sleep disorder centres receive this diagnosis.

International standardization and quantification for measurement of the depth of sleep is based on Rechtschaffen and Kales criteria from 1968. Sleep is divided into 30-second epochs, and a phase is only assessed if the specific features are evident for more than 50% of the epoch length. For example, wakefulness is scored when at least 15 seconds of continuous awakening is present. Arousal reactions not leading to macroscopic awakening were not included in the definition by Rechtschaffen and Kales. With the arousals as described by the American Sleep Disorders Association (1992) it is possible to display sub-vigilant sleep fragmentation, caused by intrinsic sensory and autonomic alarm reactions. An arousal index providing the arousal density (events per hour of sleep) was taken as a measure of the degree of severity. In one hour, 10–20 arousals are considered as normal in healthy adults. However, the use of EEG arousals with the American Sleep Disorders Association definition provides no sufficient explanation of daytime sleepiness (Ali, Pitson and Stradling 1996; Ayas et al., 2001) unless they are accompanied by vegetative arousals.

Regarding noise, different vigilance level assessments in various functional systems are important. Dumont, Montplaisir and Infante-Rivard (1988) proposed investigations of



vegetative, motor and sensory functions independently of each other. One of the possible factors indicating disturbed sleep is a vegetative arousal index. A vegetative arousal index of more than 30 per hour is certainly considered as serious, more than 20 per hour as intermediate and more than 10 as a light form of sleep disorder.

With respect to insomnia (section 2.1.2), there is the possibility of misclassification if the general practitioner (GP) overlooks excessive noise as the possible cause of the complaint. There is also the possibility that the insomnia is aggravated by noise.

### 2.1.3 CONCLUSIONS

Published information on normal sleep can serve as an outline for normal values in PSG. However, these values are only informative, because each sleep laboratory must study control subjects to identify any significant effects on sleep that result from differences in technique or environment. Excessive daytime sleepiness is a consequence of disturbed night sleep and can be objectively assessed by MSLT, which provides an objective quantification of “sleepiness”.

## 2.2 LONG-TERM HEALTH RISK MEDIATED BY SLEEP DISTURBANCES

### 2.2.1 STRESSORS, NEUROBEHAVIOURAL DATA AND FUNCTIONAL NEUROIMAGING

It is generally accepted that insufficient sleep and particularly sleep loss has a great influence on metabolic and endocrine functions (Spiegel, Leproult and van Cauter, 1999), as well as on inflammatory markers, and contributes to cardiovascular risk. C-reactive protein (CRP) as a major marker of the acute phase response to inflammatory reaction promotes secretion of inflammatory mediators by vascular endothelium and may be therefore directly involved in the development of atherosclerotic lesions. CRP as a risk predictor of strokes and heart attacks linearly increases with total and/or partial sleep loss (Meier-Ewert et al., 2004).

An additional factor, closely linked to cardiovascular health, glucose regulation and weight control, is leptin. Leptin is one of the major regulators of energy homeostasis and its circadian profile interacts closely with sleep.

Secretion of leptin increases at night and decreases during the day. A decreased leptin level, that is connected with sleep loss, increases appetite and predisposes to weight gain, impaired glucose tolerance and impaired host response.

Other studies have focused on how sleep loss affects neurobehavioural functions, especially neurocognitive performance. Functional brain imaging and EEG brain mapping studies show that the patterns of functional connectivity between brain regions, evident in the performance of specific cognitive tasks, are altered by sleep loss (NCSDR, 2003). According to this finding, the maintenance of sustained performance during sleep loss may depend upon regional functional plasticity.

Cumulative waking, neurocognitive deficits and instability of state that develop from chronic sleep loss have a basis in a neurobiological process that can integrate homeostatic pressure for sleep across days. Increased efforts have helped to determine the roles of REM and non-REM sleep in memory.

Functional brain imaging techniques, such as positron emission tomography (PET), functional magnetic resonance imaging (fMRI), magnetic resonance spectroscopy (MRS), single photon emission computed tomography (SPECT) and magneto-electroencephalography (MEG), have recently been analysed in a study of sleep and waking (NCSDR, 2003). These techniques allow the measurement of metabolic and neurochemical activity throughout the brain, and can reveal dynamic patterns of regional cerebral activity during various brain states, including stages of sleep and levels of alertness during wakefulness or during functional challenge. These techniques can also help identify both normal and abnormal sleep/wake processes.

In the last five years, functional neuroimaging techniques (particularly PET) have revealed that non-REM sleep is associated with the deactivation of central encephalic regions (brainstem, thalamus, basal ganglia) and multimodal association cortices (for instance, prefrontal and superior temporal/inferior parietal regions). REM sleep is characterized by reactivation of all central encephalic regions deactivated during non-REM sleep except the multimodal association areas. PET studies during sleep-deprived wakefulness have revealed regional cerebral deactivations that are especially prominent in prefrontal and inferior parietal/superior temporal cortices, and in the thalamus. This pattern is consistent and helpful in explaining the nature of cognitive performance deficits that occur during sleep loss. As revealed by means of fMRI techniques during cognitive task performance, the maintenance of performance following sleep loss may be a function of the extent to which other cortical brain regions can be recruited for task performance in the sleep-deprived state.

PET, SPECT and fMRI studies have revealed, in depressed patients, initially elevated activation in anterior cingulate and medial orbital cortices (NCSDR, 2003). In these patients, sleep deprivation reduces this regional hyperactivation, and improvements in mood are a function of the extent to which this activity is reduced. These studies point to possible mechanisms by which antidepressant drugs may exert their effects. Further research should be oriented towards neuroimaging and measurements of changes in the brain's metabolic activity at the neurotransmitter level.

## **2.2.2 SIGNALS MEDIATED BY A SUBCORTICAL AREA (THE AMYGDALA), THE ROLE OF STRESS HORMONES IN SLEEP DISTURBANCE AND THEIR HEALTH CONSEQUENCES**

Experimental as well as clinical studies (Waye et al., 2003; Ising and Kruppa, 2004) showed that the first and fastest signal of stressors introduced by noise is detected and mediated by a subcortical area represented by the amygdala while the stress response to noise is mediated primarily by the hypothalamus-pituitary-adrenal (HPA) axis. A major intrinsic marker of the circadian rhythm is in the level of circulating corticosteroids derived from activity within the HPA axis. A protracted stress response with activation of the HPA axis is a major physiological response to environmental stressors. The cortisol response to awakening is an index of adrenocortical activity, and long-term nocturnal noise exposures may lead, in persons liable to be stressed by noise, to permanently increased cortisol concentration above the nor-



mal range. The hypothesis that an increased risk of cardiovascular diseases is connected with stress concepts is generally accepted (Ekstedt, Åkerstedt and Soderstrom, 2004; Ising and Kruppa, 2004). Stress reactions may lead to derangement of normal neurovegetative and hormonal processes and influence vital body functions. Cardiovascular parameters such as BP, cardiac function, serum cholesterol, triglycerides, free fatty acids and haemostatic factors (fibrinogen) impede the blood flow through increased viscosity and presumably blood sugar concentration as well. Insulin resistance and diabetes mellitus, stress ulcers and immune system deficiency are also frequent consequences of stress reaction. Disturbed sleep may lead to immunosuppression and diminished protein synthesis (Horne, 1988).

As well as nonspecific effects of the stress response on the functioning of the immune system, there is considerable evidence for a relation between sleep, especially SWS, and the immune system (Brown, 1992). This evidence includes surges of certain immune parameters and growth hormones at onset of SWS, correlation of non-REM sleep, total sleep time and sleep efficiency with natural killer cell activity, and correlation of SWS with recovery from infections. These data, taken together with information on the effect of intermittent transportation noise on SWS during the first sleep cycles and overnight, suggest that the immune response could also be impacted directly by environmental noise during sleep (Carter, 1996).

### **2.2.3 SLEEP RESTRICTION, ENVIRONMENTAL STRESSORS (NOISE) AND BEHAVIOURAL, MEDICAL AND SOCIAL HEALTH CONSEQUENCES OF INSUFFICIENT SLEEP: RISK OF MORBIDITY AND MORTALITY**

Sleep restriction due to environmental stressors leads to primary sleep disorders, but health is also influenced by the consequence of stress response to noise mediated by the HPA axis and/or by restriction of specific sleep stages (see above).

Sleep restriction leads, in approximately 40% of affected subjects, to daytime sleepiness that interferes with work and social functioning. Excessive daytime sleepiness is thus a major public health problem, as it interferes with daily activities, with consequences including cognitive problems, motor vehicle accidents (especially at night), poor job performance and reduced productivity (Lavie, Pillar and Malhotra, 2002). In the last decade, experimentally based data have been collected on chronic restriction of sleep (by 1–4 hours a night), accumulating daytime sleepiness and cognitive impairment. Most individuals develop cognitive deficits from chronic sleep debt after only a few nights of reduced sleep quality or quantity. New evidence suggests additional important health-related consequences of sleep debt related to common viral illnesses, diabetes, obesity, heart disease, depression and other age-related chronic disorders.

The effects and consequences of sleep deprivation are summarized in Table 2.4 (Lavie, Pillar and Malhotra, 2002).

The relationship between sleep quantity and quality and estimates of morbidity and mortality remains controversial. Epidemiological data (NCSDR, 2003) suggest that habitually short sleep (less than 6 hours sleep per night) is associated with increased mortality. Epidemiological studies in recent years elucidated, however, that too much sleep is a problem as well. Kripke et al. (2002) evaluated a questionnaire study of 1.1 million men and women aged 30–102 years and found the lowest mortality risk between respondents sleeping 7 hours per night.

Type	Short-term	Long-term
Behavioural	Sleepiness Mood changes Irritability and nervousness	Depression/mania Violence
Cognitive	Impairment of function	Difficulty in learning new skills Short-term memory problems Difficulty with complex tasks Slow reaction time
Neurological	Mild and quickly reversible effects	Cerebellar ataxia, nystagmus, tremor, ptosis, slurred speech, increased reflexes, increased sensitivity to pain
Biochemical	Increased metabolic rate Increased thyroid activity Insulin resistance	Decreased weight despite increased caloric intake (in animals) Diabetes, obesity (in humans)
Others	Hypothermia Immune function impairment	Susceptibility to viral illness

**Table 2.4**  
**Consequences of sleep deprivation**

Mortality risk significantly increased when sleep duration was less than 6 or higher than 8 hours per night. Other authors have also published similar results (Patel et al., 2004; Tamakoshi and Ohno, 2004). Patel et al. (2004) in a prospective study of sleep duration and mortality risk in 5409 women confirmed previous findings that mortality risk is lowest among those sleeping 6–7 hours per night. The mortality risk for death from other causes significantly increased in women sleeping less than 5 and more than 9 hours per night. It is not clear how the length of sleep can increase this risk, although animal evidence points to a direct link between sleep time and lifespan (see section 2.5 in this chapter). Up to now, no epidemiological prospective study has been published that examines the relationship between sleep and health outcomes (morbidity and mortality) with subjective and objective estimates. Recent studies, however, show that sleep duration of least 8 hours is necessary for optimal performance and for prevention of daytime sleepiness and accumulation of sleep debt.

Environmental stressors, including noise, mostly cause insomnia. Insomnia also involves daytime consequences, such as tiredness, lack of energy, difficulty concentrating and irritability. A reasonable prevalence estimate for chronic insomnia in the general population is about 10%; for insomnia of any duration or severity this rises to between 30% and 50%, and incidence increases with ageing. In the course of perimenopausal time, women are particularly vulnerable to developing this complaint. The major consequences and co-morbidity of chronic insomnia (see Table 2.5) consist of behavioural, psychiatric and medical problems. Several studies also report a higher mortality risk (Zorick and Walsh, 2000).



**Table 2.5**  
**Consequences of**  
**chronic insomnia**

Type	Consequence
Behavioural	Poor performance at work, fatigue, memory difficulties, concentration problems, motor vehicle accidents
Psychiatric	Depression, anxiety conditions, alcohol and other substance abuse
Medical	Cardiovascular, respiratory, renal, gastrointestinal, musculoskeletal disorders Obesity Impaired immune system function
Mortality	Increased risk is reported

#### 2.2.3.1 Behavioural consequences

Transient (short-term) insomnia is usually accompanied by spells of daytime sleepiness and performance impairment the next day. Persistent (long-term) insomnia tends to be associated with poor performance at work, fatigue, memory difficulties, concentration problems and twice as many fatigue-related motor vehicle accidents as in good sleepers.

#### 2.2.3.2 Psychiatric conditions

Epidemiological research indicates that the prevalence of any psychiatric disorder is two or three times higher in insomniacs. The risk of depression as a co-morbid state appears to be particularly strong, being approximately four times more likely in insomnia patients. Furthermore, insomnia may be an early marker for psychiatric disorders such as depression, anxiety conditions and alcohol abuse. Anxiety has been quite commonly found in insomniacs compared with the general population. About 25–40% of insomnia patients are estimated to have significant anxiety, and the abuse of alcohol and other substances is increased in insomniacs relative to good sleepers (Ford and Kamerow, 1989). Samples of unselected psychiatric patients have about a threefold increase in the frequency of insomnia compared with healthy control subjects, and the severity of the condition correlates with the intensity of the psychiatric symptoms. Among samples of outpatients who consulted their GPs for insomnia, about 50% presented with psychiatric conditions, and about half of these patients were probably depressed (Zorick and Walsh, 2000).

#### 2.2.3.3 Medical consequences

Insomnia has been statistically associated with various medical conditions, including disorders of the cardiovascular, respiratory, gastrointestinal, renal and musculoskeletal systems. A large series of insomniac patients showed that poor sleepers are more than twice as much at risk of ischaemic heart disease (IHD) as good sleepers (Hyypä and Kronholm, 1989). Insomnia patients were also shown (Irwin, Fortner and Clark, 1995) to have impaired immune system function. Keith et al. (2006) hypothesize a connection between sleep deficit as one of the possible factors to explain the rise in obesity. Hormone changes and animal experiments apparently support this.

#### 2.2.3.4 Mortality risk

Only a few epidemiological studies deal with mortality in insomniacs. According to Kripke et al. (1979), reduced sleep time is a greater mortality risk than smoking, hypertension and cardiac disease. Higher death rates are also reported among short sleepers. In this respect, however, further systematic investigation of the link between insomnia, short sleep and death is desirable.



## 2.3 RISK GROUPS

Risk groups are people who may be either sensitive (showing more reaction to a stimulus than the average), are more exposed (also called vulnerable) or both.

### 2.3.1 HEALTH EFFECTS OF DISTURBED SLEEP IN CHILDREN

Although children appear to tolerate a single night of restricted sleep with no detrimental effect on performance of brief tasks, perhaps more prolonged restriction and prolonged tasks similar to those required in school would show negative effects. In addition, as children seem to require more time to recuperate fully from nocturnal sleep restriction than adults (Carskadon, Harvey and Dement, 1981a), with additional nights of partial sleep deprivation, cumulative sleepiness might become a significant problem.

Empirical data that directly address the effects of repeated sleep loss on children's mood or cognitive function are sparse. A range of clinical and observational data support a general picture that inadequate sleep results in tiredness, difficulties in focusing attention, low thresholds for negative reactions (irritability and easy frustration), as well as difficulty in controlling impulses and emotions. In some cases, these symptoms resemble attention-deficit hyperactivity disorder (ADHD).

Environmental noise experienced at home during night-time is a sometimes unpredictable and most often discontinuous event (for example traffic noise, aircraft or train noise, a noisy environment for other reasons, for instance proximity with a discotheque, etc.), that might lead to sleep disruption without leading to behavioural awakenings through the alteration of sleep microstructure, in a similar manner as other sleep disturbing events such as respiratory disturbances.

Therefore, in respect of clinical settings, we can assume that, in children, an experimental model for the consequences of noise can be represented by respiratory disturbances during sleep, such as snoring, upper airway resistance syndrome (UARS) or obstructive sleep apnoea syndrome (OSAS), either for the noise produced by snoring or for the effects on the arousal system and sleep microstructure.

For this reason, this section describes the well-studied effects of sleep breathing disorders on children's health and then evaluates the indicators of sleep disruption from the point of view of sleep microstructure.

In the literature few data on the medium- and long-term effects of disturbed sleep in children are available from the longitudinal point of view. Most reports focused on respiratory disturbances during sleep as a theoretical model to evaluate the long-term effects of disturbed sleep in children. This review reports on the medium- and long-term negative consequences of disturbed sleep on cognitive functioning, behaviour, mental health, growth and the cardiovascular system.

#### 2.3.1.1 *Sleep deprivation in children*

The effects of sleep deprivation were evaluated in children. The findings only indirectly pertain to this general report, although repeated noise-induced sleep disruption favours sleep deprivation.

In another study, 15 healthy infants aged 78 $\pm$ 7 days were studied during two nights: one night was preceded by sleep deprivation (kept awake for as long as pos-

sible beyond their habitual bedtime: median onset 150 min; range 0–210 min) (Thomas et al., 1996). Of the 15 children, 13 slept supine, 12 were breastfed and 4 were from smoking parents. Following sleep deprivation, infants maintained a greater proportion of quiet sleep (44% vs. 39%;  $p=.002$ ). There was no measurable change in arousal propensity by either graded photic (stroboscope) or auditory stimuli (1 kHz pure tone, delivered in the midline of the cot, from 73 dB and increased in 3 dB steps to 100 dB) during quiet sleep.

Forty-nine Finnish children (26 boys/23 girls) aged 7–12 years were interviewed together with their parents and school teachers, and recorded for 72 hours with a belt-worn activity monitor during weekdays.

The objectively measured true sleep time was associated with psychiatric symptoms reported by a teacher. The decreased amount of sleep was associated more with externalizing than internalizing types of symptoms (aggressive and delinquent behaviour, attention, social, and somatic problems) (Aronen et al., 2000).

In a survey, it was also shown that out of 100 Belgian school children, aged between 9 and 12 years, those with poor sleep (insomnia) were also showing more frequent poor school performance (failure to comply with expected grades) than good sleepers. The relation between poor sleep and a noisy environment was, however, not evaluated (Kahn et al., 1989).

#### 2.3.1.2 *Neurocognitive manifestations*

Several studies in adults have shown that sleep fragmentation and hypoxaemia can result in daytime tiredness and loss of concentration, retrograde amnesia, disorientation, morning confusion, aggression, irritability, anxiety attacks and depression. One could hypothesize that sleep fragmentation and hypoxaemia would affect the neuropsychological and cognitive performance also in children, where the impact of abnormal sleep may be even greater than in adults. In fact, neurocognitive and behavioural deficits and school problems have been reported recently in children with sleep-related obstructive breathing disorders (SROBD).

#### 2.3.1.3 *Attention capacity*

This represents the ability to remain focused on a task and appropriately attend to stimuli in the environment. Taken together the studies to date indicate that children with SROBD are less reflective, more impulsive, and show poorer sustained and selective attention. Blunden et al. (2000) reported that, compared to 16 controls, 16 children with mild SROBD showed reduced selective and sustained attention. Owens-Stively et al. (1997) suggested a dose-response in attention-impulsivity with moderate to severe obstructive sleep apnoea syndrome (OSAS) children showing greater deficits than mild OSAS children. Importantly, early treatment showed that attention deficits in children with OSAS are reversible (Guilleminault et al., 1982b). In another study, 12 children with moderate to severe OSAS showed a significant reduction in inattention and an improvement in aggressive and hyperactive behaviours and vigilance after surgical treatment (Ali, Pitson and Stradling, 1996).

#### 2.3.1.4 *Memory*

Rhodes et al. (1995) found inverse correlations between memory and learning performance and the apnoea hypopnea index in 14 morbidly obese children. Smaller deficits were observed by Blunden et al. (2000), who found in their sample of children with mild SROBD that mean global memory performance was in the lower end of the normal range compared to controls.



A recent study using actigraphy in normal school-age children showed that lower sleep efficiency and longer sleep latency were associated with a higher percentage of incorrect responses in working memory tasks; shorter sleep duration was associated with performing tasks at the highest load level only. Also, controlling for age, gender, and socioeconomic status, sleep efficiency and latency were significantly associated with the mean incorrect response rate in auditory working memory tasks. This study showed that sleep quality (evaluated as sleep efficiency =  $100 \times [\text{sleep} + \text{light sleep}] / \text{duration}$ ) is more strongly associated with performance in working memory tasks than sleep duration, suggesting that in assessing sleep, attention should be directed not only at the amount of sleep but also at sleep quality.

#### 2.3.1.5 *Intelligence*

Inspection of the mean IQ scores reported in the study by Rhodes et al. (1995) suggested that their sample of five obese children with moderate to severe OSAS performed in the borderline range whereas controls performed in the normal range. Blunden et al. (2000) showed smaller deficits in children with mild SROBD whose mean verbal and global IQ were in the lower end of the normal range.

It remains unclear as to whether the putative negative effects of SROBD on intelligence are global in nature or confined to specific areas such as verbal rather than performance or visuospatial intelligence and whether these impairments can be reversed.

#### 2.3.1.6 *Learning and school performance*

It has been widely reported (Stradling et al., 1990; Guilleminault et al., 1996; Richards and Ferdman, 2000) that children with SROBD show reduced academic performance and learning.

Weissbluth et al. (1983) found that poor academic achievers had a higher prevalence of night-time snoring (38% vs. 21%) and breathing difficulties (13% vs. 6%). Out of 297 children with SROBD (22% snorers and 18% sleep-associated gas exchange abnormalities), 40% were in the lowest 10th percentile of academic performance (Gozal, 1998) and SROBD in early childhood may continue to adversely affect learning in later years (Gozal and Pope, 2001). Gozal (1998) found in his sample of poor academic achievers that school grades improved post-adenotonsillectomy in treated but not untreated children.

As well as those with SROBD, healthy normal children with fragmented sleep (measured by actigraphy) also showed lower performance on neurobehavioural functioning (NBF) measures, particularly those associated with more complex tasks, and also had higher rates of behavioural problems (Sadeh, Gruber and Raviv, 2002). Furthermore, in normal children without sleep disorders, modest sleep restriction can also affect children's NBF. Sadeh, Gruber and Raviv (2003) monitored 77 children for 5 nights with activity monitors. On the third evening, the children were asked to extend or restrict their sleep by an hour on the following three nights. Their NBF was reassessed on the sixth day following the experimental sleep manipulation and showed that sleep restriction led to improved sleep quality and to reduced reported alertness.

These studies suggest that fragmented sleep or insufficient sleep is highly relevant during childhood and that children are sensitive to modest alterations in their natural sleep duration.

Early reports documented that untreated OSAS can have long-term negative effects, such as failure to thrive, cor pulmonale and mental retardation. These severe consequences are less common now due to early diagnosis and treatment, but recent reports have focused on other long-term effects mainly related to neurocognitive deficits, such as poor learning, behavioural problems and ADHD (Marcus, 2001).

Gozal and Pope (2001) tried to determine the potential long-term impact of early childhood snoring. Analysing questionnaires of 797 children in a low academic performance group (LP) and 791 in a high academic performance (HP) group, they found that frequent and loud snoring during early childhood was reported in 103 LP children (12.9%) compared with 40 HP children (5.1%). Therefore, children with lower academic performance in middle school are more likely to have snored during early childhood and to require surgery for snoring compared with better performing schoolmates. These findings suggest that children who experienced sleep-disordered breathing during a period traditionally associated with major brain growth and substantial acquisition of cognitive and intellectual capabilities may suffer from a partially irreversible compromise of their *a priori* potential for academic achievement. Three major components that result from the intermittent upper airway obstruction that occurs during sleep in children could theoretically contribute to such neurocognitive deficits, namely episodic hypoxia, repeated arousal leading to sleep fragmentation and sleep deprivation, and periodic or continuous alveolar hypoventilation.

Schooling problems may underlie more extensive behavioural disturbances such as restlessness, aggressive behaviour, EDS and poor neurocognitive test performances. Nearly 20–30% of children affected by OSAS or loud and frequent snoring show important signs of behavioural problems such as inattention and hyperactivity. Problems similar to symptoms of ADHD are linked to the presence of repeated sleep arousals, and intermittent hypoxic events, inducing a lack of behavioural inhibition with negative implications for working memory, motor control and self-regulation of motivation and affect.

In contrast with these data, Engle-Friedman et al. (2003) recently found a significant improvement of functions, at least in mild to moderate OSAS, when measured several months following an adenotonsillectomy, but they confirmed that their results could not rule out the possibility, even after treatment, of partial irreversible damage to academic function that may be detected only later in life. In addition, they stated that adults who also had deficits of neurocognitive executive functions related to the prefrontal area failed to improve significantly after treatment.

The negative long-term effects may be mediated by the irreversible alteration of the prefrontal cortex (PFC) and be related to structural changes of the brain as a consequence of both hypoxaemia and sleep fragmentation induced by OSAS or other pathologies affecting sleep.

In a recent report concerning OSAS adults, Macey et al. (2002) demonstrated grey matter loss in cerebral sites involved in motor regulation of the upper airway as well as in areas contributing to cognitive function (frontal and parietal cortex, temporal lobe, anterior cingulate, hippocampus and cerebellum). It can be argued that, in critical stages of brain development (that is, in childhood), these effects can lead to even more severe consequences, which could explain the negative long-term effects.

It is speculative to think that the remodelling of the brain could also be mediated by sleep and, therefore, sleep fragmentation could affect the process of brain plasticity (that is, the capacity of the brain to modify its structure and function over time). Recent studies show-



ing experience-dependent gene-expression of gene *zif-268* during paradoxical sleep in rats exposed to a rich sensorimotor environment, and the role of sleep in enhancing the remodelling of ocular dominance in the developing visual cortex are also in line with the hypothesis that sleep affects neuronal plasticity and memory processes (Peigneux et al., 2001).

#### 2.3.1.7 Neurobehavioural manifestations

Behavioural disturbances are common in children with SRODB, with higher prevalence rates of both internalized (for instance being withdrawn, shy, anxious and psychosomatic) and externalized (for instance impulsivity, hyperactivity, aggression and delinquency) problematic behaviours (Blunden, Lushington and Kennedy, 2001). The most frequently documented problematic behaviour in children with SRODB is attention deficit hyperactivity with a prevalence rate of 20–40% (Weissbluth et al., 1983; Ali, Pitson and Stradling, 1993). Conversely, children with ADHD showed a high prevalence rate of snoring (Chervin et al., 1997) and a co-diagnosis of ADHD has been reported in 8–12% of children with OSAS (O'Brien and Gozal, 2002).

A few studies have documented that children with sleep disorders tend to have behavioural problems similar to those observed in children with ADHD. A survey of 782 children documented daytime sleepiness, hyperactivity, and aggressive behaviour in children who snored, with 27% and 38% of children at high risk for a sleep or breathing disorder displaying clinically significant levels of inattention and hyperactive behaviour, respectively (Ali, Pitson and Stradling, 1994).

At 3 years of age children with persistent sleep problems ( $n = 308$ ) were more likely to have behaviour problems, especially tantrums and behaviour management problems (Zuckerman, Stevenson and Bailey, 1987).

In a study of 16 children with a mean age of  $12 \pm 4$  years suffering from chronic pain due to juvenile rheumatoid arthritis and secondary poor sleep, polysomnographic recordings showed poorer night-time sleep, longer afternoon naptime and more daytime sleepiness than normal values from the literature (Zamir et al., 1998). In a school survey of children aged 9–12 years ( $n = 1000$ ), those with poor sleep (insomnia for more than 6 months) had poorer school performance, defined as failure to comply with expected grades, than good sleepers. Their learning problems were tentatively attributed to the long-term effect of poor sleep (Kahn et al., 1989).

A questionnaire administered to children aged 4–12 years ( $n = 472$ ) showed a relation between sleep problems and tiredness during the day (Stein et al., 2001).

In children aged 9–12 years ( $n = 77$ ), shortening sleep by one hour was associated with reduced alertness and significant lowering of neurobehavioural functioning (Sadeh, Gruber and Raviv, 2003). In school-age children ( $n = 140$ ) recorded at home with an actigraph, a significant relation was shown between the presences of fragmented sleep, daytime sleepiness and lower performance in neurobehavioural functioning evaluated by various performance tests (Sadeh, Gruber and Raviv, 2000). These children also had higher rates of behavioural problems, as reported by their parents (Sadeh, Gruber and Raviv, 2002).

In Finland, children aged 7–12 years ( $n = 49$ ) were interviewed together with their parents and schoolteachers and recorded for 72 hours with a belt-worn activity monitor during weekdays. The decreased amount of sleep was associated with symptoms such as aggressive and delinquent behaviour, attention, social and somatic problems. The findings of this research were better associated with the teachers' than the par-



ents' reports, suggesting that parents may be unaware of their child's sleep deficiencies as the behavioural problems may be more evident at school than at home (Aronen et al., 2000).

A prospective long-term study conducted in Sweden on 2518 children revealed that within a subgroup of 27 children with severe and chronic sleep problems, 7 children developed symptoms that met the criteria for ADHD by the age of 5.5 years (Thunström, 2002). Compared to the other children with sleep problems, these subjects had more frequent psychosocial problems in the family, bedtime struggles and long sleep latency at bedtime.

A population-based, cross-sectional questionnaire survey was conducted in Massachusetts on 30 195 children aged 5 years (Gottlieb et al., 2003). Children described by their parents as having sleep-disordered breathing (snoring, noisy breathing, apnoea) were significantly more likely to have daytime sleepiness and problem behaviours, including hyperactivity, inattention and aggressiveness (all with an odds ratio >2.0). These problem behaviours were suggestive of ADHD.

Similar findings were found in a group of children aged 5–7 years with periodic limb movement disorder who were studied polygraphically and their recording compared with those of age-matched children with ADHD. Their repeated sleep fragmentation resulting from the periodic limb movement disorder favoured the development of symptoms similar to those seen in ADHD (Crabtree et al., 2003).

The parents of a group of children with an average age of 8.6 years (range 2–17 years) reported that their children had difficult behaviours on the day that followed a 4-hour night-time sleep restriction (Wassmer et al., 1999). In one study, a 2-hour sleep reduction induced by delayed bedtime has been shown to increase daytime sleepiness, mainly during morning hours (Ishihara and Miyke, 1998; Ishihara, 1999).

Following one night of 4 hours of sleep deprivation imposed on children (aged 11–13 years), a decrease in performance tests has been observed (Carskadon, Harvey and Dement, 1981a).

Following one night's sleep loss, adolescents showed increased sleepiness, fatigue and reaction time. They selected less difficult academic tasks during a set of tests, but the percentages of correct responses were comparable to those seen following a normal night's sleep (Engle-Friedman et al., 2003).

Another study has been conducted on 82 children, aged 8–15 years. They were assigned an optimized, 10-hour night of sleep, or a restricted 4-hour night of sleep. Sleep restriction was associated with shorter daytime sleep latency, increased subjective sleepiness, and increased sleepy and inattentive behaviours, but was not associated with increased hyperactive-impulsive behaviour or impaired performance in tests of response inhibition and sustained attention (Fallone et al., 2001).

#### 2.3.1.8 *Mental health*

A recent longitudinal study on the outcomes of early life sleep problems and their relation to behaviour problems in early childhood stressed the importance of studying the natural history of sleep problems and their consequences in order to identify whether persistent or recurrent sleep problems at age 3–4 years are associated with co-morbidities such as child behaviour problems, maternal depression and poor family functioning (Peiyoong, Hiscock and Wake, 2003).

The authors found that night waking at 3–4 years of age continued to be common. Seventy eight percent of mothers reported that their child awoke during the night at least once during the week, and of these waking children, 43% were reported to have awakenings 4 or more nights per week. Children with early sleep problems had significantly higher mean scores on internalizing and externalizing behaviour and the aggressive behaviour and somatic problems subscales of the Child Behavior Checklist (CBCL).

It has been noted that within groups of children and adolescents with psychiatric, behavioural or emotional problems, rates of sleep disorders are elevated (Sadeh et al., 1995). On the other hand, children and adolescents with disturbed sleep report more depression, anxiety, irritability, fearfulness, anger, tenseness, emotional instability, inattention and conduct problems, drug use and alcohol use.

Only a few longitudinal studies in adolescents have evaluated the impact of insomnia on future functioning. In a large sample of 11–17-year-old adolescents, followed for one year, using symptoms of DSM-IV criteria for insomnia, Roberts, Roberts and Chen (2002) found that nearly 18% of the youths 11–17 years of age reported non-restorative sleep almost every day in the past month, over 6% reported difficulty in initiating sleep, over 5% waking up frequently during the night, another 3% had early-morning awakening almost every day, over 7% reported daytime fatigue and 5% daytime sleepiness. Combining “often” and “almost every day” response categories dramatically increases prevalence, ranging from 60% for non-restorative sleep to 23% for daytime fatigue and 12% for waking up at night with difficulty going back to sleep. The re-evaluation of the sample at follow-up showed that insomnia predicted two indicators of psychological functioning: self-esteem and symptoms of depression (Roberts, Roberts and Chen, 2002).

#### **2.3.1.9 Growth impairment**

Failure to thrive is a well-known complication of disturbed sleep and childhood OSAS. The cause of poor growth is not known, although many different reasons have been implicated: (a) poor caloric intake associated with adenotonsillar hypertrophy; (b) excessive caloric expenditure secondary to increased work of breathing; (c) abnormal growth hormone (GH) release secondary to loss of deep non-REM sleep. The relative roles of these factors are unclear (Marcus et al., 1994; ATS, 1999). Circulating concentrations of insulin-like growth factor-I (IGF-I) and IGF-binding protein 3 (IGFBP-3) reflect mean daily GH levels, and seem to correlate well with physiological changes in GH secretion. In the operated children with initial OSAS a highly significant reduction in the apnoea-hypopnea index (AHI) was found and both the IGF-I and the IGFBP-3 concentrations increased significantly. GH is released in a pulsatile fashion; the initial secretion is synchronized with the onset of SWS and strongly correlated with slow-wave activity, within 90 to 120 minutes from the onset of sleep (Nieminen et al., 2002). In OSAS children, the sleep architecture is relatively well-preserved, but the microstructural alteration of SWS due to micro-arousals induced by respiratory disturbance could play a role in the abnormal profile of GH secretion.

#### **2.3.1.10 Cardiovascular complications**

Children with OSAS had a significantly higher diastolic blood pressure (BP) than those with primary snoring. Multiple linear regression showed that BP could be predicted by apnoea index, body mass index and age. The aetiology of OSAS-related hypertension is thought to be due to a number of factors, particularly sympathetic nervous system activation secondary to arousal and, to a lesser degree, hypoxaemia.



Although cortical arousals at the termination of obstructive apnoeas are less common in children than in adults, children may manifest signs of subcortical arousal, including autonomic changes such as tachycardia. It is therefore possible that these subcortical arousals are associated with elevations of BP. A correlation between the frequency of obstructive apnoea and BP, but no correlation between SaO<sub>2</sub> (arterial oxygen saturation) and BP was found, suggesting that respiratory-related subcortical arousals rather than hypoxaemia may be a major determinant of BP elevation in children (Marcus, Greene and Carroll, 1998). Similarly to BP variations induced by OSAS, other studies suggest that chronic exposure to environmental noise during sleep could contribute to a permanent increases in BP in otherwise healthy individuals and that no habituation to noise was apparent over three consecutive sleep sessions (Carter et al., 2002). This is further elaborated in Chapter 4, section 4.5.

#### 2.3.1.11 Risk of accidents

Only one study was found that evaluated the association between sleep and duration of wakefulness and childhood unintentional injury (Valent, Brusaferrero and Barbone, 2001).

Two hundred and ninety-two injured children who attended the Children's Emergency Centre in Udine, Italy, or their parents were interviewed following a structured questionnaire. The sleeping time and wakefulness of the child was assessed retrospectively for each of the 48 hours before injury. For each child, the authors compared the 24 hours immediately before the injury (hours 1–24; case period) with hours 25–48 (control period).

Overall, more children had longer hours of sleep during the control period than during the case period. A direct association between injury risk and sleeping less than 10 hours was found among boys (RR: 2.33; 95% CI: 1.07–5.09) but not among girls (RR: 1.00; 95% CI: .29–3.45). The study also found a direct association between injury occurring between 16.00 and midnight, and being awake for at least 8 hours before injury occurred (both sexes, RR: 4.00; 95% CI: 1.13–14.17). Sleeping less than 10 hours a day was associated with an 86% increase in injury risk. A significantly increased risk did not emerge in all subgroups of patients but it was evident among children aged 3–5 years, boys in particular. A fourfold increase in injury risk was also associated with being awake for at least 8 hours among males only. These findings demonstrated that inadequate sleep duration and lack of daytime naps are transient exposures that may increase the risk of injury among children. Results of a study on sleep disturbance and injury risk in young children show inadequate sleep duration and lack of daytime naps. A lack of daytime naps means transient exposures that may increase the risk of injury among children. Among children (boys in particular) aged 3–5 years, sleeping less than 10 hours a day was associated with an 86% increase in injury risk. A fourfold increase in injury risk was also associated with being awake for at least 8 hours.

Daytime sleepiness in children is often manifested by externalizing behaviours noted by parents or teachers, such as increased activity levels, aggression, impulsivity, as well as by poor concentration, instantiation irritability and moodiness (Fallone, Owens and Deane, 2002).

Analysing attendance at school, data show that accidents took place at school (25.6%) and at home (22.0%), and statistics show that there is a highly significant greater total accident rate among boys than among girls. The most frequent injuries happening at school are fractures and dislocation of joints, head injuries being more common among school injuries compared with spare-time injuries. Most injuries

occurred when children were in sports areas and it is noteworthy that 25% of all injuries were caused through intentional violence by other pupils.

#### 2.3.1.12 Use of sleeping pills

Several studies demonstrated that the use of sleeping pills is common among children and that paediatricians are prone to prescribe these medications. Twenty-five percent of firstborn infants had been given “sedatives” by 18 months (Ounsted and Hendrick, 1977). A research study into parental reports of 11 000 preschool children showed that 12% took psychoactive drugs, most commonly for sleep: 39% daily and 60% intermittently for 1–2 years (Kopferschmitt et al., 1992). Another study (Trott et al., 1995) revealed that 35% of prescriptions for children less than a year old were for sleep disturbances and that sleep disturbances were also the most common reason for prescribing medications to preschool children (23%). Two French surveys on adolescents showed that 10–12% of the respondents reported use of prescription or over-the-counter drugs for sleep disturbances (Patois, Valatz and Alperovitch, 1993; Ledoux, Choquet and Manfredi, 1994). Recently it has been reported that of 671 community-based United States paediatricians, 75% had recommended over-the-counter and 50% prescription medicines for insomnia during the past 6 months (Owens, Rosen and Mindell, 2003). In addition, an Italian survey showed that pharmacological treatment for sleep problems was prescribed during the past 6 months by 58.54% of paediatricians and by 61.21% of child neuropsychiatrists (Bruni et al., 2004).

### 2.3.2 BASIC INDIVIDUAL FACTORS: GENDER AND AGE

Gender shows itself to be an important predictor of disturbed sleep in virtually all epidemiological studies (Karacan et al., 1976; Bixler, Kales and Soldatos, 1979; Ancoli-Israel and Roth, 1999; Leger et al., 2000; Sateia et al., 2000). On the other hand, there does not seem to be much of a difference in polysomnographical parameters between males and females, except for the former losing SWS with increasing age and having slightly reduced sleep efficiency also with increasing age (Williams, Karacan and Hirsch, 1974; Hume, Van and Watson, 1998). Ehlers and Kupfer (1997) timed the start of differences between genders to between 20 and 40 years. Spectral analysis also indicates slightly larger amounts of low frequency activity in females (Dijk, Beersma and Bloem, 1989; Dijk, Beersma and Van den Hofdaker, 1989). In addition, men seem to run a higher risk of morbidity and mortality related to sleep problems than women (Nilsson et al. 2001). The inconsistency between polysomnography and subjective measures has not been resolved but it may be important that most polysomnographical studies have controlled for anxiety and depression. Thus, it is conceivable that the higher level of subjective complaints in women reflects a higher prevalence of anxiety. The latter is a speculation, however. A confounding factor in gender comparisons is that phases in female biological cycles are also usually controlled for in polysomnographical studies, meaning that potential effects of, for example, menstruation, may not receive their proper weight. A recent review has gone through the literature in this area (Moline et al., 2003). It found that the luteal phase of the menstrual cycle is associated with subjective sleep problems, but polysomnographical studies have not supported this. Pregnancy affects sleep negatively as early as in the first trimester and the effects mainly involve awakenings and difficulties getting back to sleep. Napping is a frequent coping method. The post-partum period is often associated with severe sleep disruption, mainly due to feeding and comforting the infant. There seems to be some relation between sleep disruption and post-partum mood, but nothing is known about the



causal relations. Menopause seems to involve disrupted sleep in relation to hot flushes, depression/anxiety and sleep-disordered breathing. Oestrogen is associated with improved sleep quality but it is not clear whether the effects are due to a reduction of hot flushes. Oestrogen also improves sleep-disordered breathing.

With respect to background factors, age is an established predictor of disturbed sleep (Karacan et al., 1976; Bixler, Kales and Soldatos, 1979; Ancoli-Israel and Roth, 1999; Ribet and Derriennic, 1999; Leger et al., 2000; Sateia et al., 2000). Interestingly, however, older age may be related to a lower risk of impaired awakening (Åkerstedt et al., 2002c), that is, in this study it was easier to wake up and one felt better rested with increasing age, while at the same time sleep quality was lower. The increased risk of disturbed sleep is consistent with the increasingly strong interference of the circadian morning upswing of the metabolism with increasing age (Dijk and Duffy, 1999). Thus sleep maintenance is impaired and when sleep is interrupted “spontaneously”, the awakening is, by definition, easily accomplished and will be lacking in inertia. This ease of awakening may be interpreted as “being well-rested”, and obviously the need for sleep is not great enough to prevent an effortless transition into wakefulness.

In addition, sleep homeostasis seems to be weakened with age in the sense that sleep becomes more fragmented and SWS or power density in the delta bands decrease (Williams, Karacan and Hirsch, 1974; Bliwise, 1993; Dijk et al., 1999). As mentioned above, the effects are more pronounced in males, a fact that may be linked to reduced levels of growth hormone and testosterone.

### 2.3.3 PERSONS EXPOSED TO STRESSORS AS A RISK GROUP

A number of epidemiological studies point to a strong link between stress and sleep (Åkerstedt, 1987; Urponen et al., 1988; Ancoli-Israel and Roth, 1999). In fact, stress is considered the primary cause of persistent psychophysiological insomnia (Morin, Rodrigue and Ivers, 2003). That stress can affect proper sleep seems obvious, but Vgontzas et al. (2001) at Pennsylvania State University College of Medicine have found another reason why middle-aged men may be losing sleep. It is not just because of what they worry about; rather, it is due to “increased vulnerability of sleep to stress hormones”.

As men age, it appears they become more sensitive to the stimulating effects of corticotropin-releasing hormones (CRH). When both young and middle-aged men were administered CRH, the older men remained awake longer and slept less deeply. (People who don't get enough of this “slow-wave” sleep may be more prone to depression.)

The increased prevalence of insomnia in middle age may, in fact, be the result of deteriorating sleep mechanisms associated with increased sensitivity to arousal-producing stress hormones, such as CRH and cortisol. In another study, the researchers compared patients with insomnia to those without sleep disturbances. They found that “insomniacs with the highest degree of sleep disturbance secreted the highest amount of cortisol, particularly in the evening and night-time hours”, suggesting that chronic insomnia is a disorder of sustained hyperarousal of the body's stress response system. Also, recent epidemiological studies have shown a connection between disturbed sleep and later occurrence of stress-related disorders such as cardiovascular diseases (Parish and Shepard, 1990; Nilsson et al., 2001;



Leineweber et al., 2003) and diabetes type II (Nilsson et al., 2002). The mechanism has not been identified but both lipid and glucose metabolisms are impaired in relation to experimentally reduced sleep (Åkerstedt and Nilsson, 2003). Burnout is another result of long-term stress and a growing health problem in many industrialized countries (Weber and Jaekel-Reinhard, 2000). In Sweden, burnout is thought to account for most of the doubling of long-term sickness absence since the mid-1990s (RFV, 2003). The characteristic clinical symptoms of the condition are excessive and persistent fatigue, emotional distress and cognitive dysfunction (Kushnir and Melamed, 1992; Melamed, Kushnir and Sharom, 1992). Self-reports of disturbed sleep are pronounced in subjects scoring high on burnout (Melamed et al., 1999; Grossi et al., 2003). Since shortened and fragmented sleep is related to daytime sleepiness and impaired cognitive performance (Bonnet, 1985, 1986a, 1986b; Dinges et al., 1997; Gillberg and Åkerstedt, 1998; Åkerstedt, 1990), disturbed sleep might provide an important link between the state of chronic stress and the complaints of fatigue and cognitive dysfunction seen in burnout.

Partinen, Eskelinen and Tuomi (1984) investigated several occupational groups and found disturbed sleep to be most common among manual workers and much less so among physicians or managing directors. Geroldi et al. (1996) found in a retrospective study of older individuals (above the age of 75) that former white-collar workers reported better sleep than blue-collar workers. Kupperman et al. (1995) reported fewer sleep problems in subjects satisfied with work.

In what seems to be the most detailed study so far, Ribet and Derriennic (1999) studied more than 21 000 subjects in France, using a sleep disturbance index and logistic regression analysis. They found that shift work, a long working week, exposure to vibrations, and "having to hurry" appeared to be the main risk factors, controlling for age and gender. Disturbed sleep was more frequent in women (Karacan et al., 1976; Bixler, Kales and Soldatos, 1979; Ancoli-Israel and Roth, 1999) and in higher age groups.

The particular stressor linked to disturbed sleep may be linked to pressure of work (Urponen et al., 1988; Ancoli-Israel and Roth, 1999; Ribet and Derriennic, 1999; Åkerstedt et al., 2002b). The demands of work are a classical work stress factor and, when combined with low decision latitude, a relation has been shown to cardiovascular diseases (Theorell et al., 1998) and absenteeism (North et al., 1996). Interestingly, when "persistent thoughts about work" was added to the regression in the study by Åkerstedt et al. (2002b) this variable took over part of the role of work demands as a predictor. This suggests that it may not be work demands per se that are important, but rather their effect on unwinding after work. In two studies it has been demonstrated that even moderate worries about being woken during the night or having a negative feeling about the next day will affect sleep negatively, mainly reducing SWS (Torsvall and Åkerstedt, 1988; Kecklund and Åkerstedt, 1997). On the other hand, there is very little data to connect real life stress with polysomnographical indicators of disturbed sleep. Most studies have used rather innocuous and artificial stressors in a laboratory environment. Field studies of stress are virtually lacking, with some exceptions (Hall et al., 2000).

A lack of social support at work is a risk indicator for disturbed sleep (Åkerstedt et al., 2002b). Few previous data of this type have been found, but poor (general) social support has been associated with sleep complaints in Vietnam veterans (Fabsitz, Sholinsky and Goldberg, 1997). On the other hand, there are several studies indicating a close connection with poor social support for, for example,

cardiovascular diseases (Arnetz et al., 1986) or muscle pain (Ahlberg-Hultén, Theorell and Sigala, 1995).

Interestingly, the metabolic changes seen after sleep curtailment in normal sleepers or in insomniacs and sleep apnoeics are similar to those seen in connection with stress. That is, lipid and glucose metabolisms are increased, as are cortisol levels (Spiegel, Leproult and van Cauter, 1999; Vgontzas et al., 2000, 2001). Together with the prospective links to stress-related diseases such as diabetes type II, to cardiovascular diseases as discussed above and with mortality (Kripke et al., 1979, 2002; Åkerstedt et al., 2002a; Dew et al., 2003), the findings could suggest that disturbed sleep may be an important mediator in the development of stress-related diseases.

### 2.3.4 SHIFT WORK AS A RISK FACTOR FOR SLEEP DISTURBANCE AND HEALTH EFFECTS

The dominating health problem reported by shift workers is disturbed sleep and wakefulness. At least three quarters of the shift working population is affected (Åkerstedt, 1988). When comparing individuals with a very negative attitude to shift work with those with a very positive one, the strongest discriminator seems to be the ability to obtain sufficient quality of sleep during the daytime (Axelsson et al., 2004). EEG studies of rotating shift workers and similar groups have shown that day sleep is 1–4 hours shorter than night sleep (Foret and Lantín, 1972; Foret and Benoit, 1974; Matsumoto, 1978; Tilley, Wilkinson and Drud, 1981; Torsvall et al., 1989; Mitler et al., 1997). The shorter time is due to the fact that sleep is terminated after only 4–6 hours without the individual being able to return to sleep. The sleep loss is primarily taken out of stage 2 sleep and stage REM sleep (dream sleep). Stages 3 and 4 (“deep” sleep) do not seem to be affected. Furthermore, the time taken to fall asleep (sleep latency) is usually shorter. Night sleep before a morning shift is also reduced but the termination is through artificial means and the awakening usually difficult and unpleasant (Dahlgren, 1981a; Tilley et al., 1982; Åkerstedt, Kecklund and Knutsson, 1991; Kecklund, 1996).

Interestingly, day sleep does not seem to improve much across a series of night shifts (Foret and Benoit, 1978; Dahlgren, 1981b). It appears, however, that night workers sleep slightly better (longer) than rotating workers on the night shift (Kripke, Cook and Lewis, 1971; Bryden and Holdstock, 1973; Tepas et al., 1981). The long-term effects of shift work on sleep are rather poorly understood. However, Dumont, Montplaisir and Infante-Rivard (1988) found that the amount of sleep/wake and related disturbances in present day workers were positively related to their previous experience of night work. Guilleminault et al. (1982a) found an over-representation of former shift workers with different clinical sleep/wake disturbances appearing at a sleep clinic. Recently, we have shown that in pairs of twins with different night work exposure, the exposed twin reports somewhat deteriorated sleep quality and health after retirement (Ingre and Åkerstedt, 2004).

The main reason for short daytime sleep is the influence exerted by the circadian rhythm. The more sleep is postponed from the evening towards noon next day, the more truncated it becomes and when noon is reached the trend reverts (Foret and Lantín, 1972; Åkerstedt and Gillberg, 1981). Thus, sleep during the morning hours is strongly interfered with, despite the sizeable sleep loss that, logically, should enhance the ability to maintain sleep (Czeisler et al., 1980). Also, homeostatic influences control sleep. For example, the expected 4–5 hours of daytime sleep, after a



night spent awake, will be reduced to 2 hours if a normal night's sleep precedes it and to 3.5 hours if a 2-hour nap is allowed (Åkerstedt and Gillberg, 1986). Thus, the time of sleep termination depends on the balance between the circadian and homeostatic influences. The circadian homeostatic regulation of sleep has also been demonstrated in great detail in studies of forced or spontaneous desynchronization under conditions of temporal isolation and ad lib sleeping hours (Czeisler et al., 1980; Dijk and Czeisler, 1995).

#### 2.3.4.1 *Alertness, performance and safety*

Night-oriented shift workers complain as much of fatigue and sleepiness as they do about disturbed sleep (Åkerstedt, 1988). The sleepiness is particularly severe on the night shift, hardly appears at all on the afternoon shift and is intermediate on the morning shift. The maximum is reached towards the early morning (05.00–07.00). Frequently, incidents of falling asleep occur during the night shift (Prokop and Prokop, 1955; Kogi and Ohta, 1975; Coleman and Dement, 1986). At least two thirds of the respondents report that they have experienced involuntary sleep during night work.

Ambulatory EEG recordings verify that incidents of actual sleep occur during night work in, for example, process operators (Torsvall et al., 1989). Other groups, such as train drivers or truck drivers show clear signs of incidents of falling asleep while driving at night (Caille and Bassano, 1977; Torsvall and Åkerstedt, 1987; Kecklund and Åkerstedt, 1993). This occurs towards the second half of the night and appears as repeated bursts of alpha and theta EEG activity, together with closed eyes and slow undulating eye movements. As a rule the bursts are short (1–15 seconds) but frequent, and seem to reflect lapses in the effort to fend off sleep. Approximately a quarter of the subjects recorded show the EEG/EOG patterns of fighting with sleep. This is clearly a larger proportion than what is found in the subjective reports of episodes of falling asleep.

As may be expected, sleepiness on the night shift is reflected in performance. One of the classics in this area is the study by Bjerner, Holm and Swensson (1955) who showed that errors in meter readings over a period of 20 years in a gas works had a pronounced peak on the night shift. There was also a secondary peak during the afternoons. Similarly, Brown (1949) demonstrated that telephone operators connected calls considerably slower at night. Hildebrandt, Rohmert and Rutenfranz (1974) found that train drivers failed to operate their alerting safety device more often at night than during the day. Most other studies of performance have used laboratory type tests and demonstrated, for example, reduced reaction time or poorer mental arithmetic on the night shift (Tepas et al., 1981; Tilley et al., 1982). Flight simulation studies have furthermore shown that the ability to "fly" a simulator (Klein, Bruner and Holtman, 1970), or to carry out a performance test (Dawson and Reid, 1997) at night may decrease to a level corresponding to that after moderate alcohol consumption (>0.05% blood alcohol). Interestingly, Wilkinson et al. (1989) demonstrated that reaction time performance on the night shift (nurses) was better in permanent than rotating shift workers.

If sleepiness is severe enough, interaction with the environment will cease and if this coincides with a critical need for action an accident may ensue. Such potential performance lapses due to night work sleepiness were seen in several of the train drivers discussed earlier (Torsvall and Åkerstedt, 1987). The transport area is where most of the available accident data on night shift sleepiness has been obtained (Lauber and Kayten, 1988). Thus, Harris (1977) and Hamelin (1987) demonstrated that single vehicle accidents have by far the greatest probability of occurring at night.

So do fatigue-related accidents (Reyner and Horne, 1995) but also most other types of accidents, for example head-on collisions and rear-end collisions (Åkerstedt, Kecklund and Horte, 2001). The National Transportation Safety Board ranks fatigue as one of the major causes of heavy vehicle accidents (NTSB, 1995).

For conventional industrial operations very little relevant data is available but fatal work accidents show a higher risk in shift workers (Åkerstedt et al., 2002a) and accidents in the automotive industry may exhibit night shift effects (Smith, Folkard and Poole, 1994). An interesting analysis has been put forward by the Association of Professional Sleep Societies' Committee on Catastrophes, Sleep and Public Policy (Mitler et al., 1988). Their consensus report notes that the nuclear plant meltdown at Chernobyl occurred at 01.35 and was due to human error (apparently related to work scheduling). Similarly, the Three Mile Island reactor accident occurred between 04.00 and 06.00 and was due not only to the stuck valve that caused a loss of coolant water but, more importantly, to the failure to recognize this event, leading to the near meltdown of the reactor. Similar incidents, although with the ultimate stage being prevented, occurred in 1985 at the Davis Besse reactor in Ohio and at the Rancho Seco reactor in California. Finally, the committee also states that the NASA Challenger space shuttle disaster stemmed from errors in judgement made in the early morning hours by people who had had insufficient sleep (through partial night work) for days prior to the launch. Still, there is very limited support for the notion that shift work outside the transport area actually carries a higher overall accident risk.

As with sleep, the two main factors behind sleepiness and performance impairment are circadian and homeostatic factors. Their effects may be difficult to separate in field studies but are clearly discernible in laboratory sleep deprivation studies (Fröberg et al., 1975) as well as in studies of forced desynchronization (Dijk, Duffy and Czeisler, 1992). Alertness falls rapidly after awakening but gradually levels out as wakefulness is extended. The circadian influence appears as a sine-shaped superimposition upon this exponential fall in alertness. Space does not permit a discussion of the derivation of these functions, but the reader is referred to Folkard and Åkerstedt (1991) in which the "three-process model of alertness regulation" is described. This model has been turned into computer software for predicting alertness and performance and to some extent accident risk.

#### 2.3.4.2 *Health effects*

Gastrointestinal complaints are more common among night shift workers than among day workers. A review of a number of reports covering 34 047 persons with day or shift work found that ulcers occurred in 0.3–0.7% of day workers, in 5% of people with morning and afternoon shifts, in 2.515% of persons with rotating shift systems with night shifts, and in 10–30% of ex-shift workers (Angersbach et al., 1980). Several other studies have come to similar conclusions (Thiis-Evensen, 1958; Segawa et al., 1987; Harrington, 1994). Other gastrointestinal disorders, including gastritis, duodenitis and dysfunction of the digestive system are more common in shift workers than in day workers (Koller, 1983).

The pathophysiologic mechanism underlying gastrointestinal disease in shift workers is unclear, but one possible explanation is that intestinal enzymes and intestinal mobility are not synchronized with the sleep/wake pattern. Intestinal enzymes are secreted according to the circadian rhythm, and shift workers' intake of food is irregular compared with intestinal function (Suda and Saito, 1979; Smith, Colligan and Tasto, 1982). A high nightly intake of food may be related to increased lipid levels (Lennernäs, Åkerstedt and Hambræus, 1994) and eating at the circadian low point



may be associated with altered metabolic responses (Hampton et al., 1996). In addition, reduced sleep affects lipid and glucose metabolism (Spiegel, Leproult and van Cauter, 1999).

A number of studies have reported a higher incidence of cardiovascular disease, especially coronary heart disease, in male shift workers than in men who work days (for review see Kristensen, 1989; Boggild and Knutsson, 1999). A study of 504 paper mill workers followed for 15 years found a dose-response relationship between years of shift work and incidence of coronary heart disease in the exposure interval 1–20 years of shift work (Knutsson et al., 1986). A study of 79 000 female nurses in the United States gave similar results (Kawachi et al., 1995) as did a study with more than 1 million Danish men (Tüchsen, 1993) and a cohort of Finnish workers (Tenkanen et al., 1997). As with gastrointestinal disease, a high prevalence of smoking among shift workers might contribute to the increased risk of coronary heart disease, but smoking alone cannot explain the observed excess risk (Knutsson, 1989b). Another possibility is disturbances of metabolic parameters such as lipids and glucose for which there is some support as discussed above.

Only a few studies have addressed the issue of pregnancy outcome in shift workers. In one study of laboratory employees, shift work during pregnancy was related to a significantly increased risk of miscarriage (RR: 3.2) (Axelsson, Lutz and Rylander, 1984). Another study of hospital employees also demonstrated an increased risk of miscarriage (RR: 1.44, 95% CI: 0.83–2.51) (Axelsson and Rylander, 1989). Lower birth weight in infants of mothers who worked irregular hours has been reported (Axelsson and Rylander, 1989; Nurminen, 1989). No teratogenic risk associated with shift work was reported (Nurminen, 1989).

The mortality of shift and day workers was researched by Taylor and Pocock (1972), who studied 8603 male manual workers in England and Wales between 1956 and 1968. Day, shift, and ex-shift workers were compared with national figures. The Standardized Mortality Ratio (SMR) can be calculated from observed and expected deaths reported in the paper. SMRs for deaths from all causes were 97, 101 and 119 for day, shift, and ex-shift workers respectively. Although the figures might indicate an increasing trend, the differences were not statistically significant. However, the reported SMR close to 100 is remarkable because the reference population was the general male population. Most mortality studies concerned with occupational cohorts reveal SMRs lower than 100, implying a healthy workers' effect (Harrington, 1978). The same study showed a significantly increased incidence of neoplastic disease in shift workers (SMR 116). A Danish study of 6000 shift workers failed to demonstrate any excess mortality in shift workers (Boggild et al., 1999). Not much evidence exists on the connection between shift work and cancer. The mortality study by Taylor and Pocock (1972) reported an increased incidence of neoplasms in shift workers compared with the general population. A recent Danish case-control study reported an increased risk of breast cancer among 30–45-year-old women who worked mainly nights (Hansen, 2001). Among 75 000 nurses those with more than 15 years of night work showed an increased risk of colorectal cancer (Schernhammer et al., 2003). If the results are confirmed, a possible mechanism may be the low levels of the hormone melatonin, due to light exposure during the night with a subsequent suppression of melatonin.

Very few studies are available but Koller, Kundi and Cervinka (1978) found a prevalence of endocrine and metabolic disease of 3.5% in shift workers and 1.5% in day workers. Kawachi et al. (1995) found in a prospective study of shift work-



ers that the age-standardized prevalence was 5.6% at 15 years of shift work experience compared with 3.5% for no exposure. Nagaya et al. (2002) found that markers of insulin resistance were more frequent in shift workers above the age of 50 than in day workers. Other indicators, such as body mass index, glucose levels and so forth, give a rather inconclusive impression as indicated in a review by Boggild and Knutsson (1999).

Another contributing factor to gastrointestinal diseases might be the association between shift work and smoking. A number of studies have reported that smoking is more common among shift workers (Angersbach et al., 1980; Knutsson, Åkerstedt and Jonsson, 1988). Studies concerned with alcohol consumption comparing day workers and shift workers have produced conflicting results (Smith, Colligan and Tasto, 1982; Knutsson, 1989a; Romon, Nuttens and Fievet, 1992), probably due to local cultural habits. One study, which used g-glutamyltransferase as a marker of alcohol intake, did not indicate that the shift workers had a higher intake of alcohol than the day workers (Knutsson, 1989a).

Sickness absence is often used as a measure of occupational health risks. However, sickness leave is influenced by many irrelevant factors and cannot be considered as a reliable measure of true morbidity. Studies on sickness absence in day and shift workers have revealed conflicting results and there is no evidence that shift workers have more sickness absence than day workers (for review, see Harrington, 1978).

#### 2.3.4.3 Conclusion

Shift work or similar arrangements of work hours clearly affects sleep and alertness and there is a moderate risk of cardiovascular and gastrointestinal disease. Other diseases such as cancer or diabetes may be related to shift work but the evidence is as yet rather weak.

The present review suggests that the risk of disturbed sleep increases with age but there also seems to be a recent stress-related increase in sleep disturbance in young adults. The long-term health consequences are not yet understood.

The relation between gender and disturbed sleep is confusing. Females, as a rule, complain more of sleep problems, but do not exhibit any objective indications of more disturbed sleep, at least not among otherwise healthy women. With increasing age the sleep of males deteriorates whereas that of women is relatively well upheld. Pregnancy, however, is a period of increased risk of disturbed sleep, whereas the menstrual cycle and menopause show less evidence of sleep disturbance. Clearly there is a great need for longitudinal research on gender and sleep and, in particular, on the possible health consequences connected with pregnancy.

Stress due to work or family seems to be one of the major causes of disturbed sleep. The link to the risk of insomnia is well-established, but reduced sleep in itself seems to yield the same physiological changes as stress. This suggests that several of the major civilization diseases in Europe and the United States (diabetes, cardiovascular diseases and burnout) could be mediated via disturbed sleep. This link clearly warrants longitudinal studies with interventions.

Shift workers constitute a group that suffers from disturbed sleep for most of their occupational life. The reason is the interference of work hours with the normal timing of sleep. This leads to an increased risk of accidents, directly due to excessive sleepiness, but also to cardiovascular and gastrointestinal diseases, although it is

not clear whether the latter effects are sleep related or due to circadian factors – or to a combination. Recent studies also suggest that breast cancer may result from shift work due to the effects of light on melatonin secretion. This still needs verification, however. Future research needs to identify countermeasures, the reasons for large individual differences in tolerance and the possible carcinogenic and other effects.

The conclusions above should be seen against the profound effects of reduced or fragmented sleep on the neuroendocrine (including glucose and lipid regulation) and immune systems as well as the effects on mortality, diabetes and cardiovascular disease.

### 2.3.5 CONCLUSION

Children, the elderly, pregnant women, people under stress and shift workers are vulnerable to (noise) disturbance of their sleep.

## 2.4 ACCIDENTS RELATED TO SLEEP QUALITY

As already stated in the earlier section on cardiovascular complications, children with disturbed sleep present cognitive dysfunction and behavioural disturbances, abnormal growth hormone release, increase of diastolic BP and an increased risk of accidents and use of sleeping pills.

Regarding sleep disturbance and accidents in adults, data show that 15–45% of all patients suffering from sleep apnoea, 12–30% of all patients suffering from narcolepsy and 2–8% of all patients suffering from insomnia have at least one accident (in a lifetime) related to sleepiness (statistics from the Stanford Sleep Disorders Clinic).

As already discussed in section 2.3.4, the biggest industrial catastrophes, such as the Three Mile Island, Bhopal, Chernobyl and Exxon Valdez disasters, have occurred during the night shift. The shift schedules, fatigue and sleepiness were cited as major contributing factors to each incident.

The LARES study (Large Analysis and Review of European housing and health Status) is one of the few studies analysing this issue directly. The results show that the likelihood of home accidents is significantly greater when the individual is tired all the time or most the time and there is an association between sleep disturbance and accidents, with 22% of those reporting an accident also reporting having their sleep disturbed during the previous four weeks.

The data available to document the impact of environmental noise on sleep deprivation and accidents are largely inadequate. There is no estimation of relative risk. Further research is needed in order to identify the accident-related burden of diseases attributable to noise during the night-time.



## 2.5 ANIMAL STUDIES

As pet owners know, cats sleep (most of the time it seems) and so do dogs. But do fish sleep? And flies? Yes, most animals sleep, and they even show the same phenomena as in humans; from deep sleep, dream sleep to sleep disorders. There are also many differences and weird behaviour, such as sleeping with only one half of the brain at a time (dolphins and ducks).

As Ising points out (Appendix 3), in animal experiments it is possible to assess the complete causal chain from noise exposure via physiological reactions and biological risk factors to morbidity or even mortality. However, a quantitative application of the results to humans is not possible. Instead, the method is useful in studying the pathomechanisms qualitatively. Rechtschaffen and Bergmann (1965) studied sleep deprivation in rats, showing that total sleep deprivation leads to mortality in 16 to 20 days. As the animals in the last stage died from microbial infection, Everson and Toth (2000) proceeded to show early infection of the lymph nodes and other tissues and hypothesized that daily sleep of some amount is necessary to maintain an intact immune system that will prevent bacterial invasion, a view that has been challenged.

Surprisingly, sleep in the common fruit fly – *Drosophila melanogaster* – has many similarities with mammalian sleep, including sleep deprivation leading to impaired performance. Genetic studies in fruit flies (Cirelli et al., 2005) led to mutant flies that can get by on 30% less sleep than their normal counterparts, thanks to a single mutation in one gene. While they sleep 30% less they show no immediate ill effects. The lifespan of the flies is, however, reduced by 30%.

These animal models certainly lead one to believe that sleep is a biological necessity, and tampering with it is dangerous for survival.

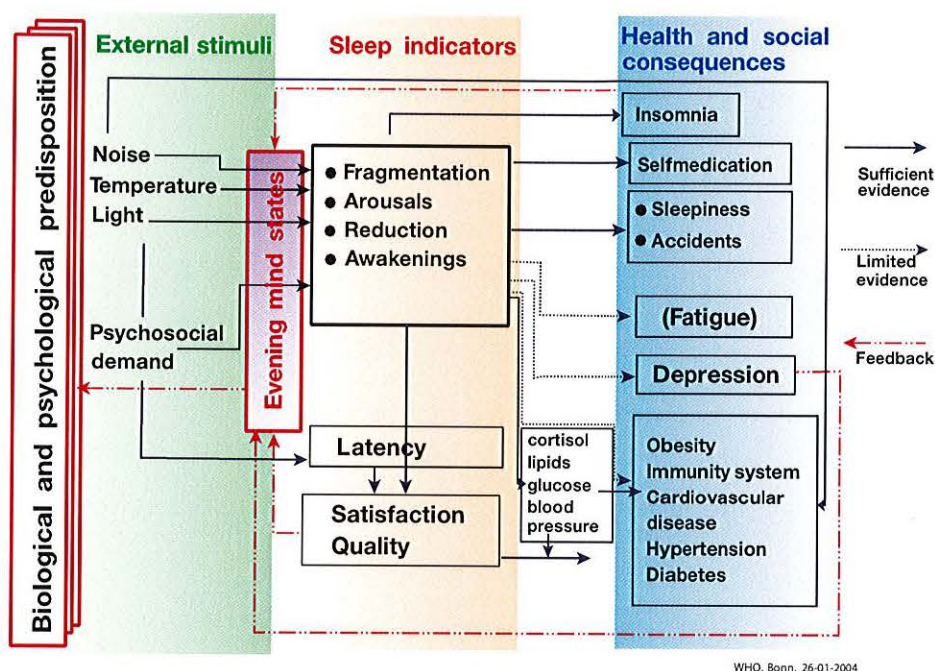
As Ising shows (Appendix 3) noise may play a role in this. Under stressful circumstances the death rate of rats is increased when noise levels are increased from “ambient” to  $L_{eq}=69$  dB(A). Are noise and sleep deprivation stressors that both lead to early death? Is the noise effect due to sleep deprivation? A carefully planned study may sort this out. The question still remains, however, as to how far this is relevant to humans.

## 2.6 CONCLUSIONS

From the evidence presented so far it can be deduced that sleep is important for human functioning. Why exactly is less evident, but it is clear that disturbed sleep (either from internal factors or from external factors) leads to or is at least associated with fatigue, lower cognitive performance, depression, viral illness, accidents, diabetes, obesity and cardiovascular diseases. Animal experiments show that sleep deprivation shortens lifespan. The fact that – in comparison – relatively mild effects turn up in human sleep deprivation experiments could be due to the short period (about 10 days in controlled experiments) and the limitation to young and healthy adults. The central position of sleep in human functioning is summarized in Fig. 2.1. In this figure relations with sufficient evidence are indicated with solid lines, while relations for which limited evidence exists are indicated with interrupted lines. Feedback connections are in red and double-dotted.

The presence of feedback loops in the system is an indication that it may be difficult to prove direct cause-effect relations. One example is the relation between sleep quality and depression. They are strongly associated, but it is uncertain if depression causes bad sleep, or bad sleep causes depression (see also Chapter 4, section 4.8.11). This may also depend on one of the many other factors, so it could be different for different personality types.

**Fig.2.1**  
Expert view on the relations  
between sleep and health



Impaired sleep is widely considered as a health problem per se, and this chapter has shown that there are many internal and external causes. In the next chapter the relation between noise and sleep quality is further unravelled.





## CHAPTER 3

### EFFECTS OF NIGHT-TIME NOISE ON SLEEP

*Best travel tip: Never ever forget to pack ear plugs.*

*(Virginia Jealous, Lonely Planet author)*

### 3.1 SHORT-TERM EFFECTS OF TRANSPORTATION NOISE ON SLEEP WITH SPECIFIC ATTENTION TO MECHANISMS AND POSSIBLE HEALTH IMPACT

#### 3.1.1 INTRODUCTION

In this section reactions to single events are presented. In Chapter 2 normal sleep and sleep disorders are described in medical terms, but here the focus is on the mechanisms underlying the relation between noise and sleep quality. How does a sound penetrate the brain and cause a disruption of sleep?

#### 3.1.2 HOW NOISE INFLUENCES NORMAL SLEEP

Noise can induce changes in the EEG or in autonomic variables that are called arousals or phasic activations. Similar brief episodes of activity also occur without noise in normal sleep, and, more frequently, in sleep that is otherwise disturbed, for example by apnoea. Arousal during sleep is not a uniform concept and has been defined differently by different researchers. Commonly, the occurrence of alpha rhythms is required for EEG arousal. Depending on the additional requirements and on the length of time that the slower cortical rhythms are interrupted, arousals have been called, for instance, micro-arousal, minor arousal, EEG awakening or transient activation phases. EEG awakening requires an interruption of the sleep patterns of at least 15 seconds (half the period) when sleep staging is scored by periods of 30 seconds, but need not be experienced consciously. Because normal REM sleep is a state characterized by cerebral arousal with frequently occurring alpha rhythms, additional criteria are needed to define arousal from REM. The criteria used are increased heart rate, EMG, or irregular respiration. However, since the mechanisms of such autonomic responses appear to be at least partly different from the causal mechanisms of EEG arousal, such definitions seem to make arousal from sleep a heterogeneous concept that may not have simple relationships with noise exposure.

EEG arousals lasting at least 30 seconds have been found to occur as often as 4 times (95% CI: 1–15) per hour during sleep on average, while micro-arousals occurred 21 times (95% CI: 7–56) per hour (Mathur and Douglas, 1995). Since these figures are from a laboratory study, they almost certainly are higher than the figures that hold for the natural situation at home. Sleep pressure decreases the density of micro-arousals (Sforza, Jouny and Ibanez, 2000). While the number of EEG arousals (dur-

ing sleep stages 1 and 2) increases with age (Mathur and Douglas, 1995; Boselli et al., 1998) possibly only for men (Hume, Van and Watson, 2003), their average length is stable and circa 15 seconds (Boselli et al., 1998). Also the threshold for auditory arousal decreases with age (Zepelin, McDonald and Zammit, 1984; Busby and Pivik, 1985; Busby, Mercier and Pivik, 1994) and towards the end of the night (Basner et al., 2004). Recovery after EEG awakenings takes longer for noise-induced awakenings than for spontaneous awakenings (Basner et al., 2004). The time required for falling asleep again depends on the sound level and especially for loud events this latency is considerably longer than after spontaneous awakenings. Thus, in general, noise-induced EEG awakenings are more disruptive than spontaneous awakenings and therefore will more often be experienced consciously and remembered afterwards. In common situations with aircraft overflight noise at home, (minor) arousals were found in 10.3% of the 64-second intervals without aircraft noise and this percentage was found to be increased by circa 4% up to 14.3% in intervals with an aircraft noise event (Hume, Van and Watson, 2003). Thus, in that particular (exposure) situation, about 1 in 24 aircraft overflights caused a (minor) arousal.

### 3.1.3 MECHANISMS

Activity in the auditory system up to the brainstem nucleus inferior colliculus occurs within 10 milliseconds after the onset of a sound. This early activity appears to be obligatory and is hardly affected by the state (sleeping or awake). Being asleep or awake does influence later activity. The auditory pathways proceed from the inferior colliculus to the thalamus and from there to the auditory cortex. The state (asleep or awake) affects the activity in the thalamocortical circuits, which occurs after 10–80 milliseconds. In particular, during SWS the transmission of auditory information through the thalamus is suppressed. This is not the case during REM sleep or when awake.

Thus, while in all (sleep) stages, sound activates the auditory system up to the inferior colliculus, the sound-induced activation of higher areas is suppressed in SWS. Therefore, further activation depending on those higher areas (for example, extracting meaning) is not likely to occur as a primary reaction to sound during SWS. For understanding arousal during SWS, it is important that the inferior colliculus and the earlier auditory nucleus of the lateral lemniscus, and also the (dorsal and ventral) cochlear nuclei project to reticular arousal system. Presumably, sound is always capable of arousing the sleeping subject through these connections. The ascending arousal system is heterogeneous and encompasses mono-aminergic, glutamatergic, and cholinergic nuclei that can directly or indirectly activate the thalamus and cortex. An important indirect route is the activation of the basal forebrain, which can activate the cerebral cortex through widespread, mainly cholinergic projections. The activation of the thalamus and cortex is indicated by an increase in EEG rhythm frequency and a reduction of the inhibition in the thalamic sensory relay nuclei. As a consequence of the latter effect, subsequent sound-induced activation may pass the thalamus and may be subject to more elaborate processing than initial sound. It can be speculated that sound in this way also reduces the threshold for somatosensory information that initiates body movements so that more body movements are observed when exposed to sound. The occurrence of habituation of cortical responses suggests an active role played by a part of the brain that blocks or at least limits the impact of the activated ascending pathways.



The parasympathetic autonomic nervous system seems to be responsible for the bradycardia observed in non-REM sleep and mainly in tonic REM sleep through the increase in vagal activity (Guazzi et al., 1968). The variability of heart rate in REM sleep could be placed under the same control, as vagotomy strongly reduced the heart rate instability (Baust and Bohnert, 1969). During falling asleep, respiration is unstable and alternates between hypo- and hyperventilation episodes. This respiration, called “periodic respiration” (Mosso, 1886), disappears when stable sleep occurs (stage 2). The main hypotheses concerning this periodic ventilation refer to metabolic control and chemoreceptor responses to levels of  $\text{PaCO}_2$  and  $\text{PaO}_2$  (Chapman et al., 1988). In stable non-REM sleep, respiration is regular in amplitude and frequency, although ventilation per minute is lower than during awakening. In REM sleep, respiration appears irregular with sudden variations in amplitude and frequency. This irregularity appears to be not modifiable by metabolic factors and, therefore, it is possibly linked to mechanisms leading to REM expression. The non-habituation of the cardiovascular responses would be explained by the absence of an inhibitory influence on the part of the arousal system that affects the centres regulating the autonomous response.

### 3.1.4 EEG RESPONSE

The sleep polygraph continuously records EEG activity, eye movement (EOG) and muscle tone (EMG). These data are used to classify sleep into various stages, and to assess times of falling asleep and waking up. Also, sleep variables such as total sleep time and total time spent in SWS (consisting of sleep stages 3 and 4, the stages of deep sleep) and in the REM stage (also called dream or paradoxical sleep) can be assessed on the basis of sleep polygraph recordings. Polygraphic indicators of responses to individual noise events are changes from a deeper to a less deep sleep and EEG awakening. Several field studies (Pearsons, Bennett and Fidell, 1973; Vernet, 1979; Vallet et al., 1983; Hume, Van and Watson, 2003; Basner et al., 2004) have been conducted regarding noise-induced changes in sleep stage and awakening using EEG recordings. Transition from a deep stage of sleep to a shallower sleep stage can be the direct consequence of a nocturnal noise event. Although not perceived by the sleeper, these transitions modify the sleep architecture and may reduce the amount of SWS (Carter, 1996; Basner et al., 2004) and the amount and rhythmicity of REM sleep may be markedly affected (Naitoh, Muzet and Lienhard, 1975; Thiessen, 1988). In addition to their results from a laboratory study, Basner et al. (2004) present results from a field study with valid data for 63 subjects (aged 18–65 years) with 15 556 aircraft noise events included in the final analyses. They established a curve that gives the probability of awakening as a function of  $L_{Amax}$  with a model that assumed a background noise level just prior to the aircraft noise event of 27 dB(A). The  $L_{Amax}$  threshold for noise-induced awakenings was found to be about 35 dB(A). Above this threshold the probability of noise-induced awakenings increases monotonically up to circa 10% when  $L_{Amax} = 73$  dB(A). This is the extra probability of awakening associated with the aircraft noise event, on top of the probability of awakening spontaneously in a 90 second interval.

Some arousals provoked by noise events are so intense that they induce awakening. Frequent awakening leads to sleep fragmentation and overall sleep disturbance. The noise threshold for awakening is particularly high in deep SWS (stages 3 and 4) while it is much lower in shallower sleep stages (stages 1 and 2). In REM sleep the awakening threshold is variable and depends on the significance of the stimulus. Total

sleep time can be reduced by both a longer time to fall asleep and premature final awakening. It has been reported that intermittent noises with maximum noise levels of 45 dB(A) and above can increase the time taken to fall asleep by a few to 20 minutes (Öhrström, 1993). In the morning hours, the sleeper can be more easily awakened by ambient noise and has more difficulty going back to sleep because sleep pressure is progressively reduced with time (Rechtschaffen, Hauri and Zeitlin, 1966; Keefe, Johnson and Hunter, 1971).

Terzano et al. (1990, 1993) showed that with increasing intensity of sound pressure level (white noise at 45, 55, 65 and 75 dB(A)), white noise induced a remarkable enhancement of cyclic alternating patterns (CAP)/non-REM, characterized by a linear trend from the lowest to the highest intensities, revealed by a significant increase in the CAP rate already at 45 dB(A). Noise decreased mainly SWS, REM and total sleep time, and increased waking after sleep onset, stage 1 non-REM and CAP rate (Terzano et al., 1993). For CAP/non-REM values between 45% and 60%, subjects generally recalled a moderate nocturnal discomfort and values of CAP/non-REM over 60% corresponded to a severe complaint.

This result corroborates previous findings described by Lukas (1972a) who reported that reactions less intense than a sleep stage change correlate better to the noise intensity than awakening reactions.

### 3.1.5 CARDIOVASCULAR RESPONSE

For sleeping persons, mean heart rate, mean systolic and diastolic BP and variability in heart rate are usually assessed. Indicators of responses to individual noise events are instantaneous changes in (variability of) heart rate and changes in systolic BP. Several field studies (Carter et al., 1994) have been conducted regarding momentary change in heart rate. Intermittent noise during sleep has been found to induce a biphasic cardiac response and a transient constriction of peripheral vessels together with a short phasic activation in the EEG, while no other behavioural effect can be seen (Muzet and Ehrhart, 1978). This biphasic cardiac response starts with an increase in heart rate, probably due to a phasic inhibition of the parasympathetic cardio-inhibitory centre, followed by a compensatory decrease due to a phasic decrease in orthosympathetic activity (Keefe, Johnson and Hunter, 1971; Muzet and Ehrhart, 1980). The vasoconstrictive response was reported to be due to the sympathetic peripheral stimulation provoked by the auditory reflex (Kryter and Poza, 1980). More recently, Carter et al. (2002) have shown that beat-by-beat BP changes can be induced by suddenly occurring noises. Although habituation in some effect parameters can occur in a few days or weeks, this habituation is not complete and the measured modifications of the cardiovascular functions remain unchanged over long periods of exposure time (Muzet and Ehrhart, 1980; Vallet et al., 1983). Most striking is that none of the cardiovascular responses show habituation to noise after a prolonged exposure, while subjective habituation occurs within a few days. In people that are used to sleep in a noisy surrounding, noise-induced changes in heart rate are dependent on the maximum sound level of a noise event, but not on the EEG sleep stage).

### 3.1.6 BODY MOVEMENT

Motility is the term used for accelerations of the body or body parts during movement. It is measured with actimeters, usually worn on the wrist in field research and



the laboratory. Brink, Müller and Schierz (2006) describe a more sophisticated method which is based on the bed being placed on accelerometers. This allows the tracking of whole body movements.

Motility is related to many variables of sleep and health (Reyner, 1995; Reyner et al., 1995; Passchier-Vermeer et al., 2002). Clinical research shows that the sleep/wake cycle (assessed by polysomnography, EEG, EOG, EMG) passes through the 24-hour period synchronously with the rest/activity cycle (assessed by actimetry) (Borbely et al., 1981). A number of investigations have compared the results of polysomnographic recordings (number of EEG-awakenings during sleep period, duration of sleep period, sleep onset time, wake-up time) with results of actimetry. The correlation between actimetrically assessed duration of sleep period, sleep onset time, wake-up time and similar variables assessed with polysomnography was found to be very high (correlation coefficients between individual test results in the order of 0.8–0.9). Measures of instantaneous motility are the probability of motility and the probability of onset of motility in a fixed time interval, for example a 15-, 30- or 60-second interval. Increased instantaneous motility during sleep is considered to be a sensitive behavioural marker of arousal, but the relation with arousal is not simple. Also other factors, such as the need to relieve the pressure on body parts for better blood circulation, cause motility, and spontaneously occurring arousals are part of the normal sleep process. The noise-induced probability of (onset of) motility is the difference between the probability of (onset of) motility during noise events minus the probability in the absence of noise.

Onset of motility and minor arousal found on the basis of EEG recordings are highly correlated. In the United Kingdom sleep disturbance study, Ollerhead et al. (1992) found for their study population that during sleep there is on average an EEG (minor) arousal in 40% of the 30-second intervals with onset of motility. Unfortunately, it is unknown whether this 40% is also valid for noise-induced awakenings. In 12% of the 30-second intervals with an EEG (minor) arousal, motility does not occur. Several field studies (Horne et al., 1994; Fidell et al., 1998, 2000; Flindell, Bullmore and Robertson, 2000; Griefahn et al., 2000; Passchier-Vermeer et al., 2002, 2004) have been conducted regarding noise-induced instantaneous motility. For this effect, relationships have been established with SEL or  $L_{Amax}$  for aircraft noise only. In Passchier-Vermeer et al. (2002) relationships between noise-induced increase in motility or noise-induced increase in onset of motility in the 15-second interval with the maximum noise level of an overflight, and  $L_{Amax}$  or SEL have been approximated by quadratic functions (see, for instance, Fig. 3.2). It may be noted that the threshold of motility ( $L_{Amax} = 32$  dB(A)) is in the same range as the threshold found by Basner et al. (2004) for EEG awakenings, with a definition that also encompassed transitions to steep stage 1 ( $L_{Amax} = 35$  dB(A)). The probability of motility at 70 dB(A) of about 0.07 is lower than the probability of noise-induced EEG awakening at  $L_{Amax} = 73$  dB(A) of about 0.10. There is no a priori reason to expect the above threshold probabilities to be the same for these two measures of sleep disturbance, but, taking into account that motility is assessed for shorter intervals (15 seconds vs. 90 seconds), the differences in probabilities above threshold appear to be limited.

One of the variables influencing the relationships between noise-induced instantaneous motility and  $L_{Amax}$  or SEL, is long-term aircraft noise exposure during sleep. The probability of instantaneous aircraft noise-induced motility is lower when the long-term exposure is higher. This may be partly due to the higher base rate motility in quiet intervals in higher long-term exposure, which is used as a reference for



the instantaneous noise-induced motility. Other factors influencing the relationships between instantaneous motility and  $L_{Amax}$  or SEL are the point of time in the night, and time since sleep onset. For example, after 7 hours of sleep, noise-induced motility is about 1.3 larger than in the first hour of sleep. Age has only a slight effect on noise-induced motility, with younger and older people showing a lower motility response than persons in the age range of 40–50 years.

### 3.1.7 BEHAVIOURAL AWAKENING IN ADULTS

Passchier-Vermeer (2003a) published a review of nine studies on awakening by noise. It was found that these studies had different definitions of what constituted an “awakening”. In this review, however, all awakening data were collected on “behavioural awakening”: these are awakenings that were followed by an action (like pressing a button) from the sleeper. The number of awakenings defined in this manner is much smaller than the number of sleep stage changes which lead to EEG patterns similar to wakefulness.

Data were available for rail traffic noise, ambient (probably road) noise, civil aviation noise and military aviation noise.

The rail traffic noise study is very small (only 20 subject nights), but showed no awakenings. The study states that “there is some evidence, be it very limited, that railway noise events, in the range of  $SEL_{indoor}$  considered (up to 80 dB(A)), do not increase [the] probability of awakening”.

Ambient noise also showed no effect on the probability of awakening, but as it is uncertain exactly what noise is meant, no firm conclusions could be drawn.

Military aircraft noise showed a very strong effect, but this study is of limited applicability since the few subjects (military) lived near the end of the runway.

For civil aviation noise there were sufficient data to derive a dose-effect relation:

$$\begin{aligned} \text{Percentage of noise-induced awakenings} = \\ -0.564 + 1.909 \cdot 10^{-4} \cdot (SEL_{inside})^2 \end{aligned} \quad [4],$$

where  $SEL_{inside}$  is the sound exposure level of an aircraft noise event in the bedroom.

This relation is confined to commercial aircraft noise over the intervals  $54 < SEL < 90$  ( $37 < L_{Amax} < 82$ ) and the number of events per night  $1 < N < 10$ .

With this relation, it is possible to calculate for an individual  $L_{night}$  the expected number of noise-induced behavioural awakenings. This requires all single contributions over the year to this  $L_{night}$  to be known. Alternatively (if, for instance, a future situation has to be estimated for which no exact data are available) a worst case scenario can be calculated. Fig. 3.1 represents the results of this worst case approach (converted to  $L_{night}$ , see Chapter 1, section 1.3.4), and so gives the maximum number of awakenings  $n_{max}$  that may be expected.

$$n_{max} = 0.3504 \cdot 10^{(L_{night} - 35.2)/10} \quad [5].$$

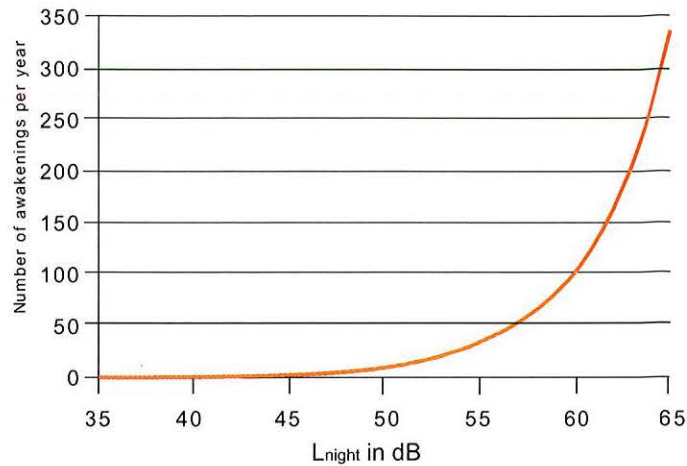


Fig. 3.1  
Worst case prediction of  
noise-induced behavioural  
awakenings.  
 $L_{night}$  converted from  
inside relation with [3]  
on page 10.

Source: Miedema, Passchier-Vermeer and Vos, 2003

It can be demonstrated that the number of awakenings reaches a maximum when the  $SEL_{inside}$  value is 58.8 dB(A).

It should be noted that, on average, 600 spontaneous awakenings per person are reported per year. This also explains why so many more awakenings are reported than can be attributed directly to aircraft noise. At 55  $L_{night}$ , nearly 100 overflights per night with  $SEL_{inside} = 58.8$ , or 1 every 5 minutes are possible. It is, therefore, very likely that an overflight coincides with a spontaneous awakening.

### 3.1.8 DOSE-EFFECT RELATIONS FOR BODY MOVEMENTS DURING SLEEP

In Passchier-Vermeer et al. (2002) motility is registered in 15-second intervals. A distinction is made between two variables:

- the *presence of motility* in the interval (indicated by  $m$ ) and
- the *onset of motility*, meaning the presence of motility when there was no motility in the preceding interval (indicated by  $k$ ).

Relations between a noise-induced increase in motility ( $m$ ) or a noise-induced increase in the onset of motility ( $k$ ) in the 15-second interval with the maximum sound level of an overflight, and  $L_{Amax,inside}$  or  $SEL_{inside}$  have been approximated by quadratic functions with the following format:

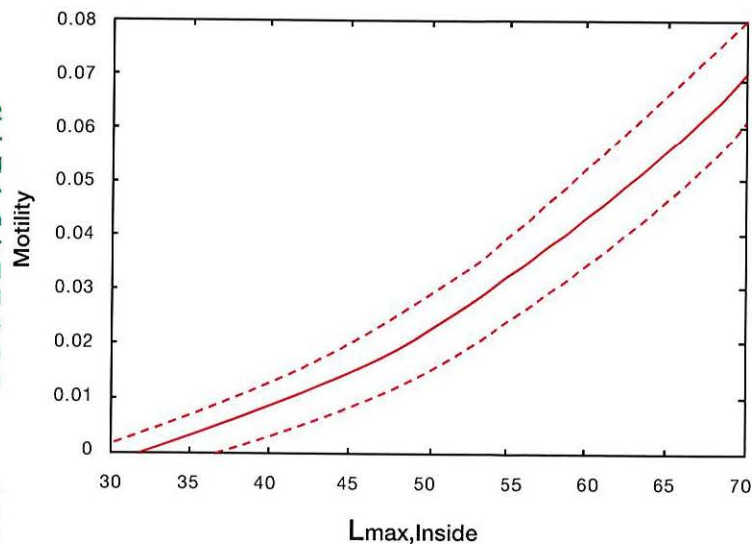
$$m = b * (L_{Amax,inside} - a) + c * (L_{Amax,inside} - a)^2 \quad [6].$$

The coefficients  $a$ ,  $b$  and  $c$  are given in Table 3.1. The value of  $a$  is the value below which  $m$  or  $k$  is zero. Fig. 3.2 shows the relationship between  $m$  and  $L_{Amax,inside}$  together with the 95% confidence interval. Relations apply to  $L_{Amax,inside}$  and  $SEL_{inside}$  values of at most 70 and 80 dB(A), respectively.

**Table 3.1.**  
Coefficients of the quadratic equation (formula [6]) of  $m$  and  $k$  as a function of  $L_{Amax,inside}$  or  $SEL_{inside}$  for the 15-second interval in which an indoor maximum sound level of an aircraft noise event occurs. The equations are applicable in the  $L_{Amax,inside}$  range from a up to 70 dB(A), or  $SEL_{inside}$  range from a up to 80 dB(A). Below a,  $m$  and  $k$  are zero.

	(Aircraft) noise-induced increase of probability of motility ( $m$ )	(Aircraft) noise-induced increase of probability of onset of motility ( $k$ )
range	$32 < L_{Amax,inside} < 70$ dB(A) (see Fig. 3.2)	$32 < L_{Amax,inside} < 70$ dB(A)
a	32	32
b	0.000633	0.000415
c	$3.14 \times 10^{-5}$	$8.84 \times 10^{-6}$
range	$38 < SEL_{inside} < 80$ dB(A)	$40 < SEL_{inside} < 80$ dB(A)
a	38	40
b	0.000532	0.000273
c	$2.68 \times 10^{-5}$	$3.57 \times 10^{-6}$

**Fig. 3.2**  
Probability of (aircraft) noise-induced motility ( $m$ ) at the 15-second interval in which the indoor maximum sound level occurs (solid line) and the 95% confidence interval, as a function of  $L_{Amax,inside}$  bedroom

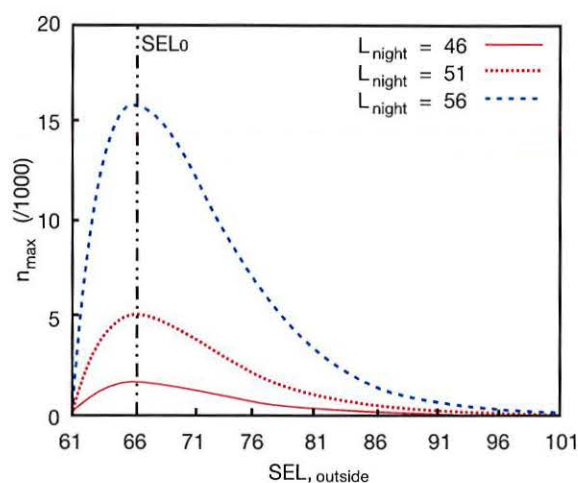


Source: Miedema, Passchier-Vermeer and Vos, 2003.

The study report also gives the upper boundaries for motility, based on the relationship between  $L_{Amax}$ ,  $SEL$  and  $L_{night}$  (Fig. 3.3). This figure is mathematically derived from relation [6] as described in Appendix 2.

This area of study is still under development. Miedema, Passchier-Vermeer and Vos (2003) give a detailed account in their study report of the relation between the study used for the data presented here (Passchier-Vermeer et al., 2002), earlier studies like the much quoted Civil Aviation Authority study (Ollerhead et al., 1992; Ollerhead, 1994) and earlier work done in the United States.





**Fig. 3.3**  
Maximum number of  
noise-induced motility for  
three values of  $L_{\text{night}}$ .  
Converted from inside  
relation with [3]  
on page 10

Source: Miedema,  
Passchier-Vermeer and Vos,  
2003.

### 3.1.9 INDIVIDUAL SENSITIVITY

Sensitivity to noise may vary greatly from one individual to another. Primary self-evaluation of sensitivity to noise has been used as a factor to evaluate highly sensitive and non-sensitive groups and to compare their reactions to noise exposure during daytime and night-time (Di Nisi et al., 1990). In this study, self-declared highly sensitive individuals had a higher cardiovascular response rate to noise than non-sensitive people during their waking exposure, while there was no difference in sensitivity to noise between these two groups during their night-time exposure while they were asleep.

The physiological sensitivity to noise depends also on the age of the sleeper. Thus, while EEG modifications and awakening thresholds are, on average, 10 dB(A) higher in children than in adults, their cardiovascular sensitivity to noise is similar, if not higher, than the older group (Muzet and Ehrhart, 1980; see also Appendix 4). Elderly people complain much more than younger adults about environmental noise. However, their spontaneous awakenings occurring during night sleep are also much more numerous. Therefore, it is difficult to conclude if elderly people are more sensitive to noise or if they hear noise because they are often awake during the night. This natural fragmentation of their night sleep tends also to lengthen their return to the sleeping state and this accounts for a significant part of their subjective complaints.

Differences in sensitivity to noise have been found between the sexes. Thus, young men seem to complain more about noise-disturbed sleep than young females (Muzet et al., 1973). However, this difference seems to reverse for populations over 30 years of age and then females (often mothers) appear to be more sensitive to noise than males (Lukas, 1972b).

### 3.1.10 USE OF INSTANTANEOUS EFFECTS IN PREDICTIONS OVER A LONGER TIME PERIOD

It is tempting to use the relations between single exposures and measured effects in long-term predictions. Although this is perhaps possible, a word of caution is appropriate.

In general, the reactions are calculated by looking at a certain time frame around an exposure, usually in the order of a few minutes. The second limitation is that order and follow-up effects are neglected. Time and order effects of identical events on

motility have been described by Brink, Wirth and Schierz (2006). Only if the situation that is modelled resembles the one that was used in the single exposure analysis, are no major deviations to be expected. Reactions to noise events are generally not independent from each other. Each event may alter a subject's tendency to awake at the next event, even if no awakening reaction is detected for that particular event. If, for example, each event would additionally increase the probability of awakening at the next event, the total probability of awakening per night would be greater than predicted by mere summation of the single event probabilities. Most likely, this underestimation of probability will occur when events in the real situation follow in close succession, whereas events in the single exposure analysis did not. Such limitations can to some degree be overcome through applying advanced statistical methods such as those put forward by Basner (2006). A third limitation is that an overall increase in the base line could go undetected.

If the situation that is calculated resembles the one that was used in the single exposure analysis, probably no major deviations are to be expected. Care should be taken to extrapolate outside the boundaries given in the number of events or  $L_{Amax}$ . Calculations for Amsterdam Schiphol Airport show a good agreement between the number of calculated awakenings per year (based on the actual SEL data) and the self-reported number of awakenings. This number is a factor 2 lower than the worst case scenario presented in section 3.1.7 above.

### 3.2 CHRONIC EFFECTS: CHRONIC INCREASE OF MOTILITY

Mean motility – all body movements counted together – during sleep is strongly related to age and is also a function of noise exposure during the sleep period. The relationships between mean motility and  $L_{night,inside}$  are shown in Fig. 3.4. Mean motility during sleep is lowest at the age of 45 years, and greater at higher and lower ages. The relation between mean motility,  $L_{night,inside}$  and age is:

$$\text{Mean motility} = 0.0587 + 0.000192 * L_{night,inside} - 0.00133 * \text{age} + 0.0000148 * \text{age}^2 \quad [7].$$

The relation between the increase in mean noise-induced motility,  $m_{night}$ , and  $L_{night,inside}$  is:

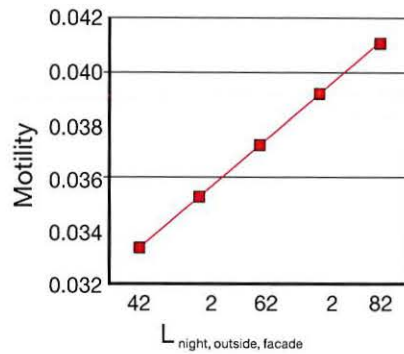
$$m_{night} = 0.000192 * L_{night,inside} \quad [8],$$

assuming, as described in Chapter 1, section 1.3.4, that  $L_{night,inside} = L_{night} - 21$ :

$$m_{night} = 0.000192 * L_{night} - 0.004032 \quad [8a].$$

Source: Miedema, Passchier-Vermeer and Vos, 2003.





**Fig. 3.4**  
Increase in mean motility (body movements during sleep). Converted from inside relation with [3]

The increase in  $m_{\text{night}}$  is 22% over the baseline motility (0.03 on average) if indoor  $L_{\text{night, inside}}$  increases from 0 (absence of aircraft noise) to 35 dB(A) (living close to a runway). This increase is independent of age, although the absolute level varies.

Other chronic effects like the use of sleeping pills, changes in BP and changes in levels of stress hormones are discussed in the next chapter.

### 3.3 CONCLUSIONS

During sleep the auditory system remains fully functional. Incoming sounds are processed and evaluated and although physiological changes continue to take place, sleep itself is protected because awakening is a relatively rare occurrence. Adaptation to a new noise or to a new sleeping environment (for instance in a sleep laboratory) is rapid, demonstrating this active protection. The physiological reactions do not adapt, as is shown by the heart rate reaction and the increase of average motility with sound level. The autonomous physiological reactions are a normal reaction to these stimuli, but the question is whether prolonged “abuse” of this system leads to adverse consequences for the organism. The next chapter tries to answer that.



## CHAPTER 4

### EFFECTS OF NIGHT-TIME NOISE ON HEALTH AND WELL-BEING

*The sick die here because they can't sleep,  
For when does sleep come in rented rooms?  
It costs a lot merely to sleep in this city!  
That's why everyone's sick: carts clattering  
Through the winding streets, curses hurled  
At some herd standing still in the middle of the road,  
Could rob Claudius or a seal of their sleep!*

(Juvenal, 1st century AD)

#### 4.1 INTRODUCTION

In Chapters 2 and 3, sufficient evidence was presented to support the hypothesis for the simplified model presented in Chapter 1: sleep disturbance is connected to health impairment, and noise is an important factor that causes sleep disturbance. The full model (Fig. 2.1, Chapter 2) showed why it is difficult to find evidence for a direct relation between noise exposure at night and health outcomes. Noise is but one of the internal and external factors that cause sleep disturbance and feedback loops obscure the view of the cause and effect chain. In this chapter the evidence for the direct relation is presented.

#### 4.2 SELF-REPORTED (CHRONIC) SLEEP DISTURBANCES

Self-reported sleep disturbance is investigated by means of a questionnaire containing questions regarding sleep disturbance. Often, sleep disturbance is not the main focus of the questionnaires used in studies of self-reported noise effects. This means that considerable effort is needed to harmonize the different response categories. The relationships for self-reported sleep disturbance are based on analyses of the 15 data sets with more than 12 000 individual observations of exposure-response combinations, from 12 field studies (Miedema, 2003; Miedema, Passchier-Vermeer and Vos, 2003).

The curves are based on data in the  $L_{\text{night}}$  (outside, most exposed facade) range 45–65 dB(A). The polynomial functions are close approximations of the curves in this range and their extrapolations to lower exposure (40–45 dB(A)) and higher exposure (65–70 dB(A)). The formulae of these polynomial approximations are as follows (SD = sleep disturbance; H = high; L = low):

for road traffic:

$$\%HSD = 20.8 - 1.05 * L_{\text{night}} + 0.01486 * (L_{\text{night}})^2 \quad [9]$$

$$\%SD = 13.8 - 0.85 * L_{\text{night}} + 0.01670 * (L_{\text{night}})^2 \quad [10]$$

$$\%LSD = -8.4 + 0.16 * L_{\text{night}} + 0.01081 * (L_{\text{night}})^2 \quad [11]$$

for aircraft:

$$\%HSD = 18.147 - 0.956 \cdot L_{\text{night}} + 0.01482 \cdot (L_{\text{night}})^2 \quad [12]$$

$$\%SD = 13.714 - 0.807 \cdot L_{\text{night}} + 0.01555 \cdot (L_{\text{night}})^2 \quad [13]$$

$$\%LSD = 4.465 - 0.411 \cdot L_{\text{night}} + 0.01395 \cdot (L_{\text{night}})^2 \quad [14]$$

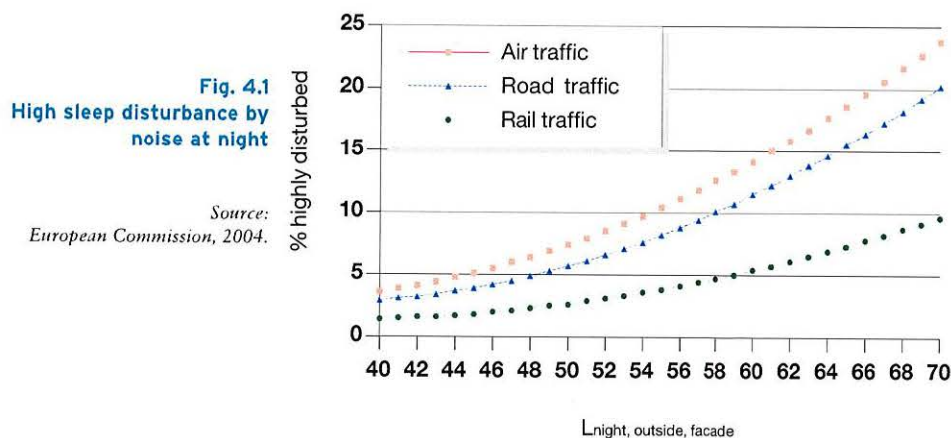
and for railways:

$$\%HSD = 11.3 - 0.55 \cdot L_{\text{night}} + 0.00759 \cdot (L_{\text{night}})^2 \quad [15]$$

$$\%SD = 12.5 - 0.66 \cdot L_{\text{night}} + 0.01121 \cdot (L_{\text{night}})^2 \quad [16]$$

$$\%LSD = 4.7 - 0.31 \cdot L_{\text{night}} + 0.01125 \cdot (L_{\text{night}})^2 \quad [17].$$

The above relations represent the current best estimates of the influences of  $L_{\text{night}}$  on self-reported sleep disturbance for road traffic noise and for railway noise, when no other factors are taken into account. Fig. 4.1 illustrates the relations [9] [12] and [15] for persons highly disturbed by road, aircraft and rail noise.



With regard to the relations for aircraft noise it should be noted that the variance in the responses is large compared to the variance found for rail and road traffic. This means that the uncertainty regarding the responses for night-time aircraft noise is large, and such responses can be considered as indicative only. Miedema (2003) suggests the following causes.

- The time pattern of noise exposures around different airports varies considerably due to specific night-time regulations.
- The sleep disturbance questions for aircraft noise show a large variation.
- The most recent studies show the highest self-reported sleep disturbance at the same  $L_{\text{night}}$  level. This suggests a time trend.

For industrial noise there is an almost complete lack of information, although there are some indications (Vos, 2003) that impulse noise may cause considerable disturbance at night.

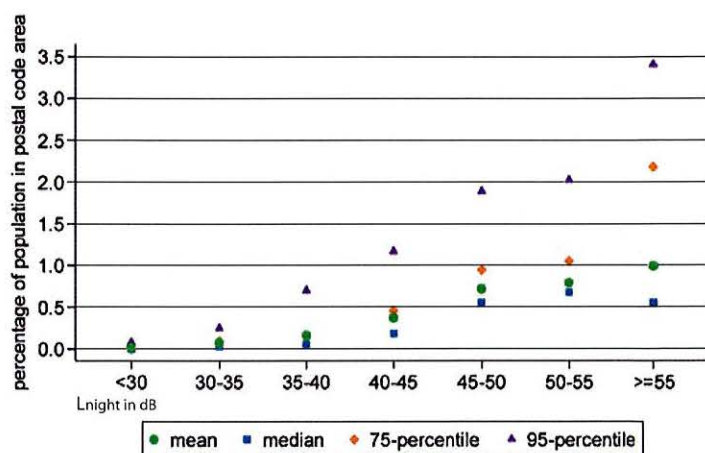


### 4.3 COMPLAINTS

According to the Health Council of the Netherlands (2004), the submission of a complaint about noise is symptomatic of reduced well-being.

Complaints about noise are widespread, and night noise seems to cause more complaints than daytime noise at the same level. Hume, Morley and Thomas (2003) found that around Manchester Airport complaints per 1000 aircraft traffic movements rose from an average of 10 in daytime hours to up to 80 in the night. When linking part of the complaints to measured noise levels, they found an increase from an average of 1 complaint at 70 PNLdB (circa 58  $L_{Amax}$ ) to 2 at 114 PNLdB (circa 102  $L_{Amax}$ ).

Due to differences in complaint cultures and registration practices, it is difficult to make comparisons between complaint registrations. Around Amsterdam Schiphol Airport a relation between complaints and  $L_{Aeq}$  was found (Ministerie Verkeer en Waterstaat, 2005). The threshold for complaints is around 45  $L_{den}$ , and increases to 7% of the population at 72  $L_{den}$ . Night-time complaints follow the same pattern, and the threshold for night complaints is 35  $L_{night}$ . In Fig. 4.2 the mean percentage shows a definite relationship with  $L_{night}$ . The 95 percentile indicates that the threshold is 35  $L_{night}$ .



**Fig. 4.2**  
Dose-effect relation  
for persons having  
complained at least  
once during a year  
between 1994 and  
2004

Source:  
Ministerie Verkeer en  
Waterstaat (2005).

### 4.4 NEIGHBOURHOOD NOISE AND NOISE FROM NEIGHBOURS

Inventory studies in the Netherlands indicate that sleep disturbance attributable to the most annoying forms of neighbourhood noise and noise from neighbours (contact noise and human noises in the environment) is on a similar scale to disturbance attributable to the most annoying sources of road traffic noise (mopeds and passenger cars). It is reasonable to assume that chronic sleep disturbance is, in the long term, liable to have consequences for health and well-being. The sound pressure level and other noise characteristics are liable to determine the nature of the influence to some extent, but certain other factors play a more prominent role than is the case with traffic noise. These factors include appreciation of the noise and of the party responsible for the noise, as well as the hearer's personal circumstances. However, scientific understanding of the relative importance of and interaction between



acoustic and non-acoustic factors is not sufficient for the committee to draw any definitive conclusions regarding the relationship between, on the one hand, exposure to night-time neighbourhood noise and noise from neighbours and, on the other, health and well-being.

Leidelmeijer and Marsman (1997) carried out an interview-based study of 1242 households in the Netherlands, in which subjects were asked about daytime and night-time noise from neighbours and any associated annoyance. A distinction was made on the basis of the part of the house in which the noises were audible and any associated annoyance was experienced. Subjects proved least tolerant of noise from their neighbours that was audible in the master bedroom. The researchers distinguished five types of noise, which are listed below (Table 4.1), along with the percentage of subjects who indicated hearing the relevant type of noise from a neighbouring dwelling at night in the master bedroom.

**Table 4.1**  
Daytime and night-time noise from neighbours

Source:  
Leidelmeijer and  
Marsman, 1997.

Type of noise	% subjects hearing noises at night in the bedroom
Contact noise	22%
Noise from sanitary fittings, central heating, etc.	19%
Noise from radio, TV and hi-fi	12%
Do-it-yourself noises	8%
Pets	6%

Where each of the five investigated types of noise was concerned, roughly 10–15% of subjects indicated that they felt it was unacceptable for the noise to be audible during the day. Overall, nearly 30% of subjects said that sanitary fittings should not be audible at night, while approximately 50% felt each of the other four types of noise was unacceptable at night.

In 1993, Kranendonk, Gerretsen and van Luxemburg produced a synthesis of the research conducted up to that point in time into the annoyance associated with noise from neighbours. Subsequently, in 1998, van Dongen et al. published a report on the relationship between noise from neighbouring dwellings and the airborne and contact noise attenuating indices  $I_{lu}$ ,  $I_{lu,k}$  and  $I_{co}$ , drawing on data from a questionnaire-based survey of the residents of 600 dwellings, whose acoustic quality was determined in 202 cases. The results of the two studies are reasonably consistent. Both found that the chief causes of annoyance were loud radios, hi-fis and TVs, audible and sometimes intelligible voices, the slamming of doors and footsteps on floors and staircases. In both cases, it proved that, when  $I_{lu}$  had a value of 0 (the minimum requirement for new homes), 10% of subjects reported high annoyance and 15% reported annoyance caused by noise from neighbouring dwellings. These figures are not specific to night-time noise, but apply to annoyance over a 24-hour period.

On the basis of the findings outlined above, the committee concludes that the standard of inter-dwelling sound attenuation presently required does not provide sufficient protection to prevent annoyance caused by noise from neighbours. Since people are less tolerant of the noise their neighbours make at night-time than of their neighbours' evening or daytime noise, it may be assumed that much of the annoyance associated with noise from neighbours relates to the influence of such noise on sleep.

## 4.5 CARDIOVASCULAR EFFECTS OF NOISE – FINDINGS FROM EPIDEMIOLOGICAL STUDIES

### 4.5.1 INTRODUCTION

It is a common experience that noise is unpleasant and affects the quality of life. It disturbs and interferes with activities of the individual including concentration, communication, relaxation and sleep (WHO Regional Office for Europe, 2000; Schwela, 2000). Besides the psychosocial effects of community noise, there is concern about the impact of noise on public health, particularly regarding cardiovascular outcomes (Suter, 1992; Passchier-Vermeer and Passchier, 2000; Stansfeld, Haines and Brown, 2000). Non-auditory health effects of noise have been studied in humans for a couple of decades using laboratory and empirical methods. Biological reaction models have been derived, which are based on the general stress concept (Selye, 1956; Henry and Stephens, 1977; Ising et al., 1980; Lercher, 1996). Amongst other non-auditory health end points, short-term changes in circulation including BP, heart rate, cardiac output and vasoconstriction, as well as stress hormones (epinephrine, norepinephrine and corticosteroids) have been studied in experimental settings for many years (Berglund and Lindvall, 1995; Babisch, 2003). Various studies have shown that classical biological risk factors are higher in subjects who were exposed to high levels of traffic noise (Arguelles et al., 1970; Eiff et al., 1974; Verdun di Cantogno et al., 1976; Algers, Ekesbo and Strömberg, 1978; Knipschild and Sallé, 1979; Manninen and Aro, 1979; Eiff et al., 1981a; Rai et al., 1981; Marth et al., 1988; Babisch and Gallacher, 1990; Babisch et al., 1990; Lercher and Kofler, 1993; Schulte and Otten, 1993; Dugué Leppänen and Gräsbeck, 1994; Yoshida et al., 1997; Goto and Kaneko, 2002). Although controls for other risk factors were not consistent in all these studies, the hypothesis emerged that persistent noise stress increases the risk of cardiovascular disorders including high BP (hypertension) and IHD.

- Sound/noise is a psychosocial stressor that activates the sympathetic and endocrine system.
- Acute noise effects do not only occur at high sound levels in occupational settings, but also at relatively low environmental sound levels when, more importantly, intended activities such as concentration, relaxation or sleep are disturbed.

The following questions need to be answered.

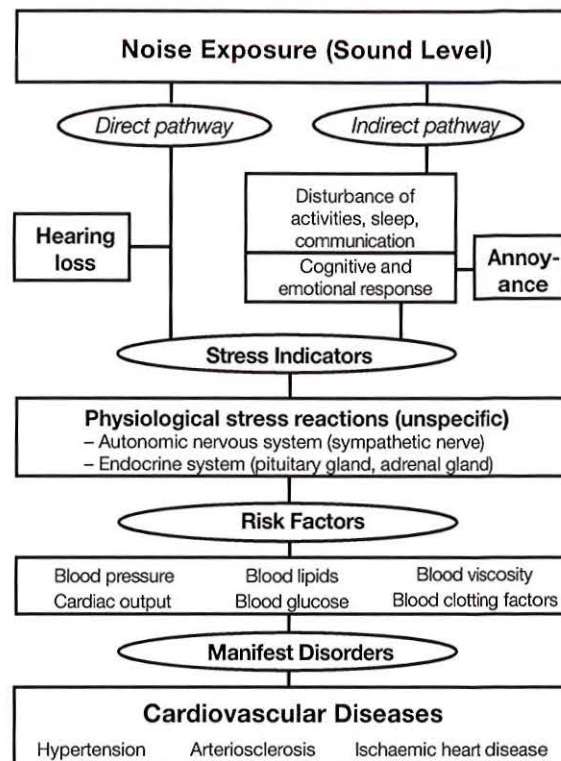
- Do these changes observed in the laboratory habituate or persist under chronic noise exposure?
- If they habituate, what are the physiological costs? If they persist, what are the long-term health effects?

The answers to these questions come from epidemiological noise research. Large-scale epidemiological studies have been carried out for a long time (Babisch, 2000). The studies suggest that transportation noise is associated with adverse cardiovascular effects, in particular IHD. The epidemiological evidence is constantly increasing (Babisch, 2002, 2004a). The biological plausibility of the association derives from the numerous noise experiments that have been carried out in the laboratory. There is no longer any need to prove the noise hypothesis as such. Decision-making and risk management, however, rely on a quantitative risk assessment which requires an established dose-response relationship. Since many of the stress indicators and risk factors that have been investigated in relation to



**Fig. 4.3**  
Noise effects  
reaction scheme

Source:  
Babisch, 2002.



noise are known to be classical cardiovascular risk factors, the hypothesis has emerged that chronic noise exposure increases the risk of hypertension, arteriosclerosis and IHD. Its relevance for public health comes from the high prevalence of cardiovascular diseases in developed and industrialized countries. It is unclear as to what extent chronically repeated noise-induced sleep disturbance contributes to the development of somatic health disorders. Only a few epidemiological studies address this particular issue. Epidemiological noise research has seldom distinguished between day and night exposures, or between the exposure of the living room and the bedroom. However, some deduction can be made from daytime to night-time exposure.

#### 4.5.2 NOISE AND STRESS-REACTION MODEL

The auditory system is continuously analysing acoustic information, which is filtered and interpreted by different cortical and subcortical brain structures. The limbic system, including the hippocampus and the amygdala, plays an important role in the emotional processing pathways (Spreng, 2000). It has a close connection to the hypothalamus that controls the autonomic nervous system and the hormonal balance of the body. Laboratory studies found changes in blood flow, BP and heart rate in reaction to noise stimuli as well as increases in the release of stress hormones including the catecholamines adrenaline and noradrenaline, and the corticosteroid

cortisol (Berglund and Lindvall, 1995; Maschke, Rupp and Hecht, 2000; Babisch, 2003). Such changes also occur during sleep without the involvement of cortical structures. The amygdala has the capacity to learn due to its plasticity, particularly with respect to the meaning of sound stimuli (for example, danger of an approaching lorry) (Spreng, 2000, 2004). Acoustic stimulation may act as an unspecific stressor that arouses the autonomous nervous system and the endocrine system. The generalized psychophysiological concept given by Henry and Stephens can be applied directly to noise-induced stress reaction (Henry, 1992). The stress mechanism as such is genetically determined but it may be modified by experience and environmental factors. Its biological function is to prepare the organism to cope with a demanding stressor. The arousal of the sympathetic and endocrine system is associated with changes in physiological functions and the metabolism of the organism, including BP, cardiac output, blood lipids (cholesterol, triglycerides, free fatty acids, phosphatides), carbohydrates (glucose), electrolytes (magnesium, calcium), blood clotting factors (thrombocyte aggregation, blood viscosity, leukocyte count) and others (Friedman and Rosenman, 1975; Cohen, Kessler and Underwood Gordon, 1995; Lundberg, 1999). In the long term, functional changes and dysregulation may occur, thus increasing the risk of manifest diseases.

Fig. 4.3 shows the principal reaction schema used in epidemiological noise research for hypothesis testing (Babisch, 2002). It simplifies the cause-effect chain, that is: sound – annoyance (noise) – physiological arousal (stress indicators) – (biological) risk factors – disease – and mortality (the latter is not explicitly considered in the graph). The mechanism works “directly” through synaptic nervous interactions and “indirectly” through the emotional and the cognitive perception of the sound. It should be noted that the “direct” pathway is relevant even at low sound levels particularly during sleep, when the organism is at its nadir of arousal. The objective noise exposure (sound level) and the subjective noise “exposure” (annoyance) may serve independently as exposure variables in the statistical analyses of the relationship between noise and health end points.

Principally, the effects of environmental noise cannot directly be extrapolated from results of occupational noise studies. The two noise environments cannot simply be merged into one sound energy-related dose-response model (for example, a simple 24-hour average noise level measured with a dose-meter). Noise effects are not only dependent on the sound intensity but also on the frequency spectrum, the time pattern of the sound and the individuals’ activities which are disturbed. Therefore, epidemiological studies carried out under real-life conditions can provide the basis for a quantitative risk assessment provided that there is adequate control over confounding and exposure variables. Other noise sources might act as confounders and/or effect modifiers on the association of interest. The effects of road traffic noise (at home) were shown to be stronger in subjects who were also exposed to high noise levels at work (Babisch et al., 1990).

#### 4.5.3 PREVIOUS REVIEWS ON ENVIRONMENTAL NOISE AND CARDIOVASCULAR RISK

Causality in epidemiology can never be completely proven (Schlesselman, 1987; Christoffel and Teret, 1991; Weed, 2000). It is a gradual term for which evidence is increasing with the increasing number of facts. However, the magnitude of effect, the presence of a dose-response relationship and consistency with other studies in different populations and with different methodology and biological plausibility are



commonly accepted arguments for a causal relationship (Bradford Hill, 1965; Evans, 1976; Morabia, 1991; Weed and Hursting, 1998). Classical, systematic and quantitative reviews have been published in the past, summarizing the results of studies that have been carried out up to the end of the last century, and assessing the evidence of the relationship between community noise and cardiovascular disease outcomes (Health Council of the Netherlands, 1994, 1999, 2004; Berglund and Lindvall, 1995; IEH, 1997; Morrell, Taylor and Lyle, 1997; Porter, Flindell and Berry, 1998; Babisch, 2000; Passchier-Vermeer and Passchier, 2000), including a classical review and synthesis report by Babisch (2000) and a systematic review (meta-analysis) by van Kempen et al. (2002).

In a meta-analysis it was concluded that the risk of hypertension due to aircraft noise was 1.26 per increase of 5 dB(A) (95% CI: 1.14–1.39,  $L_{day} = 55\text{--}72$  dB(A)) (van Kempen et al., 2002). But, only one study (Knipschild, 1977a) was considered in the meta-analysis. With respect to road traffic noise and hypertension a pooled estimate of 0.95 per 5 dB(A) (95% CI: 0.84–1.08,  $L_{day} = <55\text{--}80$  dB(A)) was calculated (van Kempen et al., 2002). Two cross-sectional studies (Knipschild and Sallé, 1979; Knipschild, Meijer and Sallé, 1984) were considered in this calculation. The highest degree of evidence was for the association between community noise and IHD. Across the studies there was not much indication of an increased risk for subjects who lived in areas with a daytime average sound pressure level of less than 60 dB(A). For higher noise categories, however, higher risks were relatively consistently found amongst the studies (Babisch, 2004a). Statistical significance was rarely achieved.

Some studies permit reflections on dose-response relationships. These mostly prospective studies suggest an increase in risk for outdoor noise levels above 65–70 dB(A) during the daytime, the relative risks ranging from 1.1 to 1.5. Noise effects were larger when mediating factors like years in residence, room orientation and window-opening habits were considered in the analyses. In a meta-analysis it was concluded that the risk of IHD increased by 1.09 per 5 dB(A) of the road traffic noise level (95% CI: 1.05–1.13,  $L_{day} = 51\text{--}70$  dB(A)) (van Kempen et al., 2002), when two cross-sectional studies (Babisch et al., 1993a) were considered. However, the pooled estimate of two prospective studies (Babisch et al., 1999) was calculated to be 0.97 per 5 dB(A) (95% CI: 0.90–1.04,  $L_{day} = 51\text{--}70$  dB(A)) (van Kempen et al., 2002). When the diagnosis of IHD was limited to myocardial infarction, three studies (Babisch et al., 1999, 1994) were considered in this meta-analysis. Then the linear effect estimate was 1.03 per 5 dB(A) increase in road traffic noise level (95% CI: 0.99–1.09,  $L_{day} = 51\text{--}80$  dB(A)). New studies have appeared in the meantime which are included in the present updated review (Matsui et al., 2001; Bluhm, Nordling and Berglund, 2001; Evans et al., 2001; Rosenlund et al., 2001; Belojevic and Saric-Tanaskovic, 2002; Goto and Kaneko, 2002; Lercher et al., 2002; Maschke, 2003; Franssen et al., 2004; Matsui et al., 2004; Niemann and Maschke, 2004; Babisch et al., 2005). Others are on their way or have not yet been finalized and published, for instance the pan-European HYENA project (Jarup et al., 2003).

#### 4.5.4 UPDATED REVIEW OF EPIDEMIOLOGICAL STUDIES

Sixty epidemiological studies were recognized as having either objectively or subjectively assessed the relationship between transportation noise and cardiovascular end points. The identification of studies was based on the author's expert



knowledge of the topic and respective literature. Details are given in the major report (Babisch, 2006). Information particularly on night-time exposure ( $L_{\text{night}}$ : 22.00–06.00 or 23.00–07.00) was seldom available. Newer studies used non-weighted or weighted averages of the 24-hour exposure ( $L_{\text{eq}}$ ,  $L_{\text{dn}}$ ,  $L_{\text{den}}$ ). Some aircraft noise studies used national calculation methods (for example, Dutch Kosten Units). For comparisons of study results and the pooling of data (meta-analysis), sound levels were converted on the basis of best guess approximations to  $L_{\text{day}}$  (Matschat and Müller, 1984; Passchier-Vermeer, 1993; Bite and Bite, 2004; Franssen et al., 2004). It should be noted in this context that doubling/halving of road traffic volume results in a 3 dB(A) higher/lower average sound pressure level. Not all studies allowed dose–response reflections because some of them considered very broad exposure categories. Besides objective noise measurements, subjective measurements of exposure have been used in some epidemiological noise studies, which is in accordance with the noise–stress model. Type of road (for example, busy street, side street, etc.), disturbances and annoyance were rated by the study subjects from given scales.

#### 4.5.5 MEAN BP

Table A2 of the major report (Babisch, 2006) lists the major findings of epidemiological traffic noise studies in which mean BP was considered as the outcome. It indicates mean systolic and diastolic BP differences as obtained from extreme group comparisons of noise exposure. The effects in children and in adults are discussed separately. The findings in children are difficult to interpret with regard to possible health risks in their later life. The effect may be of a temporary nature and may not be relevant to permanent health damage. There is evidence during childhood (Gillman et al., 1992), adolescence (Yong et al., 1993) and adulthood (Tate et al., 1995) that the BP level at an early age is an important predictor of the BP level at a later age. Studies over the full age range are missing (tracking). Growth and body weight are important factors in BP development. The impact of body size was not adequately considered in some of the studies. A crude hint regarding reversible effects on BP came from one study (Morrell et al., 2000). Results of the Munich intervention study on the effects of a reduction of aircraft noise have only been reported regarding cognitive performance but not with respect to change of BP (Hygge, Evans and Bullinger, 2002). It was concluded from the available data on the length of exposure that children do not seem to adapt to high levels of road traffic noise but to some extent to aircraft noise (Passchier-Vermeer, 2000; Bistrup et al., 2001). However, the database appears to be too poor to draw final conclusions. Aircraft noise studies focused on exposure at school, while road traffic noise studies mostly considered noise exposure at home. The conclusions given by Evans and Lepore (1993) seem still to hold true:

“We know essentially nothing about the long-term consequences of early noise exposure on developing cardiovascular systems. The degree of blood pressure elevations is small. The clinical significance of such changes in childhood blood pressure is difficult to determine. The ranges of blood pressure among noise-exposed children are within the normal levels and do not suggest hypertension. The extent of BP elevations found from chronic exposure are probably not significant for children during their youth, but could portend elevations later in life that might be health damaging.”

Regarding mean BP, no consistent findings in the relationship between traffic noise level and mean systolic or diastolic BP can be seen in adults across the studies. In longitudinal studies, problems arose from migration of subjects, which had a considerable impact on sample size. The latter problem also applies to cross-sectional studies, in general. Sensitive subjects may tend to move out of the polluted areas, which dilutes the effect of interest. Medication due to high BP may affect the BP readings. However, the exclusion of subjects with hypertension or hypertension treatment dilutes the true effect on BP differences, if the hypothesis (noise causes high BP) is true. In principle, hypotension – a fall in BP – can also be a stress reaction. All this makes it more reasonable to look at manifest hypertension (defined by a cut-off criterion) as a clinical outcome rather than at mean BP readings (Ising, 1983; Winkleby, Ragland and Syme, 1988). To date, there is no evidence from epidemiological data that community noise increases mean BP readings in the adult population. However, this does not discard the noise hypothesis as such. Studies suffered from insufficient power, narrow exposure range or other difficulties in the study design.

#### 4.5.6 HYPERTENSION

Table A3 of the major report (Babisch, 2006) gives the results of epidemiological traffic noise studies on the relationship between community noise level and the prevalence or incidence of hypertension. Hypertension in these studies was either defined by WHO criteria (WHO-ISH Guidelines Subcommittee, 1999), similar criteria based on measurements of systolic and diastolic BP, from information which was obtained from a clinical interview, or a social survey questionnaire about hypertension diagnosed by a doctor. Most studies refer to road traffic noise. However, in recent years some new aircraft noise studies entered the database. The subjects studied were the adult male and female population, sometimes restricted to certain age ranges. With regard to the association between community noise and hypertension, the picture is heterogeneous. With respect to aircraft noise and hypertension, studies consistently show higher risks in higher exposed areas. The evidence has improved since a previous review (Babisch, 2000). The relative risks found in four significantly positive studies range between 1.4 and 2.1 for subjects who live in high exposed areas, with approximate daytime average sound pressure level in the range of 60–70 dB(A) or more. Swedish studies found a relative risk of 1.6 at even lower levels >55 dB(A). With respect to road traffic noise, the picture remains unclear. New studies, more than older studies, tend to suggest a higher risk of hypertension in subjects exposed to high levels of road traffic noise, showing relative risks between 1.5 and 3.0. However, the earlier studies cannot be neglected in the overall judgement process. Across all studies no consistent pattern of the relationship between community noise and prevalence of hypertension can be seen. Dose–response relationships were considered in new studies. Subjective ratings of noise or disturbances due to traffic noise seem to consistently show a positive association with prevalence of hypertension. The relative risks found here range from 0.8 to 2.3. These studies, however, are of lower validity due to principal methodological issues regarding over-reporting (Babisch et al., 2003).

#### 4.5.7 IHD

Table A5 of the major report (Babisch, 2006) gives the results of cross-sectional epidemiological traffic noise studies on the relationship between noise level and prevalence of IHD. Table A6 of the major report gives the results of case-control



and cohort studies on the association between noise level and incidence of IHD. In cross-sectional studies, IHD prevalence was assessed by clinical symptoms of angina pectoris, myocardial infarction, ECG abnormalities as defined by WHO criteria (Rose and Blackburn, 1968), or from self-reported questionnaires regarding doctor-diagnosed heart attack. In longitudinal studies, IHD incidence was assessed by clinical myocardial infarction as obtained from hospital records, ECG measurements or clinical interviews. The majority of studies refer to road traffic noise. With regard to IHD, the evidence of an association between community noise and IHD risk has increased since a previous review (Babisch, 2000). There is not much indication of a higher IHD risk for subjects who live in areas with a daytime average sound pressure level of less than 60 dB(A) across the studies. For higher noise categories, a higher IHD risk was relatively consistently found amongst the studies. Statistical significance was rarely achieved. Some studies permit reflections on dose-response relationships. These mostly prospective studies suggest an increase in IHD risk at noise levels above 65–70 dB(A), the relative risks ranging from 1.1 to 1.5 when the higher exposure categories were grouped together. Noise effects were larger when mediating factors like residence time, room orientation and window-opening habits were considered in the analyses. This accounts for an induction period (Rose, 2005) and improves exposure assessment. The results appear as consistent when subjective responses of disturbance and annoyance are considered, showing relative risks ranging from 0.8 to 2.7 in highly annoyed/disturbed/affected subjects. However, these findings may be of lower validity due to methodological issues.

#### 4.5.8 MEDICATION AND DRUG CONSUMPTION

Table A8 of the major report (Babisch, 2006) gives the results of studies on the relationship between drug consumption and community noise. Medication was primarily investigated with respect to aircraft noise. A significant prevalence ratio for medication with cardiovascular drugs of 1.4 was found in the sample of Amsterdam Schiphol Airport (Knipschild, 1977a). The results of the “drug survey”, where the annual data of the pharmacies regarding the purchase of cardiovascular drugs were analysed (repeated cross-sectional survey), supported this finding. An increase in drug purchase over time in the exposed areas and not in the less exposed was found. This refers to the purchase of cardiovascular and antihypertensive drugs, as well as the purchase of hypnotics, sedatives and antacids (Knipschild and Oudshoorn, 1977). Furthermore a dependency with changes in night flight regulations was found (decrease after reduction of night flights). A large recent study around Amsterdam Schiphol Airport found only a slightly higher risk of self-reported medication with cardiovascular drugs, including antihypertensive drugs (relative risk 1.2), in subjects exposed to aircraft noise where the noise level  $L_{den}$  exceeded 50 dB(A) (Franssen et al., 2004). Dose-response relationships across noise levels ( $L_{den} = <50$ –65 dB(A)) with respect to prescribed and non-prescribed sedatives/sleeping pills were found (relative risk 1.5 and 2.0, respectively) in the highest noise category of  $L_{den} = 61$ –65 dB(A). The preliminary results of an ongoing aircraft noise study from Sweden carried out around Stockholm’s airport are in line with the Dutch studies (Bluhm et al., 2004). A significant relative risk of 1.6 for the use of antihypertensive drugs was found in male subjects, where the noise level according to the Swedish calculation standard exceeded FBM = 55 dB(A). The road traffic noise studies, where medication/purchase of drugs was investigated also tend to show a higher use in higher exposed subjects (Eiff and Neus, 1980; Schulze et al., 1983; Lercher,

1992). The relative risk for cardiovascular drugs was 1.3 in the Bonn study and 5.0 in the Erfurt study. The results for other drugs including sleeping pills, sedatives, tranquillizers and hypnotics ranged between 1.2 and 3.8 in these studies. All in all, the studies on the relationship between the use of medication or purchase of drugs and community noise support the general hypothesis of an increase in sleep disturbance and cardiovascular risk in noise-exposed subjects.

#### 4.5.9 EVALUATION OF STUDIES

This section refers only to studies where the prevalence or the incidence of manifest cardiovascular diseases was considered as a potential health outcome of chronic exposure to environmental noise. The focus here is on a quantitative risk assessment with respect to manifest diseases. Furthermore, studies on the effects of low-altitude jet-fighter noise are also excluded, because this type of noise includes other dimensions of stress (for instance, fear). Thirty-seven studies have assessed the prevalence or incidence of manifest diseases, including hypertension and IHD (angina pectoris, myocardial infarction, ECG abnormalities).

##### 4.5.9.1 Criteria

Epidemiological reasoning is largely based on the magnitude of effect estimates, dose-response relationships, consistency of findings, biological plausibility of the effects and exclusion of possible bias. Internal (the role of chance) and external validity (absence of bias and confounding) are important issues in the evaluation of studies (Bradford Hill, 1965). Analytic studies (for example, cohort or case-control studies) are usually considered as having a higher validity and credibility than descriptive studies (for example, cross-sectional or ecological studies) (Hennekens and Buring, 1987), although many of the reservations against cross-sectional studies seem to be of minor importance when considering noise. For example, it does not appear to be very likely that diseased subjects tend to move differentially more often into exposed areas. Rather the opposite may be true, if noise stress is recognized as a potential cause of the individual's health problem. Thus, a cross-sectional study design may act conservatively on the results. The presence of a dose-response relationship is not a necessary criterion of causality. Non-linear relationships, including "u-" or "j-" shaped, saturation and threshold effects may reflect true associations (Calabrese and Baldwin, 2003; Rockhill, 2005). With respect to the derivation of guideline values in public health policy, the assessment of a dose-response relationship enables a quantitative risk assessment on the basis of continuous or semi-continuous (for instance 5 dB(A) categories) exposure data. Dichotomous exposure data, on the other hand, that refer to a cut-off criterion which splits the entire exposure range into two halves, can be used to evaluate the hypothesis of an association (qualitative interpretation), but not a quantitative assessment. The objective or subjective assessment of exposure and/or health outcomes is an important issue when judging the validity of a study (Malmström, Sundquist and Johansson, 1999; Cartwright and Flindell, 2000; Hatfield et al., 2001). The objective prevalence of hypertension was found to be higher in a population sample than the subjective prevalence of hypertension (Schulte and Otten, 1993). In a telephone survey more than half of the hypertensives classified themselves as normotensive (sensitivity 40% for men and 46% for women) (Bowlin et al., 1993). In a representative health survey, the validity of the self-reported assessment of morbidity (subjective morbidity) was found to be "low" with respect to hypercholesterolaemia, "intermediate" with respect to angina pectoris, hypertension and stroke and "high" with respect to



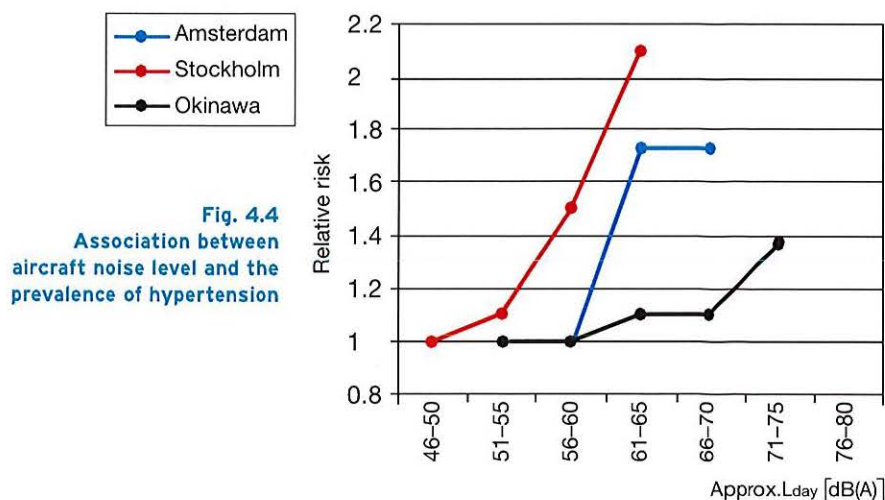
myocardial infarction (Bormann et al., 1990). Myocardial infarction is a very definite and severe health outcome which subjects would clearly know about if they had experienced it. Its assessment by questionnaire tends to be more credible than that regarding hypertension. Test-retest reliability was found to be good with respect to “harder” outcomes, including high BP and heart attack (Lundberg and Manderbacka, 1996; Lipworth et al., 2001). Over-reporting, on the other hand, may be a source of potential bias, particularly when both exposure and outcome are assessed on a subjective basis (Winkleby, Ragland and Syme, 1988; Babisch et al., 2003). The subjects may be more prone to blame their environment for their health problems, or may even tend to exaggerate adverse effects or exposure in order to influence noise policy. Therefore, a higher credibility and ranking was given to studies where exposure and outcome were assessed objectively (for example sound level versus subjective ratings, and measurement of BP or a clinical interview versus self-reported hypertension in a self-administered questionnaire). This means that the sound level must have been measured or calculated on the basis of the traffic counts, and clinical interviews or measurements must have been carried out by medically trained personnel (no self-administered questionnaire data) to give a study a high ranking. Studies which have been adequately controlled (for instance stratification, model adjustment (regression), matching) for a reasonable set of confounding variables in the statistical analyses, besides age and sex, were given a high ranking.

#### 4.5.9.2 Assessment

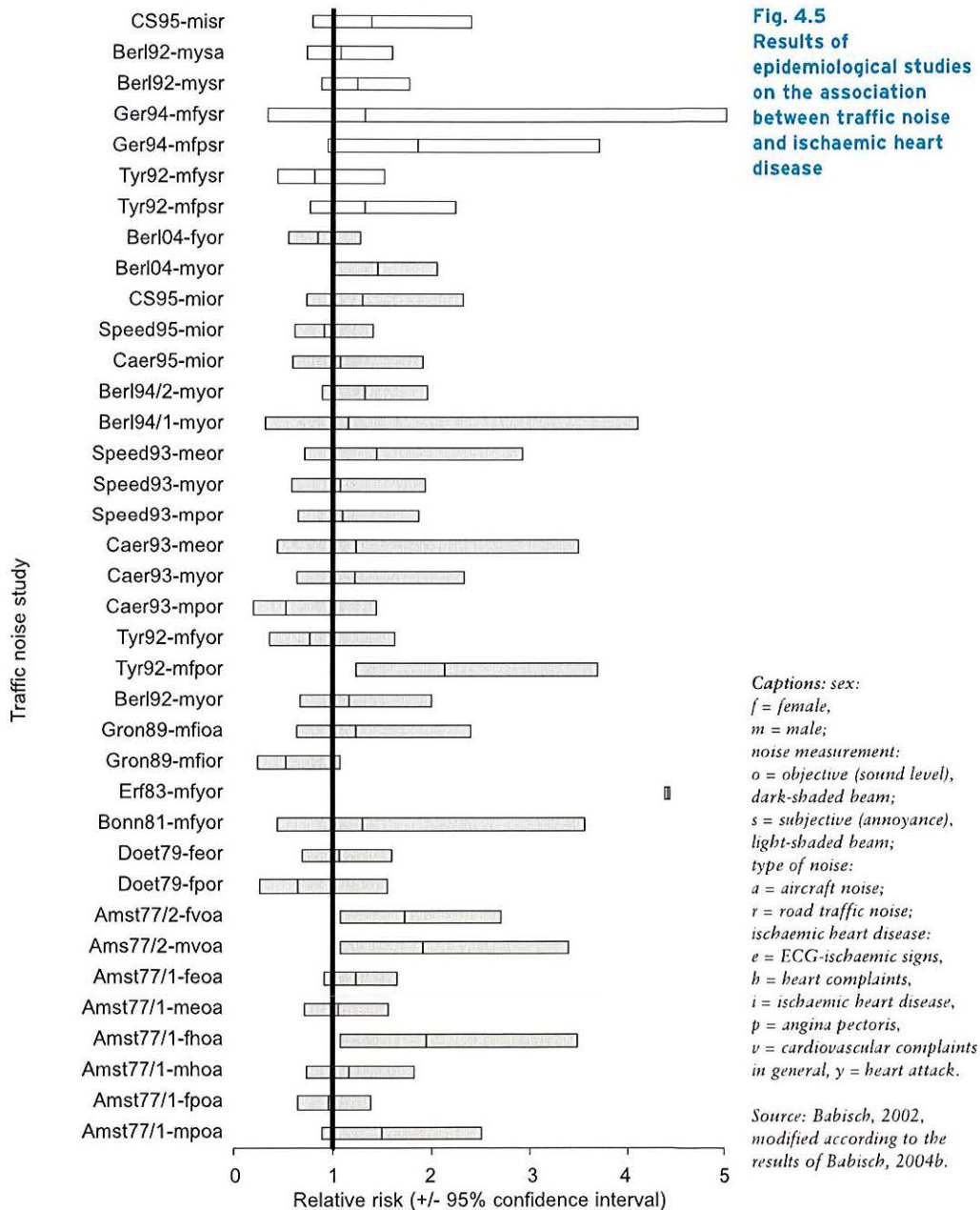
The evaluation concerning the epidemiological studies was made with respect to the identification of good quality studies that can be feasibly considered for the derivation of guideline values. These studies can either be used for a statistical meta-analysis, for a combined interpretation (synthesis) or for singular interpretations. All the studies were evaluated with respect to the following criteria for inclusion or exclusion in the synthesis process. Necessary criteria were: (1) peer-reviewed in the international literature; (2) reasonable control of possible confounding; (3) objective assessment of exposure; (4) objective assessment of outcome; (5) type of study; and (6) dose-response assessment. All six criteria were fulfilled by the two prospective cohort studies carried out in Caerphilly and Speedwell (Babisch et al., 1999; Babisch, Ising and Gallacher, 2003), the two prospective case-control studies carried out in the western part of Berlin (“Berlin I” and “Berlin II”) (Babisch et al., 1992, 1994), and the new prospective case-control study carried out in the whole of Berlin (“NaRoMI” = “Berlin III”) (Babisch, 2004b; Babisch et al., 2005). The studies refer to road traffic noise and the incidence of myocardial infarction. They were also the only ones considered in an earlier meta-analysis on this issue (van Kempen et al., 2002), with the exception of the “NaRoMI” study, which was not available at that time. All these studies are observational analytic studies (Hennekens and Buring, 1987). If descriptive studies on individuals – namely cross-sectional studies – are allowed, another two studies from Caerphilly and Speedwell on the association between road traffic noise and the prevalence of IHD, myocardial infarction and angina pectoris can be taken into account (Babisch et al., 1988, 1993a, 1993b). These studies were also considered in the meta-analysis by van Kempen et al. (2002). However, the results of the Berlin study on the prevalence of myocardial infarction (Babisch et al., 1994) – which was also considered in that meta-analysis – are not considered here, because the outcome was assessed subjectively with a self-administered questionnaire (an exclusion criterion). All the studies suggest an increase in IHD, in particular myocardial infarction. These studies are used for a new meta-analysis (section 4.5.10).

Regarding aircraft noise, the cross-sectional Okinawa study (Matsui et al., 2001; Matsui et al., 2004) on the association between aircraft noise and hypertension fulfils the inclusion criteria. When studies are included that did not assess dose-response relationships but only compared dichotomous categories of exposure in the analyses, two more studies appear on the list. The studies were carried out in the vicinity of Amsterdam Schiphol Airport. They suggest a higher risk of cardiovascular diseases in general (Knipschild, 1977b), and – specifically – for hypertension and IHD (angina pectoris, ECG abnormalities, heart trouble) (Knipschild, 1977a) in subjects from areas exposed to high aircraft noise. These studies were considered in the meta-analysis by van Kempen et al. (2002). However, they do not fulfil the strict criteria set here. Finally, if the inclusion criteria are widened to include peer-reviewed studies that assessed dose-response relationships between objective indicators of exposure and the subjective (self-reported) prevalence of diseases, a further two studies can be considered. These are the cross-sectional study carried out in Stockholm regarding the association between aircraft noise and hypertension (Rosenlund et al., 2001), and the cross-sectional part of the study in Berlin regarding the association between road traffic noise and myocardial infarction (Babisch et al., 1994). Fig. 4.4 shows the results of the three aircraft noise studies carried out in Amsterdam, Okinawa and Stockholm (Knipschild, 1977a; Rosenlund et al., 2001; Matsui et al., 2004). The graph clearly indicates that the results are too heterogeneous to derive a pooled dose-response curve. However, all three studies show an increase in risk with increasing noise level.

Studies that are not given a high ranking according to the above mentioned criteria, however, may serve as additional sources of information to support the evidence of the conclusions being made on the basis of this review. This is illustrated in Fig. 4.5. The entries are relative risks (centre of the bars) with 95% confidence intervals (the bars) for dichotomous comparisons of noise exposure (extreme groups or high vs. low). A relative consistent shift of the bars to relative risks greater than 1 can be seen. The dark-shaded bars in the diagram refer to studies where the noise exposure was determined objectively (noise levels), the



light-shaded bars where it was determined subjectively (annoyance). Road traffic and aircraft noise studies are here viewed together. No corresponding results are available for rail traffic studies. If different subgroups of the population (males/females) or different health end points were taken into account, specific studies appear more than once in the illustration.





## 4.5.10 DOSE-RESPONSE CURVE: META-ANALYSIS

For a quantitative risk assessment and the derivation of guidelines for public health noise policy a common dose-response curve is required. The risk estimates obtained from different noise studies can be summarized using the statistical approach of a meta-analysis. Based on the judgement criteria discussed in section 4.5.9.2, five analytic and two descriptive studies emerged that can be used to derive a common dose-response curve for the association between road traffic noise and the risk of myocardial infarction. Two separate meta-analyses were made by considering the analytic studies that were carried out in Caerphilly and Speedwell (cohort studies) and Berlin (case-control studies) on the one hand, and the descriptive studies that were carried out in Caerphilly and Speedwell (cross-sectional studies) on the other hand. It turned out, as a result of the evaluation, that all these studies referred to road traffic noise during the day ( $L_{day}$ : 06.00–22.00) and the incidence or prevalence of myocardial infarction as the outcome. Study subjects were men. In all analytic studies the orientation of rooms was considered for the exposure assessment (facing the street or not). With respect to the Caerphilly and Speedwell studies, the six years of pooled follow-up data provided the respective information. In all descriptive studies the traffic noise level referred to the facades that were facing the street and did not consider the orientation of rooms/windows. All individual effect estimates were adjusted for the covariates considered in each of the studies. Different sets of covariates were considered in each study. However, this pragmatic approach accounts best for possible confounding in each study and provides the most reliable effect estimates derived from each study. The concept of meta-analysis was used to aggregate and summarize the findings of the different studies (Okin, 1995; Blettner et al., 1999). The program “meta” was downloaded from the “STATA” web site for use in the statistical package STATA (version 8.0), and for calculating the pooled random effect estimates.

**Table 4.2**  
Single and pooled (meta-analysis) effect estimates (odds ratios and 95% confidence intervals) of descriptive and analytic studies on the relationship between road traffic noise level ( $L_{day}$ ) and the incidence/prevalence of myocardial infarction

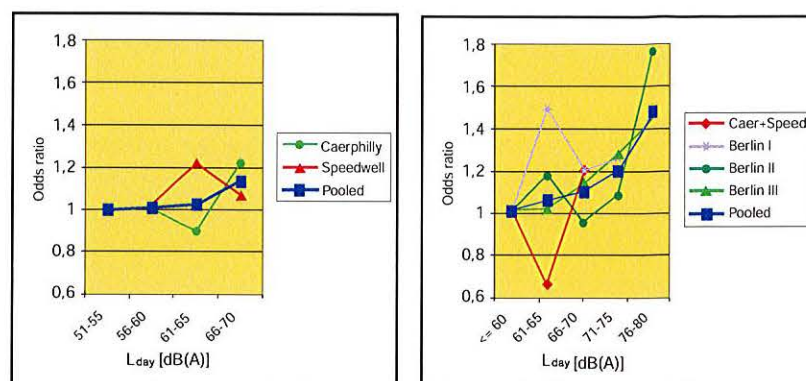
Descriptive studies	Road traffic noise level - $L_{day}$ [dB(A)]					N
	51-55	56-60	61-65	66-70		
Caerphilly	1.00	1.00 (0.58-1.71), [13.29]	0.90 (0.56-1.44), [17.23]	1.22 (0.63-2.35), [8.98]		2512
Speedwell	1.00	1.02 (0.57-1.83), [11.19]	1.22 (0.70-2.21), [12.62]	1.07 (0.59-1.94), [10.94]		2348
Pooled	1.00	1.01 (0.68-1.50)	1.02 (0.72-1.47)	1.14 (0.73-1.76)		
Q-Test		p=0.96	p=0.41	p=0.77		
Analytic studies	60	61-65	66-70	71-75	76-80	N
Caerphilly + Speedwell	1.00	0.65 (0.27-1.57), [4.95]	1.18 (0.74-1.89), [17.48]	---	---	3950
Berlin I	1.00	1.48 (0.57-3.85), [4.21]	1.19 (0.49-2.87), [4.94]	1.25 (0.41-3.81), [3.09]	1.76 (0.11-28.5), [0.50]	243
Berlin II	1.00	1.16 (0.82-1.65), [31.43]	0.94 (0.62-1.42), [22.76]	1.07 (0.68-1.68), [18.92]	1.46 (0.77-2.78), [9.27]	4035
Berlin III	1.00	1.01 (0.77-1.32), [54.42]	1.13 (0.86-1.49), [50.87]	1.27 (0.88-1.84), [28.24]	---	4115
Pooled	1.00	1.05 (0.86-1.29)	1.09 (0.90-1.34)	1.19 (0.90-1.57)	1.47 (0.79-2.76)	
Q-Test		p=0.57	p=0.87	p=0.84	p=0.90	

Table 4.2 shows individual and pooled effect estimates with confidence intervals (rounded brackets), statistical weights (square brackets) for the individual studies, and the Q-test of heterogeneity between studies. According to the Q-test, the nil hypothesis of non-heterogeneity was never discarded. Figs 4.6 and 4.7 show odds ratios of individual studies and the pooled estimates for the descriptive and analytic studies.



Fig. 4.6 and Fig. 4.7

Single and pooled effect estimates (odds ratios) for the descriptive and analytic studies of the association between road traffic noise level and the prevalence (left graph) and incidence (right graph), respectively, of myocardial infarction



#### 4.5.11 EFFECT MODIFICATION

Support for any noise–effect relationship may come from subgroup analyses that are in line with the noise hypothesis. This refers to effect modification with respect to residence time, window-opening behaviour and other determinants that affect the noise exposure and cumulative noise dose. In the Amsterdam aircraft noise studies, a steady increase in the purchase of cardiovascular and antihypertensive drugs at local pharmacies was found over the period of eight years in a community newly exposed to aircraft noise. No such increase was found in a control community that was not exposed to aircraft noise (Knipschild and Oudshoorn, 1977). Positive associations between the prevalence of cardiovascular diseases and residence time in exposed areas (but not in unexposed) were also found in the road traffic noise studies carried out in Bonn with respect to hypertension (Eiff and Neus, 1980; Neus et al., 1983) and in Caerphilly and Speedwell with respect to IHD (Babisch et al., 1999; Babisch, Ising and Gallacher, 2003). When the analyses of the road traffic noise studies carried out in Berlin, Caerphilly and Speedwell were restricted to subjects who had not moved within a retrospective period of 10–15 years, the effect estimates turned out to be larger than for the total samples of each study (Babisch et al., 1994, 1999, 2005). Similarly, a larger effect was found in the study in Sollentuna with respect to hypertension (Bluhm, Nordling and Berglind, 2001). No such effect was found in the Lübeck study (Hense, Herbold and Honig, 1989; Herbold, Hense and Keil, 1989). The cross-sectional data of the study carried out in Los Angeles on children regarding mean BP indicated some habituation to aircraft noise (Cohen et al., 1980). The longer the children were enrolled in the school, the smaller was the difference in BP between exposed and non-exposed children.

However, the follow-up study suggested that this may also be an effect of attrition (Cohen et al., 1981). The longer the families experienced the noise, the more likely that they moved away from the exposed areas (selection bias). In contradiction to this, BP differences between children exposed and not exposed to road traffic noise increased with school grade (Karsdorf and Klappach, 1968). Intervention studies were conducted with respect to changes in BP and changes in air traffic operation (for example the opening/closing of airports or runways). In the Munich study, a

larger increase in BP was found in children from a noisy area (Evans, Bullinger and Hygge, 1998). Other studies suggested reversible effects on BP when the exposure was lowered (Wölke et al., 1990; Morrell et al., 1998, 2000). In the Tyrol study, significantly lower BP readings were found in subjects who kept the windows closed throughout the night (Lercher and Kofler, 1993, 1996). When the subjects lived close to the highway (within a distance of approximately 500 metres), the prevalence of hypertension was higher in subjects whose bedroom was facing the main road than in those whose bedroom was not facing the main road. The orientation of rooms and window opening was also found to be an effect modifier of the association between road traffic noise and IHD in the Caerphilly and Speedwell studies (Babisch et al., 1999). The relative risk with respect to the noise level was slightly higher in subjects with rooms facing the street and subjects keeping the windows usually open when spending time in the room. A much greater relative risk of hypertension was found in subjects who slept with open bedroom windows in the Spandau Health Survey (Maschke, 2003; Maschke, Wolf and Leitmann, 2003). Hearing impairment was found to be an effect modifier on the association between aircraft noise and hypertension (Rosenlund et al., 2001). Amongst the exposed subjects, a higher risk associated with the noise was only found in subjects without hearing loss.

#### 4.5.12 EXPOSURE DURING THE NIGHT

Unfortunately, epidemiological noise research provides nearly no information regarding the particular impact of noise exposure during the night on cardiovascular health outcomes. The Spandau Health Survey explicitly distinguished between the exposure of the living room (during the day) and the exposure of the bedroom (during the night). There, a slightly higher relative risk of hypertension was found with respect to the traffic noise level during the night (relative risk 1.9 vs. 1.5) compared with the noise level during the day (Maschke, 2003; Maschke, Wolf and Leitmann, 2003). Furthermore, sleeping with open bedroom windows was associated with a large increase in risk. However, due to the small sample size, the confidence intervals were very large. In the drug survey of the Amsterdam aircraft noise studies, a steady increase in purchase of hypnotics (sleeping pills) and sedatives was found (Knipschild and Oudshoorn, 1977). This trend decreased considerably when night flights were largely banned. Such a decrease was not found regarding cardiovascular drugs for which the purchase also increased over time. However, this may partly be due to the fact that atherosclerotic manifestations of high BP were less reversible (in contrast to vasoconstriction, which is more related to acute or semi-acute effects, for instance in children). It was mentioned in the previous section that closing the windows had a protective effect on BP readings in the Tyrol study (Lercher and Kofler, 1993). This was only found regarding closing the windows during the night and not during the day. Furthermore, subjects who had switched the bedroom and the living room because of the noise had a significantly lower BP than those who did not do so. The findings are discussed in a broader context of coping strategies (Lercher, 1996). When subjective responses to community noise were considered, higher relative risks of cardiovascular diseases were found for noise-related disturbances of sleep and relaxation, rather than for other disturbances or subjective descriptors of noise exposure, which did not refer to the night-time. This was found in the Caerphilly and Speedwell studies (Babisch, Ising and Gallacher, 2003), the NaRoMI study (Babisch et al., 2005), the Spandau Health Survey (Maschke, Wolf and Leitmann, 2003) and a general population sample of Germany (Bellach et al., 1995). The LARES study (Niemann and Maschke,



2004), in which noise-induced sleep disturbance was assessed, did not show a higher relative risk compared with the general annoyance.

#### 4.5.13 RISK GROUPS

Most epidemiological noise studies looked at the cardiovascular effects of community noise in men. This may simply be due to the fact that the prevalence of cardiovascular diseases in middle-aged subjects is higher in men than in women. Statistical power is an important issue for the design of a study. Furthermore, in noise experiments, physiological reactions controlled by the autonomic nervous system were less pronounced in females than in males (Neus et al., 1980; Ising and Braun, 2000). Improper control for possible differential effects of the intake of sex hormones, including contraceptives, which may prevent or promote adverse (noise) stress effects, may act conservatively on the results (Cairns et al., 1985; Eiff, 1993; Farley et al., 1998). The studies carried out in Lübeck (Hense, Herbold and Honig, 1989; Herbold, Hense and Keil, 1989), Pancevo (Belojevic and Saric-Tanaskovic, 2002), Berlin (Babisch et al., 2005), Stockholm (Rosenlund et al., 2001), a German population sample (Bellach et al., 1995), Bonn (residence time) (Eiff and Neus, 1980; Eiff et al., 1981b) and in Amsterdam (angina pectoris) (Knipschild, 1977a) found higher prevalences of hypertension, IHD and the use of cardiovascular drugs in noise-exposed men than in women. The studies carried out in Bonn (sound level) (Eiff and Neus, 1980; Eiff et al., 1981b), Sollentuna and Amsterdam (heart trouble) (Knipschild, 1977a; Bluhm, Nordling and Berglind, 2001) found the opposite. In the studies carried out in the former Soviet Union, it was reported that noise effects on the cardiovascular system were more pronounced in young and middle-aged subjects (Karagodina et al., 1969). Swedish noise studies (Bluhm, Nordling and Berglind, 2001, 2004) and the LARES study (Niemann and Maschke, 2004) found similar results. The opposite (larger effects in elderly subjects) was reported from the Amsterdam study (Knipschild, 1977a) and the Stockholm study (Rosenlund et al., 2001). The available database on cardiovascular effects of noise in children is poor. No data are available that refer, in particular, to noise and sleep. The quantitative impact of transportation noise on the cardiovascular system is still a matter of research. A quantitative health risk assessment for children cannot be made at the moment.

Based on the available information from noise studies, it must be concluded that children do not appear to be a particular risk group with respect to cardiovascular outcomes, especially BP. This does not mean that the literature does not suggest higher BP readings in children. It only means that the effect in children does not appear to be different than that in adults. However, children may be exposed longer to noise throughout their lifetime than the adults that have been studied. No long-term follow-up studies are known that focus on noise exposure. Most studies on children considered noise in schools rather than noise at home, which implies different mechanisms about how noise could contribute to a rise in BP (raised effort in learning/speech perception vs. disturbed relaxation/sleep). The prospective part of the Caerphilly and Speedwell studies gave a small hint that health status could be a modifying factor. In subjects with prevalent chronic diseases, road traffic noise was associated with a slightly larger increase in the incidence (new cases) of IHD than in subjects without prevalent diseases – when the objective noise level was considered (Babisch et al., 2003). Surprisingly, when annoyance and disturbances due to traffic noise were considered for exposure, the opposite was found. Noise effects were only seen in subjects without prevalent diseases. This was discussed with respect to reporting bias.

#### 4.5.14 RISK EVALUATION

The process of risk assessment (risk evaluation) comprises hazard identification (“Which health outcome is relevant for the exposure?”), exposure assessment (“How many are affected?”) and dose-response assessment (“threshold of effect”). This information is summarized in “risk characterization” (“health hazard characterization”). It involves the interpretation of the available evidence from the available data and other scientific disciplines, and is subject to discussion of the uncertainties. These include chance, bias and validity of studies as well as transparency, replicability and comprehensiveness of reviews. As a result of the risk evaluation process, a quantitative estimate about the likelihood that the hazard will affect exposed people will be derived. Usually, attributable risk percentages are calculated (Walter, 1998). This will serve as key information for any kind of risk management including regulatory options (Jasanoff, 1993). The term “adverse” is essential in this context of environmental standard setting. Risk management should ensure that “adverse” health effects do not occur. The fact that an organism responds to noise does not have to be per se “adverse”. The severity of a health outcome is an important determinant of the adversity of an effect and implies variable action levels for public health policy (Babisch, 2002, 2004a; Griefahn et al., 2002; Health Council of the Netherlands, 2003). Since considerable parts of the population are exposed to high noise levels (EEA, 2004), noise policy can have a significant impact on public health (Neus and Boikat, 2000). Due to the increasing number of people affected with the decreasing severity of the effect, even small individual risks and less severe health outcomes can be relevant for public health and decision-making. It has been shown that moderate noise exposures implying a small individual risk may cause more noise-induced cases of health-impaired subjects than higher noise exposures. Franssen et al. (2004) pointed out that the number of people suffering from poor health due to aircraft noise is dominated by the larger number of people that is exposed to relatively moderate-to-low noise levels and not by those exposed to high noise levels. This means that more emphasis should be put on the reduction of noise in moderately exposed areas. However, public health policy cannot only consider population attributable risks (risk percentages), but must also consider individual risks (lifetime risk).

In practice, it seems to be reasonable that noise policy should reduce noise, beginning with the highest exposures and ending with the lowest ones. Decision-making will have to find common standards of acceptable risks, which may vary according to the cost-benefit considerations within and between communities and countries. Such practical standards may, however, vary due to economic development and abilities, cost-benefit considerations and priority settings of a community or country. Health quality targets derived from scientific research are usually intended to minimize risks; decision-making in the political process is only partly scientifically based due to economic limitations and concurring interests (Nijland et al., 2003). Different health outcomes or indicators of well-being and quality of life imply different action levels. Environment and health policy must determine acceptable noise standards that consider the whole spectrum from subjective well-being to somatic health (for example annoyance, physiological arousal, health risk). The evidence for a causal relationship between community or transportation noise and cardiovascular risk appears to have increased over recent years due to new studies that accomplish the database.



#### 4.5.15 CONCLUSIONS

The evaluation process used in this paper considered the “necessary” criteria: peer-reviewed publication in an international journal, reasonable quantitative control of possible confounding, objective assessment of exposure and outcome, type of study (analytic vs. descriptive), and dose-response assessment (not only dichotomous “high” vs. “low”). The approach differs from that of an earlier meta-analysis (van Kempen et al., 2002) in that there regression coefficients were calculated for the entire dose-response curve within a single study (for instance the increase in risk per 5 dB(A)), which were then pooled between studies. Since higher exposure categories usually consist of smaller numbers of subjects than the lower categories, regression coefficients across noise levels tend to be influenced by the lower categories. This may lead to an underestimation of the risk in higher noise categories. The approach presented here pooled the effect estimates of single studies within each noise category, thus giving more weight to the higher noise categories and accounting for possible non-linear associations.

Fig. 4.8 and Fig. 4.9

Pooled effect estimates (meta analysis) of descriptive and analytic noise studies of the association between road traffic noise level and the prevalence (left graph) and incidence (right graph), respectively, of myocardial infarction (odds ratio  $\pm$  95% confidence interval).

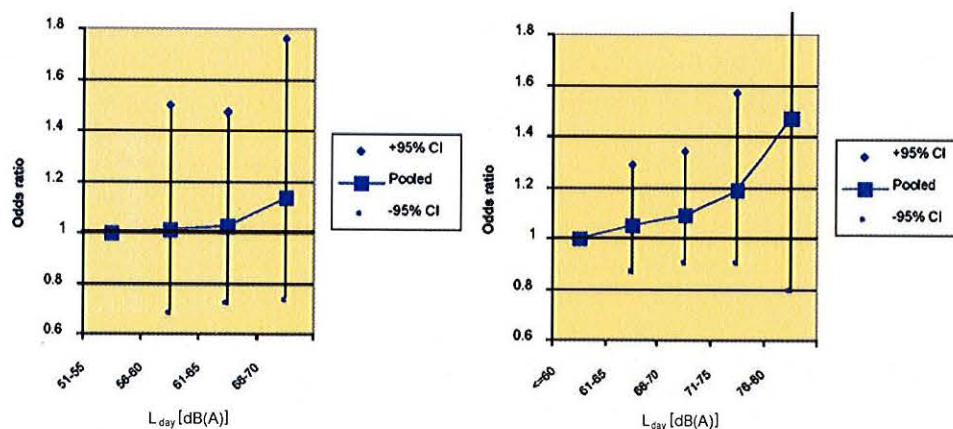


Fig. 4.8 and Fig. 4.9 show the two risk curves for descriptive and analytic studies (Hennekens and Buring, 1987). The graphs show the pooled effect estimates (odds ratios) and the 95% confidence intervals for each noise category. Whereas the cross-sectional studies (Fig. 4.9) cover the sound level range of  $L_{day}$  from  $>50$  to 70 dB(A), the cohort and case-control studies (Fig. 4.8) cover the range from  $\leq 60$  to 80 dB(A). Both curves together can serve as a basis for a quantitative risk assessment. From Fig. 4.8 it can be seen that below 60 dB(A) for  $L_{day}$  no noticeable increase in risk of myocardial infarction is to be detected. Therefore for the time being,  $L_{day} = 60$  dB(A) can be seen as NOAEL (no observed adverse effect level) for the relationship between road traffic noise and myocardial infarction (Babisch, 2002). For noise levels greater than 60 dB(A), the risk of myocardial infarction increases continuously, and is greater than 1.2 for noise levels of 70 dB(A). This can be seen in Fig. 4.9. It should be mentioned that the risk estimates, in general, were found to be higher in subjects that had lived in the exposed areas for a longer time (Babisch et al., 1994, 1999, 2005). This is in accordance with the noise hypothesis and the effects of chronic noise stress (Lercher and Kofler, 1996; Thompson, 1997). However, for the calculation of population attributable risks the figures for the whole population are relevant due to unknown information about residence time.

No particular risk groups could be identified on the basis of epidemiological research on cardiovascular effects of community noise. The assessment of dose-effect relationships sometimes suggested a cut-off level, above which the risk tends to increase. From a biological point of view, one would expect a continuous increase in risk with increasing noise level. However, adaptation, habituation and coping may be reasons for an empirical threshold of effect. Decisions with respect to guideline values usually refer to a quantitative risk assessment of populations (for example population attributable risk percentage). However, prevention strategies – for ethical reasons – should not ignore the individual risks of highly exposed subjects, even if their number may be small.

With respect to night noise exposure, nearly no information is available from epidemiological studies on the cardiovascular effects of long-term noise exposure of the bedroom during the night. Only one study distinguished between the exposures of the bedroom and the living room in the statistical analyses (Maschke, Wolf and Leitmann, 2003). The results suggested slightly higher effect estimates for the prevalence of hypertension with respect to the noise exposure of the bedroom (during the night) compared with the exposure of the living room (during the day). However, the difference was small (odds ratio 1.9 vs. 1.5), which means that it still remains an open question whether the night exposure or the overall exposure throughout the whole day is the driving force. The study has some methodological limitations that were addressed in the summary of the major technical report and in a recent advisory report of the Health Council of the Netherlands (2004). They are mainly concerned with the fact that the study population consisted of a selected, predominantly older and health conscious group of persons that might have already suffered from regular health problems (risk group). A few studies that looked at the association between subjective responses to community noise and cardiovascular outcomes suggest a closer relationship with sleep-related annoyance/disturbance reaction rather than with non-sleep-related annoyance/disturbance (Bellach et al., 1995; Babisch et al., 1999, 2005; Maschke, Wolf and Leitmann, 2003; Niemann and Maschke, 2004). Closing the bedroom window or, vice versa, sleeping with the bedroom window open, was associated with a lower or higher risk, respectively (Lercher, 1996). The same was found with respect to changing the bedroom to the living room because of noise. These findings may indicate that night-time noise may be more a determinant of noise-induced cardiovascular effects than daytime exposure. However, daytime activity patterns and expectations of the individuals are much more inhomogeneous than during the night, which tends to dilute the statistical association of true effects with the day noise exposure.

Given the situation that only a few data are available from epidemiological studies with respect to effects on sleep (exposure of the bedroom during the night), there does not seem to be any other way of reasoning than inferring night noise recommendations or guidelines from the results of studies that refer to noise exposure during the daytime period ( $L_{\text{day}}$ ) or the whole day ( $L_{\text{dn}}$ ,  $L_{24\text{h}}$ ).  $L_{\text{den}}$ , in this context, appears to be a useful noise indicator for decision-making and regulatory purposes. Penalties of 5 dB(A) and 10 dB(A) are usually given to the evening period and the night period, respectively. It can be used for noise mapping and refers normally to the most exposed facade, which incorporates a certain degree of exposure misclassification regarding cause-effect relationships. This weighted indicator was introduced to assess the relationship between sound level and noise annoyance (European Commission, 2002a). However, it may not be adequate for research into (somatic) health-related noise effects. Non-weighted separate exposure indicators, such as  $L_{\text{day}}$ ,  $L_{\text{evening}}$  or  $L_{\text{night}}$ , may be more appropriate when assessing physiological responses to the noise. In urban settings, night-time average noise levels (22.00–06.00) for road traffic tend to be approximately 7–10 dB(A) lower than daytime average noise levels – relatively independent (no freeways) of the traffic volume of the street (Utley, 1985; Ullrich, 1998; Evans et al., 2001). In such cases,  $L_{\text{den}}$  is approximate-



ly 2–3 dB(A) higher than  $L_{\text{day}}$  (Bite and Bite, 2004). Therefore, in epidemiological studies in which the relative effects of road traffic noise are studied, the sound emission during the daytime can as well be viewed as an approximate relative measure of the overall sound emission including the night. This seems to be further justified because existing noise regulations usually consider a 10 dB(A) difference between the day and the night. The NOAEL of 60 dB(A) for  $L_{\text{day}}$  corresponds, in this respect, with 50 dB(A) for  $L_{\text{night}}$ . This approximation can only be made with respect to road traffic noise.

Aircraft noise has been less intensively studied in noise epidemiology. The studies focused on high BP. Dose–response curves were hardly considered. A large European study on the association between aircraft noise and road traffic noise on BP is currently being conducted (Jarup et al., 2003). Regarding aircraft noise – and particularly the ongoing debate on night flight restrictions in the vicinity of busy airports – no other alternative exists at present than to take the myocardial infarction risk curves derived from road traffic noise studies as an approximate for aircraft noise. Since aircraft noise acts on all sides of a building, that is, different to road traffic noise, the suspicion exists that the effects induced by aircraft noise could be greater than those induced by road traffic (Ortscheid and Wende, 2000; Babisch, 2004a). This may be due to the lack of evasive possibilities within the home and the greater annoyance reactions to aircraft noise, which are usually expressed in social surveys (Miedema and Vos, 1998). More research is needed regarding the association between aircraft noise and cardiovascular end points.

This section is clearly focused on ill health as an outcome of the adverse effect of noise. A common dose-effect curve for the relationship between road traffic noise (outdoors) and the risk of myocardial infarction was developed. This curve can be used for a quantitative risk assessment and the calculation of attributable cases in a community. However, decisions regarding limit values have to be made within the spectrum between discomfort (annoyance) and ill health (disease) (Lindström, 1992; Babisch, 2002). Whereas quality targets at the lower end of the effects scale may be more flexible, quality targets at the upper end may be more obligatory. For example, for ethical reasons (equality principle) it does not seem to be justified if (ill) health-based limit values are varied according to the type of living area as expressed in land development plans (for example residential, mixed or commercial).

## 4.6 INSOMNIA

A group of Japanese researchers carried out a questionnaire-based survey of 3600 adult Japanese women (aged between 20 and 80) to gather information about the factors that contribute to insomnia (Kageyama et al., 1997). Some 11% of subjects were found to be affected by insomnia (as defined on the basis of WHO's International Statistical Classification and Related Health Problems, 10th revision – ICD10). Analysis of the survey data took account of various distorting variables, such as age, number of (small) children in the family, social status, receipt of medical treatment, regularity of bedtimes, apnoea-like problems and serious unpleasant experiences in the six months prior to completing the questionnaire. When the percentage of insomniacs in each of the three areas with the highest exposures was compared with the percentage in the low-exposure areas, the ratios worked out at, respectively, 1.4 (2100 vehicles per hour,  $L_{\text{night}}$  of around 65 dB(A)), 2.1 (2400 vehicles per hour,  $L_{\text{night}}$  of around 67 dB(A)) and 2.8 (6000 vehicles per hour,  $L_{\text{night}}$  of around 70 dB(A)). The most frequently reported problem was difficulty getting to sleep.

Research into the effects of exposure to air and road traffic noise has shown that increases in night-time noise exposure or in noise exposure during the sleep latency period have a statistically significant adverse impact on subjects' ability to get off to sleep and on sleep inception periods.

## 4.7 EFFECTS ON PERFORMANCE

### 4.7.1 COGNITION AND SWS

Jan Born and co-workers at the University of Lübeck (Wagner, Gais and Born, 2001; Benedict et al., 2004; Born and Wagner, 2004; Gais and Born, 2004; Drosopoulos, Wagner and Born, 2005) have reported interesting research and put forward intriguing hypotheses on the relation between noise exposure, sleep loss and subsequent cognitive performance. They conclude that declarative memory benefits mainly from sleep periods dominated by SWS, while there is no consistent benefit for this memory from periods rich in REM sleep. This points to the importance of SWS for declarative memory.

Since sleep in the early night is dominated by SWS, in contrast to late night when REM sleep dominates, this would imply that noise in the early night, for example aircraft noise before midnight, would be particularly damaging to memory and related cognitive functions. However, this implication has not yet been explicitly tested. That is, there seems to be a certain risk for impoverished memory due to noise in the early night, but there is as yet no graded quantification about whether ordinary pre-midnight noise levels around large airports are sufficient to make a difference to SWS. We also lack graded quantification about the relationship between impoverished SWS and the resulting effect on different aspects of declarative memory.

Thus, in terms of Fig. 1.1 we have evidence for the arrow marked (b), but we do not have enough information to say whether the strength of arrow (a) is sufficient to cause reduced SWS in field settings.

Furthermore, since children's memory systems pass through developmental changes and are not structured in the same way as for adults, it would be interesting to know to what extent the Born group results are also valid for children, and whether the depth of children's sleep counteracts or enhances SWS dominance in the early night.

### 4.7.2 COMPARING DAYTIME AND NIGHT-TIME NOISE EXPOSURE

As implied by Fig. 1.1, the relation between noise exposure and resulting effects on cognition should be analysed somewhat differently depending on whether the noise exposure takes place during the day or night. Analysing the cognitive effects of daytime noise exposure is fairly straightforward. For night-time noise exposure, however, any effects on cognition can either be a more or less direct effect of the noise exposure, or an indirect effect mediated by reduced sleep or sleep quality.

Also, comparing, for example, memory and learning functions when exposed to



night-time noise, in contrast to daytime noise, shifts the focus of analysis away from encoding (in memory) or acquisition (in learning) while experiencing noise, to a focus on storing the material to be remembered or learnt while asleep (compare to daytime noise effects on cognition as reported by Hygge, Evans and Bullinger, 2002; Stansfeld et al., 2005). Thus, assuming that people are mainly asleep at night, all cognitive work that relies on the intake of information, listening or reading is not relevant. In all, this suggests that studies of daytime noise levels cannot be used much to give rough estimates of the effects of night-time exposure.

### 4.7.3 COMPARING CHILDREN AND ADULTS

How far can effects of daytime noise levels on children be generalized to give a rough estimate of the effects on adults? Are children more sensitive? Judging from earlier daytime studies of children and adults doing the same cognitive tasks while exposed to noise, children are not more sensitive than adults to noise (Boman, Enmarker and Hygge, 2004), but they perform at a lower level than the adults both in noisy and in quiet environments. Thus, it could be said that children are not more vulnerable to (daytime) noise in relation to cognitive performance, but since so much more cognitive work is expected from children while in school, their learning environment and their cognitive tasks can be said to be more noise vulnerable than corresponding environments for adults.

### 4.7.4 NOISE AND AFTER-EFFECTS

An argument can be made for noise as a stressor leading to reduced motivation (Glass and Singer, 1972), which in turn may act as a mediator of impaired cognitive performance. Along this line of reasoning, night-time noise may be more potent in inducing reduced motivation than daytime noise, but for the time being this is only a conjecture and has not been tested.

#### 4.7.4.1 *The role of restoration*

Noise can be viewed both as a source of stressful demands and as a constraint on restoration. Noise levels and noise sources that are not by themselves particularly demanding during the waking hours of the day, may nevertheless be quite effective in blocking and constraining when they appear in periods meant to be restorative, such as sleep (Hartig, 2004). To what extent this idea is applicable to night-time noise exposure has not yet been explored.

#### 4.7.4.2 *Noise and communication*

Some of the difficulties with children's responses to noise are related to problems in speech perception. A metric that weights night-time exposure more heavily is, in fact, less useful since children's auditory processing with parents and teachers is obviously more critical during waking hours.

## 4.8 EFFECTS ON PSYCHIC DISORDERS

Noise exposure at night may be more disturbing than daytime noise because it interferes with rest and sleep at a time when people want to relax. It seems plausible that night-time noise might have a particular effect on mental health. However, there is lit-

the direct research into night-time noise and mental health and it is first necessary to consider the evidence for environmental noise and mental health in general. The association between noise and mental health has been examined using a variety of outcomes including (at the simplest level) individual symptoms, as well as psychiatric hospital admission rates, use of health services and psychotropic medication, and community surveys.

#### 4.8.1 TRANSPORTATION NOISE AND MENTAL HEALTH

Sources of transportation noise that have been studied in relation to mental health include road traffic noise and aircraft noise. Studies relating to each type of noise will be considered in turn.

##### 4.8.1.1 Road traffic noise

The association between road traffic noise exposure and psychological distress has been studied in the small town of Caerphilly, South Wales. In the cross-sectional results, no association was found between the initial level of road traffic noise based on traffic noise maps, in terms of  $L_{eq}$  referring to the period 06.00–22.00, and minor psychological distress, measured by the General Health Questionnaire (GHQ), a screening questionnaire for depression and anxiety, even after adjustment for sociodemographic factors (Stansfeld et al, 1993). In longitudinal analyses in the Caerphilly Study, no association was found between road traffic noise and psychological distress, even after adjustment for sociodemographic factors and baseline psychological distress, although there was a small non-linear association of noise with increased anxiety scores (Stansfeld et al, 1996).

The disadvantage of the Caerphilly study is that it relied on one location with not very high levels of traffic noise. In a secondary analysis of a large British road traffic noise study, which took into account multiple noise exposure sites, the noise level in dB(A) exceeded for 10% of the time was weakly associated with a mental health symptoms scale of five items adjusting for age, sex, income and length of residence (Halpern, 1995). Weaker associations between traffic density and the mental health symptoms scale may relate to the skewed distribution of this traffic density variable. It seemed that traffic noise was more important than traffic flow. The scale used included some clear mental health items but also some that were less obviously related to mental health. It may be questioned whether the reported association between noise level and mental health symptoms was actually due to noise exposure; adjustment for the amount of “noise heard” reduced the association very little, suggesting no causal association with noise, but it is likely that there was a good deal of error in the measurement of this variable, reducing its validity.

It may be that the peak noise level is a better indicator of environmental noise heard indoors than noise measures averaged over time and that peak levels are a crucial indicator for mental health. Furthermore, in a road traffic noise study in Belgrade, 253 residents exposed to road traffic noise levels of >65dB(A), with high levels both day and night ( $L_{eq}$  76.5 in the day, 69.5 at night in the noise-exposed area), experienced significantly more fatigue, depression, nervousness and headaches, compared to residents exposed to <55dB(A) (Belojevic and Jakovljevic, 1997). Sleep quality was also found to be worse among the inhabitants of noisy streets, compared to inhabitants of quiet streets, and those living in noisy streets had more difficulties falling asleep, more night awakenings and more pronounced tiredness after sleep. However, there were no differences in time taken to fall asleep or to go back to sleep,



duration of sleep or consumption of sleeping pills between noise-exposed and non-exposed residents. A great methodological advantage of this study was that the high and low noise exposure areas were homogenous for age, sex, employment and subjective noise sensitivity. A community study in 366 Japanese women suggests that road traffic noise only has effects on depression, fatigue and irritability above a threshold of 70 dB(A) (Yoshida et al., 1997). However, it is difficult to be confident of the results of these analyses as they were unadjusted for age or social deprivation. Milder psychological states such as health functioning and well-being have also been examined in the first stage of an intervention study on the effect of introducing a bypass to relieve traffic congestion in a small town in North Wales (Stansfeld, Haines and Brown, 2000). Health functioning was measured by the SF-36 General Health Survey (Ware and Sherbourne, 1992), including dimensions of general health status, physical functioning, general mental health and social functioning. Ninety-eight respondents were studied who lived on a busy high street with traffic noise levels varying between 72 and 75 dBA outdoor  $L_{eq}$ . These respondents were compared with 239 control subjects living in adjacent quieter streets (noise level 55–63 dB(A) outdoor  $L_{eq}$ ). Although subjects were well-matched on age, sex, housing insulation, car ownership and employment status, they were not so well-matched on proportion of manual workers, household crowding, deprivation and home ownership. There was no evidence that respondents exposed to higher levels of road traffic noise had worse health functioning than those exposed to lower levels of the noise, adjusting for levels of deprivation.

Another method of assessing mental health effects related to noise exposure is to use an indirect indicator such as medication use. In five rural Austrian communities exposed to road traffic noise, noise levels above 55 dB(A), including increasing night-time exposure to noise from trucks, were associated with increased risk of taking sleeping tablets (OR = 2.22 [CI: 1.13–4.38]) and overall prescriptions (OR = 3.65 [CI: 2.13–6.26]) relative to road traffic noise exposure less than 55 dB(A) (Lercher, 1996). This suggested effects at fairly low noise levels. In this case mental ill health may be secondary to sleep disturbance, which is likely to occur at lower nocturnal noise levels than mental health symptoms resulting from daytime noise exposure. As this occurred in a rural setting where road traffic was the predominant source of noise it would be interesting to replicate these findings in other settings.

#### 4.8.1.2 Road traffic noise and mental health in children

Noise exposure and mental health has also been studied in children where child self-reported mental health on a standard scale and teacher ratings of classroom adjustment in response to motorway, road and rail noise were measured in a large sample of 8–11-year-old Austrian primary school children and in a second stage sample of extreme noise-exposed groups. Noise exposure was significantly associated with classroom adjustment scores but, intriguingly, child self-reported mental ill health was only impaired in noisy settings for children of low birth weight and preterm birth (Lercher et al., 2002).

#### 4.8.1.3 Aircraft noise

Community surveys have found that high percentages of people reported “headaches”, “restless nights”, and “being tense and edgy” in high aircraft noise areas (Kokokusha, 1973; Finke et al., 1974; Öhrström, 1989). An explicit link between aircraft noise and symptoms emerging in such studies raises the possibility of a bias towards over-reporting of symptoms (Barker and Tarnopolsky, 1978). Notably, a study around three Swiss airports (Grandjean et al., 1973), did not mention that it was related to aircraft noise and did not find any association between the

level of exposure to aircraft noise and symptoms. In the West London Survey, “tinnitus”, “burns, cuts and minor accidents”, “ear problems” and “skin troubles” were all more common in areas of high noise exposure (Tarnopolsky, Watkins and Hand, 1980). Acute symptoms such as “depression”, “irritability”, “difficulty getting off to sleep”, “night waking”, “skin troubles”, “swollen ankles” and “burns, cuts and minor accidents” were particularly common in high noise areas. However, apart from “ear problems” and “tinnitus”, 20 out of 23 chronic symptoms were more common in low noise environments. Symptoms did not increase with increasing levels of noise. This is possibly related both to more social disadvantage and associated ill health among residents in low aircraft noise exposure areas and the possible unwillingness of chronically unhealthy individuals to move into potentially stressful high noise exposure areas. Nevertheless, it would not exclude an effect of noise in causing some acute psychological symptoms. As the majority of aircraft noise exposure is during the day, daytime exposure is likely to have greater effects than night-time exposure. Many of the effects of noise in industrial and teaching settings may be related primarily to disturbances in communication.

#### 4.8.2 NOISE EXPOSURE AND MENTAL HOSPITAL ADMISSION RATES

Much of the concern with the possible effects of noise on mental health began with the study of admissions to psychiatric hospitals from noisy areas. Early studies found associations between the level of aircraft noise and psychiatric hospital admissions, both in London (Abey Wickrama et al., 1969) and Los Angeles (Meecham and Smith, 1977). These results have been criticized on methodological grounds (Chowns, 1970; Frerichs, Beeman and Coulson, 1980) and a replication study by Gattoni and Tarnopolsky (1973) failed to confirm these findings. Jenkins et al., (1979) found that age-standardized admission rates to a London psychiatric hospital over four years were higher as the level of noise of an area decreased, but lower noise areas were also central urban districts, where high admission rates would be expected. In a further extensive study of three hospitals (Jenkins, Tarnopolsky and Hand, 1981), high aircraft noise was associated with higher admission rates in two hospitals, but in all three of them, admission rates seemed to follow non-noise factors more closely; the effect of noise, if any, could only be moderating that of other causal variables but not overriding them. Kryter (1990), in a re-analysis of the data, found “a more consistently positive relation between level of exposure to aircraft noise and admissions rates”. Undoubtedly, the route to hospital admission is influenced by many psychosocial variables that are more potent than exposure to noise. Therefore, whether or not noise causes psychiatric disorder is more suitably answered by studying a community sample.

#### 4.8.3 NOISE EXPOSURE AND PSYCHIATRIC MORBIDITY IN THE COMMUNITY

In a community pilot study carried out in West London, Tarnopolsky et al. (1978) found no association between aircraft noise exposure and either GHQ scores (Goldberg, 1972) (dichotomized 4/5, low scorers/high scorers) or estimated psychiatric cases (Goldberg et al., 1970). This was the case even when exposure to road traffic noise was controlled, except in three subgroups: persons “aged 15–44 of high education” (41%, 14%  $p < 0.05$ ), “women aged 15–44” (30%, 13% n.s.), and those in “professional or managerial occupations”. The authors expressed the guarded opinion that



noise might have an effect in causing morbidity within certain vulnerable subgroups. In the subsequent West London Survey of Psychiatric Morbidity (Tarnopolsky, Morton-Williams and Barker, 1980), 5885 adults were randomly selected from within four aircraft noise zones, according to the Noise and Number Index. No overall relationship was found between aircraft noise and the prevalence of psychiatric morbidity either for GHQ scores or for estimated numbers of psychiatric cases, using various indices of noise exposure. However, there was an association between noise and psychiatric morbidity in two subgroups: "finished full-time education at age 19 years +", and "professionals". These two categories, which had a strong association with each other, were combined and then showed a significant association between noise and psychiatric morbidity ( $X^2 = 8.18$ ,  $df\ 3\ p < 0.05$ ), but only for the proportion of high GHQ scorers. Tarnopolsky, Morton-Williams and Barker (1980) concluded that their results "show so far that noise per se in the community at large, does not seem to be a frequent, severe, pathogenic factor in causing mental illness but that it is associated with symptomatic response in selected subgroups of the population".

More recent studies have examined the effects of higher levels of military aircraft noise. Exposure to higher levels of military aircraft noise around the busy Kadena military airport in Japan was related in an exposure-effect association to depressiveness and nervousness measured by questionnaire using the Todai Health Index, based on the Cornell Medical Index (Ito et al., 1994; Hiramatsu et al., 1997). Mental health subscales included in this study measured depressiveness, nervousness, neurosis, and mental instability. Noise level was expressed as WECPNL (the power average of the maximum perceived noise exposure level in dB(A)) from 75–79, 80–84, 85–89, 90–94 and over 95). In unadjusted analyses, statistically significant differences were found in scores of depressiveness, nervousness and neurosis between the non-noise exposed control group and the pooled group exposed to 75–95 WECPNL. In multivariate analysis adjusting for age, sex, marital status, type of house and length of residence, noise exposure greater than 95 WECPNL was associated with higher scores on depressiveness and neurosis (Hiramatsu et al., 1997). Clear exposure-effect relationships were not found between scale scores and noise exposure, as expressed in five unit steps. However, using more broadly defined groups, an exposure-effect association was evident. This highlighted differences between the highest noise exposure group and lower exposure groups and indicated a threshold effect rather than a linear relationship – that mental health effects are more likely to be found at higher noise levels. In general, psychological rather than somatic symptoms were more related to noise in this study. Further analyses of the Japanese studies suggest that high levels of military aircraft noise may have effects on mental health. In a cross-sectional study of 5963 inhabitants around two air bases in Okinawa, those exposed to noise levels of  $L_{dn}\ 70$  or above had higher rates of "mental instability" and depressiveness (Hiramatsu et al., 2000). Those who were more annoyed showed a higher risk of mental or somatic symptoms. A further survey using similar methodology on 6486 respondents found exposure-effect associations between aircraft noise exposure, nervousness and mental health (Miyakita et al., 1998). These are important studies because of the opportunity to examine the effect of high noise-exposure levels and the probability that vulnerable people migrating out of noisy areas and thus biasing the sample was small.

The use of health services has also been taken as a measure of the relationship between noise and psychiatric disorder. Grandjean et al. (1973) reported that the proportion of the Swiss population taking drugs was higher in areas with high levels of aircraft noise and Knipschild and Oudshoorn (1977) found that the purchase of sleeping pills, antacids, sedatives and antihypertensive drugs all increased in a vil-

lage newly exposed to aircraft noise, but not in a “control” village where the noise level remained unchanged. In both studies, there was also an association between the rate of contact with general practitioners and level of noise exposure. In the Heathrow study (Watkins, Tarnopolsky and Jenkins, 1981), various health care indicators were used – use of drugs, particularly psychiatric or self-prescribed, visits to the GP, attendance at hospital, and contact with various community services – but none of these showed any clear trend in relation to levels of noise. A recent study found that the use of sleeping tablets and sedatives was elevated with increasing night-time noise exposure, especially in the elderly (Passchier-Vermeer et al., 2002). This has been judged to be “sufficient” evidence of a noise effect (Health Council of the Netherlands, 2004).

#### 4.8.4 AIRCRAFT NOISE EXPOSURE AND MENTAL HEALTH IN CHILDREN

Poustka, Eckermann and Schmeck (1992) studied the psychiatric and psychosomatic health of 1636 children aged 4–16 in two geographical regions that differed according to the noise made by jet fighters frequently exercising at low altitude. Psychological and neurological outcomes were not related to noise exposure. They found that associations between noise exposure and depression and anxiety could be demonstrated, but only beneath the threshold of clinical significance. These results are less convincing because the areas differed socioeconomically and the results were not adjusted for these factors and also because of lack of precision of the measures of noise exposure. However, in Munich, children living in areas exposed to high aircraft noise had lower levels of psychological well-being than children living in quieter environments (Evans, Hygge and Bullinger, 1995). The longitudinal data from around Munich showed that after the inauguration of the new airport, the newly noise-exposed communities demonstrated a significant decline in self-reported quality of life measured on the Kindl scale, after being exposed to the increased aircraft noise for 18 months (third wave of testing), compared with a control sample (Evans, Bullinger and Hygge, 1998). Impairment of “quality of life” is a less severe disturbance than impairment of mental health. Further studies have examined the effects of noise on child psychiatric disorders.

Chronic aircraft noise exposure was not associated with anxiety and depression (measured with psychometrically valid scales), after adjustment for socioeconomic factors, in the Schools Health and Environment Study around Heathrow Airport (Haines et al., 2001a). In a further larger study of children’s health around Heathrow Airport – the West London Schools Study (Haines et al., 2001b) – an association was found between aircraft noise exposure level and increased hyperactivity scores on the hyperactivity subscale of the Strength and Difficulties Questionnaire (Goodman, 1997). These studies suggest that noise influences child mental health in terms of hyperactivity and that it may affect child stress responses and sense of well-being.

#### 4.8.5 NEIGHBOURHOOD NOISE AND MENTAL HEALTH

Noise from neighbours is the commonest source of noise complaints to local authorities in the United Kingdom (Chartered Institute of Environmental Health, 1999). Noise which is continuous, apparently indefinite, of uncertain cause or source, emotive or frightening or apparently due to thoughtlessness or lack of consideration is most likely to elicit an adverse reaction (Grimwood, 1993). In the 1991 BRE survey,



people most objected to barking dogs, banging doors, noise from radio, television, or hi-fi and human voices (Grimwood, 1993). In this survey, two types of emotional response to noise were observed: outwardly directed aggression, characterized by feelings of annoyance, aggravation, bitterness and anger towards the source of the noise, and a more emotional response of tension, anxiety and feelings of pressure. These responses are reminiscent of the distinction between internalizing and externalizing disorders. Whether noise from neighbours can induce psychiatric disorder has been little studied in community research, but this is an area that deserves further study (Stansfeld, Haines and Brown, 2000).

Undoubtedly, prolonged exposure to noise can be very upsetting, intrusive and interfering for sleep and everyday activities. In poorly built dwellings, especially apartments, even low intensity noises may be clearly audible through walls, floors, or ceilings (Raw and Oseland, 1991). In this situation, noise is destructive of privacy, especially for those living alone, and may be associated with perceptions of threat or increase a sense of isolation. This may be especially the case among people who are chronically anxious and likely to complain of sensitivity to noise; prolonged noise exposure may make them more anxious and unhappy. Often, this leads to arguments with neighbours, leading to a breakdown of neighbourly relationships and further isolation which may well in itself have a bad effect on mental health. Occasionally, this may be a sign of feelings of persecution associated with psychotic illness in which noise exposure is just an external trigger of an internally generated condition.

#### 4.8.6 MECHANISMS FOR CAUSAL LINKS BETWEEN NOISE AND MENTAL HEALTH

What might the mechanism be for the effects of noise on mental health? One way to approach this is through the effects of noise on cognitive performance where the laboratory evidence of effects is fairly robust (Smith and Broadbent, 1992). Effects of noise on mental health might be expected because there is evidence that noise impairs other aspects of human functioning, such as performance (Loeb, 1986) and sleep, that are important in maintaining normal functioning, and that noise causes adverse emotional reactions such as annoyance. In general, it seems that noise exposure increases arousal, and decreases attention through distraction (Broadbent, 1953), increases the need for focusing attention to cut out irrelevant stimuli (Cohen and Spacapan, 1978), as well as altering choice of task strategy (Smith and Broadbent, 1981). Even relatively low levels of noise may have subtle ill effects, and in this respect, the state of the person at the time of performance may be as important as the noise itself (Broadbent, 1983). Individuals' perception of their degree of control over noise may also influence whether it impairs memory (Willner and Neiva, 1986) while perception of lack of control over environmental conditions may be an important mediator of health effects.

Additionally, noise may also affect social performance as: (1) a stressor causing unwanted aversive changes in affective state; (2) by masking speech and impairing communication; and (3) by distracting attention from relevant cues in the immediate social environment (Jones, Chapman and Auburn, 1981). It may be that people whose performance strategies are already limited for other reasons (for instance through high anxiety) and who are faced with multiple tasks may be more vulnerable to the masking and distracting effects of noise.

The mechanism for the effects of noise on health is generally conceptualized as fit-

ting the stress–diathesis model, in which noise exposure increases arousal, and chronic exposure leads to chronic physiological change and subsequent health effects. It is not clear, however, whether this model is appropriate for mental health effects. A more sophisticated model (Biesiot, Pulles and Stewart, 1989; Passchier-Vermeer, 1993) incorporates the interaction between the person and their environment. In this model, the person readjusts their behaviour in noisy conditions to reduce exposure. An important addition is the inclusion of the appraisal of noise (in terms of danger, loss of quality, meaning of the noise, challenges for environmental control, etc.) and coping (the ability to alter behaviour to deal with the stressor). This model emphasizes that dealing with noise is an active not a passive process.

#### 4.8.7 HABITUATION TO NOISE AND MENTAL HEALTH

It is likely that mental health effects arise from persistent exposure to noise over a long period of time. But do people habituate or adapt to noise over time? In some studies people do seem to adapt to noise and no longer notice noise that they are frequently exposed to. On the other hand, in some studies of annoyance there seems to be little evidence of adaptation (Cohen and Weinstein, 1981). It may be that, as in physiological studies, a failure of adaptation occurs if the stimulus is novel, salient or implies threat. The development of mental health symptoms implies a failure to habituate to noise, or at least to adapt to noise. In some studies control over noise or active coping with noise rather than passive emotion-focused coping is related to lower levels of symptom (van Kamp, 1990). Habituation has not been formally studied in relation to noise and mental health.

#### 4.8.8 RISK GROUPS FOR MENTAL HEALTH EFFECTS FROM NOISE

One way to look at susceptibility to noise is to think about groups in the population who may be more susceptible to noise, for instance people with existing physical or mental illness tend to be more highly annoyed by noise and potentially could be vulnerable to mental health effects. Similarly, people with hearing impairment may be vulnerable to communication difficulties in noisy environments that could increase the risk of mental health symptoms. People who report that they are sensitive to noise tend to be more prone to noise annoyance and may be more at risk for common mental disorders (Stansfeld et al., 2002).

#### 4.8.9 POPULATION GROUPS AT RISK FOR MENTAL HEALTH EFFECTS FROM NOISE

There is some evidence that children are more vulnerable to the mental health effects of noise than adults in terms of prematurity, low birth weight and through scoring higher on hyperactivity. There is no consistent evidence of age, social class, ethnic or gender differences in susceptibility to mental health effects from environmental noise.

#### 4.8.10 NOISE SENSITIVITY

Noise sensitivity, based on attitudes to noise in general (Anderson, 1971; Stansfeld, 1992), is an intervening variable which explains much of the variance between exposure and individual annoyance responses (Weinstein, 1978; Langdon, Buller and



Scholes, 1981; Fields, 1993). Individuals who are noise-sensitive are also likely to be sensitive to other aspects of the environment (Broadbent, 1972; Weinstein, 1978; Thomas and Jones, 1982; Stansfeld et al., 1985a). This raises the question as to whether noise-sensitive individuals are simply those who complain more about their environment. Certainly, there is an association between noise sensitivity and neuroticism (Thomas and Jones, 1982; Öhrström, Bjorkman and Rylander, 1988; Jelinkova, 1988; Belojevic and Jakovljevic, 1997; Smith, 2003), although it has not been found in all studies (Broadbent, 1972). On the other hand, Weinstein (1980) hypothesized that noise sensitivity is part of a critical/uncritical dimension, showing the same association as noise sensitivity to measures of noise, privacy, air pollution and neighbourhood reactions. He suggested that the most critical subjects, including noise-sensitive people are not uniformly negative about their environment, but more discriminating than the uncritical group, who comment uniformly on their environment.

Noise sensitivity has also been related to current psychiatric disorder (Bennett, 1945; Tarnopolsky, Morton-Williams and Barker, 1980; Iwata, 1984). Stansfeld et al. (1985) found that high noise sensitivity was particularly associated with phobic disorders and neurotic depression, measured by the Present State Examination (Wing, Cooper and Sartorius, 1974). Similar to this association with phobic symptoms, noise sensitivity has also been linked to a coping style based on avoidance, which may have adverse health consequences (Pulles, Biesiot and Stewart, 1988) and a tendency to report health complaints rather than take a more active coping approach to noise (Lercher and Kofler, 1996). Noise sensitivity may be partly secondary to psychiatric disorder: depressed patients followed over four months became less noise-sensitive as they recovered (Stansfeld, 1992). These "subjective" psychological measurements were complemented by an "objective" psychophysiological laboratory investigation of reactions to noise in a subsample of depressed patients. Noise-sensitive people tended to have higher levels of tonic physiological arousal, more phobic and defence/startle responses and slower habituation to noise (Stansfeld, 1992). Thus, noise-sensitive people attend more to noises, discriminate more between noises, find noises more threatening and out of their control, and adapt to noises more slowly than people who are less sensitive. Through its association with greater perception of environmental threat and its links with negative affectivity and physiological arousal, noise sensitivity may be an indicator of vulnerability to minor psychiatric disorder, although not necessarily psychiatric disorder caused by noise (Stansfeld, 1992).

In analysis of a subset of noise-sensitive women, compared to less sensitive women in the West London survey, there was no evidence that aircraft noise exposure predicted psychiatric disorder in the sensitive women (Stansfeld et al., 1985). In the Caerphilly study, noise sensitivity predicted psychological distress at follow-up after adjusting for baseline psychological distress, but did not interact with the noise level, suggesting that noise sensitivity does not specifically moderate the effect of noise on psychological distress (Stansfeld et al., 1993). However, in further analyses, a statistically significant association between road traffic noise exposure and psychological distress, measured by the General Health Questionnaire (GHQ), was found in noise-sensitive men, that was not found in men of low noise sensitivity (Stansfeld et al., 2002). In the original analyses, after adjusting for trait anxiety at baseline, the effect of noise sensitivity was no longer statistically significant. This suggests that much of the association between noise sensitivity and psychological distress may be accounted for by the confounding association with trait anxiety. Constitutionally anxious people may be both more aware of threatening aspects of their environment and more prone to future psychiatric disorder. It seems possible that these traits might be linked.

In a United Kingdom community study, associations were examined between noise exposure, noise sensitivity, subjective symptoms and sleep disturbance in a random sample of 543 adults (Smith, 2003). Perceived noise exposure was related to subjective health, but this association became non-significant after adjustment for negative affectivity. In a similar way, adjustment for negative affectivity eliminated the association between noise sensitivity and subjective health. Thus, it was suggested that noise sensitivity was merely a proxy measure of negative affectivity or neuroticism. However, although this means that noise sensitivity is not specific to noise, the more recent analyses suggest that high levels of trait anxiety or neuroticism may be an indicator of vulnerability to noise effects and could put people at risk of adverse psychological effects from noise, even if they do not increase the risk of physical ill health.

#### 4.8.11 MENTAL HEALTH CONSEQUENCES OF INSOMNIA

Transient insomnia is usually accompanied by reports of daytime sleepiness and performance impairment the next day. Chronic insomnia is generally associated with poorer emotional and physical health. Several large-scale epidemiological studies of the general adult population have shown that between one third and one half of people who complain of chronic insomnia are also diagnosable with primary psychiatric disorders, mostly anxiety and mood disorders. Mellinger, Balter and Uhlenhuth (1985) found that 17% of adults reported “a lot” of trouble falling asleep or staying asleep over the past year; 47% of them had high levels of psychological distress, with symptom complexes suggestive of depression and anxiety disorders. In contrast, only 11% of individuals with no history of insomnia showed elevated levels of psychiatric symptoms. In a survey of almost 8000 individuals, Ford and Kamerow (1989) reported that 10% had suffered from significant insomnia for at least a two-week period during the previous six months; 40% of the insomniacs met criteria for psychiatric disorders, with the majority being anxiety disorders and depression; only 16% of those with no sleep complaints had psychiatric illness.

Breslau et al. (1996) found a strong correlation between lifetime prevalence of sleep problems and psychiatric disorders, with anxiety, depression, and substance abuse disorders being the most common. Similar results have been found by Vollrath, Wicki and Angst (1989), Chang et al. (1997) and Dryman and Eaton (1991). In a large-scale European population-based study (Ohayon and Roth, 2003), it was found that insomnia more often precedes rather than follows incident cases of mood disorders.

Insomniacs not only have higher rates of psychiatric disorders, but they also have increased rates of various kinds of psychological symptoms: patients with insomnia reported increased psychological stress and/or decreased ability to cope with stress according to surveys of the American (Roth and Ancoli-Israel, 1999) and Japanese (Kim et al., 2000) population. Almost 80% of insomniacs had a significant increase on one or more clinical scales on the Minnesota Multiphasic Personality Inventory (MMPI) (Kalogjera-Sackellares and Cartwright, 1997). Even people whose insomnia was due to identified medical factors showed elevation on the MMPI, suggesting a possible causal relationship or specific association between insomnia and psychiatric symptomatology. Compared to good sleepers, severe insomniacs reported more medical problems, had more GP office visits, were hospitalized twice as often and used more medication. Severe insomniacs had a higher rate of absenteeism, missing work twice as often as did good sleepers. They also had more problems at work (including decreased concentration, difficulty performing duties and more work-related accidents) (Leger et al., 2002).



#### 4.8.12 INSOMNIA AS A MENTAL HEALTH SYMPTOM

Insomnia is a symptom of many psychiatric disorders, especially depression and anxiety. In studies of depressed patients compared to control subjects, there was prolonged latency to sleep, increased wakefulness during sleep, early morning wakening, decreased sleep efficiency and reduced total sleep time. There is also evidence that insomnia may be a risk factor for developing depression (Riemann, Berger and Voderholzer, 2001; Roberts, Roberts and Chen, 2002). This raises the question as to whether prolonged noise exposure leading to insomnia provokes the onset of depression in susceptible people? This seems theoretically possible, but there is little evidence to support it. In a longitudinal study of adolescents, it was the other way round – that depressive symptoms preceded the onset of insomnia (Patton et al, 2000). Delayed sleep latency in children has been linked to increased externalizing symptoms including aggressive behaviour, and impaired attention and social problems (Aronen et al., 2000). In this cross-sectional study, the direction of association was uncertain, but it seems most plausible that the sleep disturbance is a feature of the behavioural disturbance rather than a cause of it. Three criteria have been suggested for sleep disturbance to be environmentally determined: (1) the sleep problem is temporally associated with the introduction of a physically measurable stimulus or definable set of environmental circumstances; (2) the physical rather than the psychological properties of the environmental factors are the critical causative elements; and (3) removal of the responsible factors results in an immediate or gradual return to normal sleep and wakefulness (Kraenz et al., 2004). Most studies do not fulfil these criteria. In a German school-based study of 5–6-year-old children, sleep disturbance by noise, largely from road traffic, was reported “sometimes” in 10% by parents of children and 2% “often”. Children’s reports were slightly higher: “sometimes” in 12% and 3% “often” (Kraenz et al., 2004). Further longitudinal research is needed to ascertain whether noise-induced insomnia leads on to overt psychiatric disorder.

In summary, population as well as clinic-based studies have demonstrated a high rate of psychiatric morbidities in patients with chronic insomnia. It has traditionally been assumed that insomnia is secondary to the psychiatric disorders; however, it is possible that in some cases the insomnia preceded the psychiatric disorder.

#### 4.8.13 DEPRESSIVE EPISODE AND ANXIETY DISORDERS

A mild depressive episode is diagnosed by clinical interview. The criteria for a mild depressive episode include two or more symptoms of depressed mood, loss of interest or fatigue lasting at least two weeks, with two or three symptoms such as reduced concentration, reduced self-esteem, ideas of guilt, pessimism about the future, suicidal ideas or acts, disturbed sleep, diminished appetite and social impairment, and fewer than four symptoms including lack of normal pleasure/interest, loss of normal emotional reactivity, waking =>2 hours early, loss of libido, diurnal variation in mood, diminished appetite, loss of =>5% body weight, psychomotor agitation or psychomotor retardation.

Anxiety disorders are similarly diagnosed by clinical interview. The criteria for “generalized anxiety disorders” include duration of at least six months of free-floating anxiety and autonomic overactivity.

#### 4.8.14 ASSOCIATIONS BETWEEN INSOMNIA AND PSYCHIATRIC DISORDERS

At the present time, exposure–effect associations have not been established between parameters of sleep disturbance (number of behavioural awakenings, body movements or EEG awakenings) and the onset of depressive and anxiety disorders, although there is some evidence that insomnia is a risk factor for developing depression (Riemann, Berger and Voderholzer, 2001; Roberts, Roberts and Chen, 2002). A number of longitudinal prospective studies in different age groups have found associations between self-reports of insomnia and the subsequent onset of psychiatric disorder, in particular major depression. A selection of the most important studies and their findings are outlined in Table 4.3 below.

**Table 4.3**  
Insomnia as a  
predictor of  
psychiatric  
disorder

Study	Sample size	Sample	Follow-up interval	Depression measure	Results
Ford and Kamerow, 1989	7954	Community sample	1 year	Diagnostic interview schedule	Risk of developing new depression for insomnia on two occasions: [OR=39.8, 95% CI 19.8-80.0]
Breslau et al., 1996	1200	21–30 years members of health maintenance organization	3 years	Diagnostic interview schedule	RR for new onset major depression associated with baseline insomnia [RR=4.0, 95% CI 1.5-5.6]
Chang et al., 1997	1053	Male medical students	34 years (median)	Clinical depression	RR for clinical depression for those who reported insomnia at medical school [RR= 2.0, 95% CI 1.2-3.3]
Roberts, Roberts and Chen, 2002	3136	11–17 years from managed care rosters	1 year	Diagnostic interview schedule for children major depression module	Fully adjusted OR for insomnia in waves 1 and 2 for depression at follow-up [OR=1.92, 95% CI 1.30-2.82]

#### 4.8.15 CONCLUSIONS: ASSOCIATIONS BETWEEN NOISE AND PSYCHIATRIC DISORDERS

The effects of noise are strongest for those outcomes that, like annoyance, can be classified under “quality of life” rather than illness. What they lack in severity is made up for in numbers of people affected, as these responses are very widespread.



Current evidence does seem to suggest that environmental noise exposure, especially at higher levels, is related to mental health symptoms and possibly raised anxiety and consumption of sedative medication, but there is little evidence that it has more serious effects. Further research is needed on mental health effects at very high noise levels. Existing studies may be confounded either by prior selection of subjects out of (or into) noisy areas as a result of noise exposure, or by confounding between noise exposure, socioeconomic deprivation, and psychiatric disorder. It is also possible that people underestimate or minimize the effects of noise on health through optimism bias (Hatfield and Soames Job, 2001) and that this is particularly protective for mental health.

The evidence is not strong for the association between noise exposure and mental ill health. What evidence there is suggests that noise exposure may be responsible for psychological symptoms above 70 dB(A)  $L_{eq}$ . Almost all studies have only examined the effects of daytime noise on mental health, but it is possible that night-time noise, during sleep time, may have effects on mental health at lower levels than daytime noise.

The most powerful evidence of noise on mental health comes from studies of military aircraft noise. There is also some evidence that intense road traffic noise may lead to psychological symptoms. There is no evidence of any effects of railway noise on mental health.

## 4.9 THE SEVERITY OF SELF-REPORTED SLEEP DISTURBANCE

### 4.9.1 INTRODUCTION

In section 2.1.2 of Chapter 2 of this report, it is stated that sleep disturbance caused by noise may either be diagnosed (Environmental Sleep Disorder: ICSD 780-52-6) or self-reported. Although self-reported sleep disturbance is subjective by definition, its observed occurrence correlates with noise levels as well as with important diagnostic criteria for ICSD 780-52-6. It appears justified to consider self-reported sleep disturbance as an impairment of health, especially if indicated by representative population samples in social surveys. Furthermore, section 4.1 of Chapter 4 of this report gives a quantitative relationship between noise level  $L_{night}$  and the percentage of population that reports a disturbed sleep of high, medium or low disturbance intensity.

But an open question concerns severity: even if night-time noise causes large percentages of the population to declare themselves as highly sleep-disturbed, this could nevertheless represent an almost negligible loss of health, if the mean severity of self-reported sleep disturbance were negligible in comparison with commonly accepted diseases. Attempts have been made to give an answer to this important question, using WHO's concept of disability weights (Murray et al., 1996) as a basis for severity comparisons.

### 4.9.2 AN ASSESSMENT OF DISABILITY WEIGHTS

A Swiss study (Müller-Wenk, 2002) aimed at determining a disability weight for sleep disturbance due to road traffic noise. For this purpose, a description of road-

noise-related sleep disturbance was set up: essentially, this state of health was assumed to be present if a person indicated that, due to traffic noise, he or she, almost every night, had problems with falling asleep, with continuing sleep during the night or with early or non-restorative waking in the morning. In addition, a list was established with already available disability weights (Murray et al., 1996; Stouthard et al., 1997) for a selection of 28 diseases of various types, covering a range from very light severity to high severity (Müller-Wenk 2002:65–66). All 64 members of the medical staff of the Swiss Accident Insurance Institute (SUVA) were then asked in a written questionnaire to determine the hitherto unknown disability weight of sleep disturbance by interpolation, that is, by inserting sleep disturbance at the appropriate place between the presented 28 diseases that were sorted according to ascending disability weight. These participants were chosen because the physicians of the SUVA, besides being medical doctors, have a particularly high professional know-how in comparing the severity of different types of disability. Forty-two questionnaires were completed, of which 41 were usable.

From these questionnaires, an arithmetical mean of 0.055 of the disability weight for sleep disturbance could be calculated, with a 95% confidence limit of 0.039 at the low end and 0.071 at the high end. This result can be illustrated by mentioning diseases from the catalogues of Murray et al. (1996) or Stouthard et al. (1997) with the same disability weight: hence the disability weight of the road-noise-related sleep disturbance is roughly the same as the disability weight of “chronic hepatitis B infection without active viral replication”, the latter having a mean disability weight of 0.06 and a 95% confidence interval from 0.034 to 0.087. The low-end estimate of 0.039 for sleep disturbance severity would correspond to the mean disability weight of “benign prostatic hypertrophy (symptomatic cases)”, whilst the high estimate of 0.071 would correspond to the mean disability weight of “uncomplicated diabetes mellitus”. The conclusion is that the mean disability weight of road-noise-related sleep disturbance is not smaller (= less severe) than the disability weight of health impairments commonly recognized as diseases, and there is a strong overlap amongst the probability distributions of these disability weights. On the basis of the chosen disability weight 0.055 for self-reported sleep disturbance, and taking into account the current traffic noise levels during the night in many European states, it is justified to consider noise-related sleep disturbance as a substantial loss of public health.

#### 4.9.3 COMPARISON BETWEEN INSOMNIA AND SELF-REPORTED SLEEP DISTURBANCE

The original list of disability weights (Murray et al., 1996) did not contain any kind of non-normal sleep. In the meantime, WHO has published an extended list (Mathers et al., 2003, Annex Table 5a) containing a disability weight of 0.100 for insomnia (diagnostic code 307.42). This has opened a way to recheck the disability weight of 0.055 (Müller-Wenk, 2002), by asking a panel of medical professionals to compare, on the basis of disability weights, the mean severity of self-declared sleep disturbance due to road noise at night with the mean severity of insomnia. It may be debated whether it is more straightforward to compare two types of sleep anomalies with similar symptoms, or to compare self-declared sleep disturbance with various types of completely different diseases. But it makes sense anyway to use the comparison with insomnia as a second approach for determining the disability weight of self-reported sleep disturbance.



This severity comparison between different sleep anomalies was made in 2005 by structured oral interviews, executed by a medical staff member of the sleep clinic of Kantonsspital St. Gallen (Switzerland), with 14 GPs selected at random from all GPs who had admitted patients to the sleep clinic during the nine preceding months. These patients were mainly suffering from OSAS. The question was as follows:

“Could you please give us your opinion on the relative severity of three different cases of insomnia:

1. (primary) insomnia, in our region usually called psychophysiological insomnia
2. Obstructive Sleep Apnoea Syndrome (OSAS)
3. traffic-noise-related sleep disturbance, that may occur with persons who are forced to sleep along through roads with nocturnal motor traffic.

Your opinion should be based on the patients you have seen in your office lately, or on other persons of your social environment. When comparing the severity of the health impairment, the focus should be above all on the person's condition during the day after the sleep-disturbed night. The absolute value of the severity is less important for the current study than the relative severity amongst the three cases of insomnia. The opinion of the severity may be expressed on a linear scale from 0 (no impairment at all) to 10 (impairment almost unsupportable). On the scale from 0 to 10, you may give us your mean value of the severity, or you may give us a span from a low to a high for the severity.”

All of the interviewed GPs gave their opinions, and the result is presented in Table 4.4.

**Table 4.4**  
Severity ratings (10 = almost insupportably disturbing, 0 = not in the least disturbing) by 14 GPs selected at random

No	Primary insomnia				OSAS (sleep apnoea)				Sleep disturb.(noise)				Ratio noise/ priminsomnia	Noise/ OSAS
	Max	Min	Mean	Rank	Max	Min	Mean	Rank	Max	Min	Mean	Rank		
10	6	4	5	3	8	6	7	1	8	6	7	1	1.40	1.00
11	5	3	4	3	9	7	8	1	8	4	6	2	1.50	0.75
12			5	3			10	1	7	8	7.5	2	1.50	0.75
13	2	3	2.5	2	4	5	4.5	1	1	2	1.5	3	0.60	0.33
14			3	2			6	1	1	2	1.5	3	0.50	0.25
15			8	2			9	1			6	3	0.75	0.67
16			8	1			7	2			4	3	0.50	0.57
17			5	1			5	1			3	3	0.60	0.60
18	2	3	2.5	2			6	1	1	2	1.5	3	0.60	0.25
19			8	1			3	2			2	3	0.25	0.67
20			6	2			7	1			4	3	0.67	0.57
21			7	2			8	1			0	3	0.00	0.00
22			4	3			5	2			6	1	1.50	1.20
23			4	3	6	7	6.5	2	8	9	8.5	1	2.13	1.31
Mean			5.143	2.143			6.57	1.286			4.18	2.429	0.89	0.64
Sigma													0.60	
Median													0.63	
Upper value 95% C.I. for mean													1.20	
Lower value 95% C.I. for mean													0.58	

Clearly, the severity judgements vary widely between the participating GPs. Apart from the differences in personal judgement, this variation is certainly influenced by the mix of patients visiting a particular GP. For instance, GP number 15 could have encountered one or two very serious cases of OSAS, whilst his/her experience with noise-related sleep disturbance might refer to persons that were only moderately disturbed by night-time noise in their bedroom. On the other hand, number 22 could

have had experience with persons suffering very much from sleep disturbance due to high traffic noise exposure, whilst his/her OSAS or primary insomnia patients happened to be light cases. One must accept that even GPs have a limited experience with the whole range of cases of each of the three types of insomnia, so that their opinion on the mean severity of noise-related sleep disturbance, compared to the mean severity of OSAS or insomnia, is influenced by the randomness of their patient mix.

Nevertheless, the table supports the following statements.

- With respect to severity, the majority of GPs rank noise-related sleep disturbance lower than insomnia and OSAS, while three of them put noise-related sleep disturbance in the first rank. Only one of the participants (number 21) considers noise-related sleep disturbance as a fully negligible disturbance.
- The severity ratio between noise-related sleep disturbance and insomnia varies between 0 and 2.1. Seven of the fourteen GPs indicate a severity ratio between 0.5 and 0.75, that is to say that half the participants are of the opinion that the severity of noise-related sleep disturbance amounts to 50–75% of the severity of insomnia.
- The mean of this severity ratio is 0.89, with a standard deviation (sigma) of 0.60. The confidence interval (CI) for the mean goes from 0.58 to 1.20. The median of the severity ratio is 0.63. The distribution is skewed to the right.

The severity ratio developed above can be used as a proportionality factor between the known disability weight for insomnia and the required disability weight for self-reported sleep disturbance. Bearing in mind that the already existing WHO disability weight for insomnia is 0.10, a best guess for the mean disability weight for self-reported sleep disturbance due to road traffic noise at night is therefore 0.089, with a CI from 0.058 to 0.12.

#### 4.9.4 CONCLUSIONS

According to the two groups of interviewed medical professionals, persons that declare themselves to be chronically deprived of normal sleep by road traffic noise have a health state whose mean disability weight is comparable to “chronic hepatitis B infection without active viral replication” or higher. Irrespective of the question whether self-reported sleep disturbance is formally recognized as a disease or not, its severity is comparable to commonly accepted diseases.

The best estimate for a mean disability weight for self-reported sleep disturbance due to road traffic noise was 0.055 (CI: 0.039; 0.071) according to Müller-Wenk (2002), whilst our recheck based on a comparison with insomnia resulted in a disability weight of 0.09 (CI: 0.06; 0.12). The higher disability weight according to the second approach might be caused by the fact that in this second approach, there was a stronger focus on “the person’s condition during the day after the sleep-disturbed night”.

The above figures compare reasonably with a study published by van Kempen (1998), cited in Knol and Staatsen (2005:46), where a severity weight of 0.10 for severe sleep disturbance was found, based on the judgement of 13 medical experts according to the protocol of Stouthard et al. (1997).



In conclusion, a mean disability weight of 0.07 is proposed for self-reported sleep disturbance due to road noise or similar ambient noise. This disability weight can be used in connection with the equations of section 4.1 of this chapter for highly sleep-disturbed persons.

#### 4.10 DISCUSSION: CAN CHRONIC SHORT-TERM EFFECTS CAUSE LONG-TERM EFFECTS ON HEALTH?

EEG modifications, cardiovascular responses, body movements and awakenings due to noise occur within a few seconds after the stimulus. In addition to the instantaneous effects related to single events, large field studies on aircraft (Passchier-Vermeer et al., 2002) and road traffic noise exposure during night-time (Griefahn et al., 2000; Passchier-Vermeer et al., 2004) show that also sleep latency and average motility during the sleep period increased monotonously as a function of the noise exposure level. The increase in average motility was substantially higher than would be expected on the basis of the instantaneous extra motility at the times of the noise events (Passchier-Vermeer et al., 2002) suggesting persistent arousal during the sleep related to aircraft noise. Furthermore, an international field study (Jurriëns et al., 1983) found slightly reduced REM sleep, increased time being awake according to the EEG, increased average heart rate, and reduced performance on a reaction time test in people when exposed during the night to higher road traffic noise levels.

The relationship between instantaneous effects and more global modifications of one night sleep, as well as chronic changes, is not simple, as illustrated by the findings concerning motility. An increase in average motility that is substantially higher than would be expected on the basis of the instantaneous extra motility at the times of the noise events (Passchier-Vermeer et al., 2002) suggests a persistent arousal during sleep related in a dose-dependent way to the aircraft noise.

Since EEG arousal and instantaneous motility are correlated, this finding suggests that also the number of (micro-)arousals may increase during noise exposure more than by the sum of the instantaneous (micro-)arousals that occur contingent upon a noise event.

For overall motility during sleep, clear indications have been found of associations with further effects, although the causal direction is not in all cases clear. Mean (onset of) motility during sleep is associated with the following variables based on questionnaires and diaries (Passchier-Vermeer et al., 2002):

- frequency of conscious awakening during the sleep period: the increase is 0.8 conscious;
- awakenings per night, if motility increases from low to high;
- frequency of awakening remembered next morning: the increase is 0.5 remembered;
- awakenings per night, if motility increases from low to high;
- long-term frequency of awakening attributed to specific noise sources assessed with a questionnaire;
- sleep quality reported in a morning diary;
- long-term sleep quality assessed with a questionnaire;

- number of sleep complaints assessed with a questionnaire;
- number of general health complaints assessed with a questionnaire.

The associations of mean motility with these variables are stronger than the corresponding associations of mean onset of motility.

For evaluating the adverseness of the instantaneous effects, it is important to consider whether they bring the body into a more persistent state of higher arousal or not, although this is not the only criterion. Those effects which are progressively disappearing with the repetition of the stimulus may be less harmful than those which do persist over long exposure time, provided that the suppression of the effects do not require costs in another form. For example, short-term cardiovascular effects that appear not to habituate could lead to permanent cardiovascular system impairment (Carter, 1996, 1998).

The relations presented for motility and conscious awakening imply that motility is sensitive to noise and has a relatively low threshold, while conscious awakening, the strongest instantaneous interference of noise with sleep, has the highest threshold of the instantaneous effects considered.

In one of the most sophisticated field studies (Passchier-Vermeer et al., 2002), increased probability of instantaneous motility was found for events with a maximum sound level  $L_{Amax} > 32$  dB(A), while in a meta-analysis conscious awakening was found for events with  $L_{Amax} > 42$  dB(A) (Passchier-Vermeer, 2003a). Above their threshold, these effects were found to increase monotonously as a function of the maximum sound level during a noise event (aircraft noise). It is important to note that in another recent sophisticated field study (Basner et al., 2004), the threshold found for EEG awakening was  $L_{Amax} = 35$  dB(A), that is, only a little higher than the 32 dB(A) found for noise-induced awakenings. This strengthens the evidence that noise starts to induce arousals at  $L_{Amax}$  values in the range 30–35 dB(A). Given the night-time noise levels to which people are exposed, these results imply that instantaneous effects are common. Although most studies concerned aircraft noise, the instantaneous effects can be assumed to occur at similar levels for different types of transportation.

The above observations can be used as a basis for setting limits with respect to night-time transportation noise. For transparency, it is useful to distinguish two steps in choosing actual limits: the first step is the derivation of a health-based limit; the second step is the derivation of an actual limit that takes into account the health-based limit as well as feasibility arguments. Here the concern is with the first step.

When deriving a health-based limit, two points need to be considered: the dose-dependent effects of a single noise event, and the number of events. With respect to the dose-dependent effects of a single event, adverse effects can be distinguished from effects that by themselves need not be adverse but can contribute to an adverse state. It is proposed to classify conscious awakenings as an adverse effect. Conscious awakenings have been estimated to occur at a baseline rate of 1.8 awakening per night. A substantial increment of conscious awakenings over this baseline is thought to be adverse. Since, in general, falling asleep after conscious awakening takes some time, and this latency is longer after noise-induced conscious awakening that will often also induce an emotional reaction (anger, fear), it will also reduce the time asleep and may affect mood and functioning next day. Although additional, more sophisticated analyses could be performed to refine this estimate, we propose  $L_{Amax}$



= 42 dB(A) is proposed as the currently best estimate of the threshold for conscious awakening by transportation noise. This would mean that the no observed effect level ( $\text{NOEL}_{\text{Amax}}$ ) for transportation noise events is at most 42 dB(A). The most sensitive instantaneous effect that has been studied extensively in field studies is motility. A single interval with (onset of) noise-induced motility by itself cannot be considered to be adverse.

However, noise-induced motility is a sign of arousal, and frequent (micro-)arousal and accompanying sleep fragmentation can affect mood and functioning next day and lead to a lower rating of the sleep quality. Therefore, motility is relevant for adverse health effects, but more than a few intervals with noise-induced motility are needed for inducing such effects. Although additional, more sophisticated analyses could be performed to refine this estimate, we propose  $L_{\text{Amax}} = 32$  dB(A) as the currently best estimate of the threshold for motility induced by transportation noise. The threshold found for EEG awakening was  $L_{\text{Amax}} = 35$  dB(A), that is, only a little higher than the 32 dB(A) found for noise-induced awakenings. This would mean that the  $\text{NOEL}_{\text{Amax}}$  for transportation noise events is most likely at most 32 dB(A), and definitely not higher than 35 dB(A). It is important to note that the above given  $\text{NOEL}_{\text{Amax}} \sim 32$  dB(A) and  $\text{NOEL}_{\text{Amax}} \sim 42$  dB(A) are indoor levels, in the sleeping room. Although events below 32 dB(A) are audible, and, hence, further research may show more sensitive effects than motility, on the basis of the present available evidence we propose to assume that  $\text{NOEL}_{\text{Amax}} = 32$  dB(A) and set a health-based night-time noise limit that is tolerant for transportation noise events with  $L_{\text{Amax}} \sim 32$  dB(A). On the other hand, since adverse health effects need to be prevented by health-based limits and even though vulnerable groups may require lower limits, on the basis of the present available evidence we propose to assume that  $\text{NOEL}_{\text{Amax}} = 42$  dB(A) and set a health-based night-time noise limit that does not tolerate transportation noise events with  $L_{\text{Amax}} > 42$  dB(A).

On the basis of the above proposal, it would be possible to derive a night-time noise guideline value in terms of  $L_{\text{night}}$ . Such a guideline value would indicate the level below which no short-term effects are to be expected that would lead to temporary reduced health or chronic disease. Such a guideline value needs to be compared with guideline values derived directly with a view to preventing temporary reduced health and chronic diseases. In particular, for self-reported sleep disturbance, which is an expression of reduced well-being and may be an indication of effects that could contribute to cardiovascular disease, exposure-effect relationships have been derived on the basis of an extensive set of original data from studies from various countries (Miedema, Passchier-Vermeer and Vos, 2003; Miedema, 2004). The percentage of people reporting high noise-induced sleep disturbance (%HS) levels off at 45 dB(A) but at a non-zero effect level. The remaining effect may be caused by events not incorporated in the exposure assessment and it appears that if all noise contributions would be incorporated in the exposure metric, high noise-induced sleep disturbance would vanish between 40 dB(A) and 45 dB(A), say at 42 dB(A). Since values found for other temporary reduced health effects or chronic diseases, in particular cardiovascular diseases, will be higher, and considering self-reported sleep disturbance as an adverse effect, this would suggest  $L_{\text{night}} = 42$  dB(A) as the NOAEL to be compared with the value derived from the short-term effects. Note that this is an outdoor level, which would, assuming partly opened windows and an actual insulation of 15 dB(A), correspond to an indoor equivalent night-time sound level of 27 dB(A). The above discussion is based on motility, EEG awakenings, and conscious awakening. In addition, EEG micro-/minor arousals, and autonomic reactions have been discussed above.

Furthermore, there are potential instantaneous effects, such as effects on memory consolidation or restoration of the immune system, for which the information on a possible relation with noise exposure is so limited that they were not considered here. In order to acquire more insight into these effects, more field research is needed. Field research is needed because earlier studies have shown that estimates of effects on the basis of laboratory studies are much higher than estimates from field studies. Methodological differences between the different approaches certainly cannot be the only possible explanation. Research allowing the introduction of some specific but light laboratory technique into the sleeper's own bedroom, should be encouraged, as, for example, used in the Swiss Noise Study 2000 (Brink, Müller, and Schierz, 2006). The key to better insight into effects of night-time noise, leading to mechanistic models describing the relationships between noise exposure, instantaneous effects, effects at the level of a 24-hour period and chronic effects, appears to be epidemiological studies at home with well-designed instrumentation.

The relationships between noise exposure, instantaneous effects, effects at the level of a single 24-hour period and chronic effects is complex because the effects at a smaller time scale do not simply add up to effects at a larger time scale. For example, the noise-related increase in night-time average motility was substantially higher than would be expected on the basis of the instantaneous extra motility at the times of the noise events (Passchier-Vermeer et al., 2002), suggesting persistent arousal during sleep related to aircraft noise. It is likely that such shifts in the basic state are more important for the development of chronic effects than the instantaneous effects per se. A further complication is that some effects habituate. Habituation in some effect parameters can occur in a few days or weeks, but the habituation is not always complete. The measured modifications of the cardiovascular functions remain unchanged over long periods of exposure time (Muzet and Ehrhart, 1980; Vallet et al., 1983). Most striking is that none of the cardiovascular responses show habituation to noise after a prolonged exposure, while subjective habituation occurs within a few days. It appears plausible that, in particular non-habituating effects lead to the development of chronic effects, but also the disappearance of effects with continuing exposure may come at a cost associated with suppressing the effects. A third complication is that daytime noise exposure may contribute to the effects found in relation to night-time noise. Large epidemiological studies are needed that compare populations exposed to similar daytime noise and differ in their night-time noise exposure only. A specific challenge for mechanistic models on the effects of noise on sleep is the identification of factors that make subjects vulnerable to night-time noise. The following groups may be hypothesized to be more vulnerable to noise during sleep: old people, ill people, people with chronic insomnia, shift workers and people resting during daytime, people with a tendency to depression, light sleepers, pregnant women, people with high anxiety and high stress levels. Furthermore, children need attention because of their relatively high exposure during sleep, and because they are in a phase of neurocognitive development for which undisturbed sleep may be particularly important.



## CHAPTER 5

### GUIDELINES AND RECOMMENDATIONS

#### 5.1 ASSESSMENT

In Chapter 1 the need for a guideline document for night-time exposure to noise was defended on the basis of the lack of existing guidance, the signs that a substantial part of the population could be exposed to levels of noise that might risk their health and well-being and the EU activities that compel the public and authorities to take notice when noise maps showing  $L_{\text{night}}$  levels are made public.

Where sufficient direct evidence concerning the effects of night-time noise on health could not be collected, indirect evidence was looked at: the effects of noise on sleep (quality) and the relations between sleep and health.

In Chapter 2 the evidence was presented that sleep is a biological necessity and disturbed sleep is associated with a number of health outcomes. Studies of sleep disturbance in children and in shift workers clearly show the adverse effects. Unravelling the relations between sleep and health (Fig. 2.1) shows that sleep is an essential feature of the organism, so that simple direct relations can hardly be expected.

In Chapter 3 it was shown beyond doubt that noise disturbs sleep through a number of direct and indirect pathways. Even at very low levels physiological reactions (heart rate, body movement and arousals) can be reliably measured. It was also shown that awakening reactions are relatively rare, occurring at a much higher level.

Chapter 4 summarized the known evidence for the direct effects of night-time noise on health. The working group agreed that there is sufficient evidence that night noise is related to self-reported sleep disturbance, use of pharmaceuticals, self-reported health problems and insomnia-like symptoms. These effects can lead to a considerable burden of disease in the population. For other effects (hypertension, myocardial infarctions, depression and others), limited evidence was found: although the studies were few or not conclusive, a biologically plausible pathway could be constructed from the evidence.

An example of a health effect with limited evidence is myocardial infarction. Although evidence for increased risk of myocardial infarction related to  $L_{\text{day}}$  is sufficient according to an updated meta-analysis, the evidence in relation to  $L_{\text{night, outside}}$  was considered limited. This is because  $L_{\text{night, outside}}$  is a relatively new exposure indicator, and few field studies have focused on night noise when considering cardiovascular outcomes. Nevertheless, there is evidence from animal and human studies supporting a hypothesis that night noise exposure might be more strongly associated with cardiovascular effects than daytime exposure, highlighting the need for future epidemiological studies on this topic.

The review of available evidence leads to the following conclusions.

- Sleep is a biological necessity and disturbed sleep is associated with a number of health outcomes.

- There is sufficient evidence for biological effects of noise during sleep: increase in heart rate, arousals, sleep stage changes and awakening.
- There is sufficient evidence that night noise exposure causes self-reported sleep disturbance, increase in medicine use, increase in body movements and (environmental) insomnia.
- While noise-induced sleep disturbance is viewed as a health problem in itself (environmental insomnia), it also leads to further consequences for health and well-being.
- There is limited evidence that disturbed sleep causes fatigue, accidents and reduced performance.
- There is limited evidence that noise at night causes hormone level changes and clinical conditions such as cardiovascular illness, depression and other mental illness. It should be stressed that a plausible biological model is available with sufficient evidence for the elements of the causal chain.

In the next section threshold levels are presented for the effects, where these can be derived.

## 5.2 THRESHOLDS FOR OBSERVED EFFECTS

The NOAEL is a concept from toxicology, and is defined as the greatest concentration which causes no detectable adverse alteration of morphology, functional capacity, growth, development or lifespan of the target organism. For the topic of night-time noise (where the adversity of effects is not always clear) this concept is less useful. Instead, the observed effect thresholds are provided: the level above which an effect starts to occur or shows itself to be dependent on the dose. This can also be an adverse effect (such as myocardial infarcts) or a potentially dangerous increase in a naturally occurring effect such as motility.

Threshold levels are important milestones in the process of evaluating the health consequences of environmental exposure. The threshold levels also delimit the study area, which may lead to a better insight into overall consequences. In Tables 5.1 and 5.2 all effects are summarized for which sufficient or limited evidence exists (see Table 1.2 in Chapter 1 for a definition). For the effects with sufficient evidence the threshold levels are usually well known, and for some the dose-effect relations over a range of exposures could also be established.

## 5.3 RELATIONS WITH $L_{\text{NIGHT,OUTSIDE}}$

Over the next few years, the END will require that night exposures are reported in  $L_{\text{night, outside}}$ . It is therefore interesting to look into the relation between  $L_{\text{night, outside}}$  and the effects from night-time noise. The relation between the effects listed in Tables 5.1 and 5.2 and  $L_{\text{night, outside}}$  is, however, not straightforward. Short-term effects are mainly related to maximum levels per event inside the bedroom:  $L_{\text{Amax, inside}}$ . In order to express the (expected) effects in relation to the single EU indicator, some calculation needs to be done.

**Table 5.1**  
Summary of effects and threshold levels for effects where sufficient evidence is available

Effect	Indicator	Threshold, dB	Reference (chapter, section)	
Biological effects	Change in cardiovascular activity	*	*	3.1.5
	EEG awakening	L <sub>Amax, inside</sub>	35	4.10
	Motility, onset of motility	L <sub>Amax, inside</sub>	32	3.1.8, dose-effect relation for aircraft
	Changes in duration of various stages of sleep, in sleep structure and fragmentation of sleep	L <sub>Amax, inside</sub>	35	3.1
	Waking up in the night and/or too early in the morning	L <sub>Amax, inside</sub>	42	3.1.7, dose-effect relation for aircraft
Sleep quality	Prolongation of the sleep inception period, difficulty getting to sleep	*	*	3.1
	Sleep fragmentation, reduced sleeping time	*	*	3.1
Well-being	Increased average motility when sleeping	L <sub>night, outside</sub>	42	3.2, dose-effect relation for aircraft
	Self-reported sleep disturbance	L <sub>night, outside</sub>	42	4.2, dose-effect relation for aircraft/road/rail
	Use of somnifacient drugs and sedatives	L <sub>night, outside</sub>	40	4.5.8
Medical conditions	Environmental insomnia**	L <sub>night, outside</sub>	42	3.1; 4.1; 4.2

\* Although the effect has been shown to occur or a plausible biological pathway could be constructed, indicators or threshold levels could not be determined.

\*\* Note that "environmental insomnia" is the result of diagnosis by a medical professional whilst "self-reported sleep disturbance" is essentially the same, but reported in the context of a social survey. Number of questions and exact wording may differ.



**Table 5.2**  
**Summary of effects and threshold levels for effects**  
**where limited evidence is available<sup>a</sup>**

Effect	Indicator	Estimated, threshold dB	Reference (chapter, section)
Biological effects	Changes in (stress) hormone levels	*	2.5
	Drowsiness/tiredness during the day and evening	*	2.2.3
	Increased daytime irritability	*	2.2.3
Well-being	Impaired social contacts	*	2.2.3
	Complaints	$L_{night, outside}$	4.3
	Impaired cognitive performance	*	2.2.3
	Insomnia	*	4.6
	Hypertension	$L_{night, outside}$	2.2.3; 4.5.6
	Obesity	*	2.2.3
	Depression (in women)	*	4.8
	Myocardial infarction	$L_{night, outside}$	4.5.15
	Reduction in life expectancy (premature mortality)	*	2.2.3; 2.5
	Psychiatric disorders	$L_{night, outside}$	4.8.15
	(Occupational) accidents	*	2.2.3; 2.4

<sup>a</sup> Note that as the evidence for the effects in this table is limited, the threshold levels also have a limited weight. In general they are based on expert judgement of the evidence.

<sup>b</sup> Although the effect has been shown to occur or a plausible biological pathway could be constructed, indicators or threshold levels could not be determined.

The calculation for the total number of effects from reaction data on events (arousals, body movements and awakenings) needs a number of assumptions. The first that needs to be made is independence: although there is evidence (Brink, Müller and Schierz, 2006) that the order of events of different loudness strongly influences the reactions, the calculation is nearly impossible to carry out if this is taken into consideration.



Secondly, the reactions per event are known in relation to levels at the ear of the sleeper, so an assumption for an average insulation value must be made. In this report a value of 21 dB (see Chapter 1, sections 1.3.4 and 1.3.5) has been selected. This value is, however, subject to national and cultural differences. One thing that stands out is the desire of a large part of the population to sleep with windows (slightly) open. The relatively low value of 21 dB already takes this into account. If noise levels increase, people do indeed close their windows, but obviously reluctantly, as then complaints about bad air increase and sleep disturbance remains high. This was already pointed out in the WHO guidelines on community noise (WHO, 1999).

From source to source the number of separate events varies considerably. Road traffic noise is characterized by relatively low levels per event and high numbers, while air and rail traffic are characterized by high levels per event and low numbers. For two typical situations estimates are made and presented in graphical form. The first is an average urban road (600 motor vehicles per night, which corresponds roughly to a 24-hour use of 8000 motor vehicles, or 3 million per year, the lower boundary the END sets) and the second case is for an average situation of air traffic exposure (8 flights per night, nearly 3000 per year).

Fig. 5.1 shows how effects increase with an increase of  $L_{\text{night, outside}}$  values for the typical road traffic situation (urban road). A large number of events lead to high levels of awakening once the threshold of  $L_{\text{Amax, inside}}$  is exceeded. To illustrate this in practical terms: values over 60 dB  $L_{\text{night, outside}}$  occur at less than 5 metres from the centre of the road.

In Fig. 5.2 the same graph is presented for the typical airport situation. Due to a lower number of events there are fewer awakenings than in the road traffic case (Fig. 5.1), but the same or more health effects.

In these examples the worst case figures can be factors higher: the maximum number of awakenings for an  $L_{\text{night, outside}}$  of 60–65 dB is around 300 per year.

A recent study suggests that high background levels (from motorways) with low numbers of separate events can cause high levels of average motility (Passchier-Vermeer, to be published). In Table 5.3 the full details are summarized.

## 5.4 DEALING WITH SITUATIONS EXCEEDING THE THRESHOLDS

Noise exposure data demonstrate that a large part of the population is over the no-effect levels. It is expected that this will extend into the future for quite some time. This means that circumstances may require that a risk assessment must be made. It is then recommended to apply the method laid out in Chapter 1, using the values given in Tables 5.1 and 5.2 and the dose–effect relations given in Chapter 4.

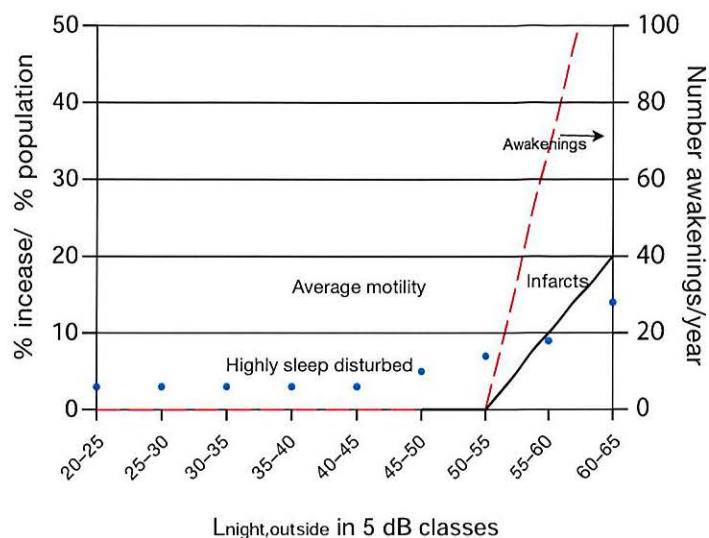
Typical actions requiring risk assessment are:

- new infrastructure projects (if an environmental impact statement is required)
- improvement programmes

- policy evaluation
- national or international setting of limit values.

In the EU *Position Paper* (European Commission, 2002a) an overview of national night-time noise regulations can be found.

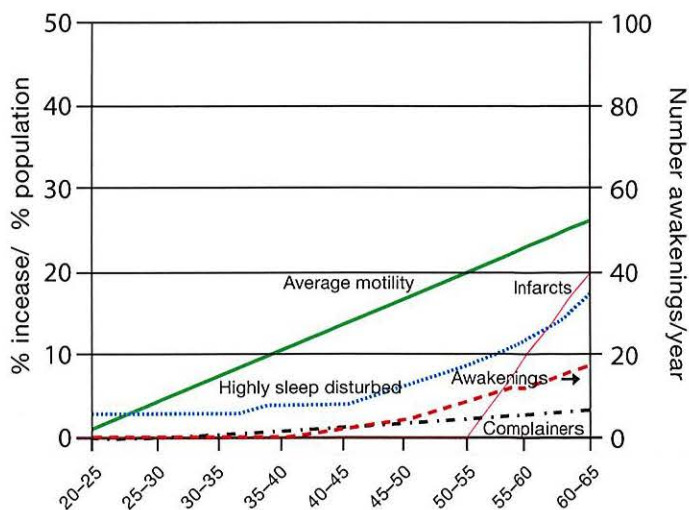
**Fig. 5.1**  
Effects of road traffic noise at night\*



Source: European Commission, 2002 a

\* Average motility and infarcts are expressed in percent increase (compared to baseline number); the number of highly sleep disturbed people is expressed as a percent of the population; awakenings are expressed in number of additional awakenings per year.

**Fig. 5.2**  
Effects of aircraft noise at night\*



Source: European Commission, 2002 a

\* Average motility and infarcts are expressed in percent increase (compared to baseline number); the number of highly sleep disturbed people is expressed as percent of the population; complainers are expressed as a percent of the neighbourhood population; awakenings are expressed in number of additional awakenings per year.

Table 5.3

Effects (yearly, additional with respect to the normal except odd ratio) 0=below threshold, +=increase

L <sub>night,outside</sub>	Arousals		Body movements related to single exposures (15 sec intervals)		Average body movements (without single exposures)	Awakenings		% sleep disturbed (% highly sleep disturbed)			Myocardial infarcts
	number	number	number	number	number	number	number	% of exposed			odd ratio
UNIT		air	average traffic	average urban road		average air traffic	average urban road	air	road	rail	
NORMAL	Children 2 555	Adults 3 650	21 000		21 000		600	0			1
20-25	0	0	0	0	200	0	0	0	0	0	1
25-30	0	0	7	0	875	0	0	<3	<3	<2	1
30-35	+	+	22	0	1 547	0	0	<3	<3	<2	1
35-40	+	+	37	0	2 220	0	0	4	3	2	1
40-45	+	+	58	243	2 900	2	0	4	3	2	1
45-50	+	+	85	635	3 600	5	0	6	5	2	1
50-55	+	+	111	1 145	4 200	9	0	9	7	3	1
55-60	+	+	145	1 770	4 900	12	54	12	9	4	1.1
60-65	+	+	180	2 520	5 500	17	155	17	14	6	1.2

Source: European Commission, 2002 a

## 5.5 PROTECTION MEASURES AND CONTROL

What is the best strategy to reduce sleep disturbance? The first thought should always be to reduce the impact, either by reducing the number of events or by reducing the sound levels, or both. For some effects reducing the number of events may seem to be more effective (although that depends on the exact composition). Other effects are reduced by lowering overall noise level by either the number of events, the levels per event or by any combination.

In combination with other measures, sound insulation of bedroom windows is an option, but care must be taken to avoid negative impact on inside air quality. Even then, many people may want to sleep with their windows open, thereby making the insulation ineffective. Although good instruction may go some way to helping to overcome this, it is still a matter well worth taking into account. In warmer climates, in particular, insulation is not a serious option for residential purposes and excessive exposure must be avoided either by removing the people exposed or removing the source if source-related measures fail.

Although air conditioning of houses (or just bedrooms) is not commonplace in the EU, there are indications that its use is increasing, especially in the warmer parts of the Region. Although this still leaves the possibility that people may sleep with their windows open outside the summer season, it is something to consider when discussing measures.

Exposed areas could be a good choice for uses such as offices, where there will be no people at night, or where it is a physical impossibility to sleep with the windows open (fully air-conditioned buildings, for example hotels and sometimes hospitals).



A simple measure is the orientation of noise-sensitive rooms on the quiet side of the dwelling (this applies to road and rail traffic noise).

Zoning is an instrument that may assist planning authorities in keeping noise-sensitive land uses away from noisy areas. In the densely populated areas of the EU this solution must often compete, however, with other planning requirements or a simple lack of suitable space.

## 5.6 RECOMMENDATIONS FOR HEALTH PROTECTION

Sleep is an essential part of healthy life and is recognized as a fundamental right under the European Convention on Human Rights<sup>1</sup> (European Court of Human Rights, 2003). Based on the systematic review of evidence produced by epidemiological and experimental studies, the relationship between night noise exposure and health effects can be summarized as below. (Table 5.4)

**Table 5.4**  
**Effects of different levels of night noise on the population's health<sup>2</sup>**

Average night noise level over a year $L_{\text{night, outside}}$	Health effects observed in the population
Up to 30 dB	Although individual sensitivities and circumstances may differ, it appears that up to this level no substantial biological effects are observed. $L_{\text{night, outside}}$ of 30 dB is equivalent to the NOEL for night noise.
30 to 40 dB	A number of effects on sleep are observed from this range: body movements, awakening, self-reported sleep disturbance, arousals. The intensity of the effect depends on the nature of the source and the number of events. Vulnerable groups (for example children, the chronically ill and the elderly) are more susceptible. However, even in the worst cases the effects seem modest. $L_{\text{night, outside}}$ of 40 dB is equivalent to the LOAEL for night noise.
40 to 55 dB	Adverse health effects are observed among the exposed population. Many people have to adapt their lives to cope with the noise at night. Vulnerable groups are more severely affected.
Above 55 dB	The situation is considered increasingly dangerous for public health. Adverse health effects occur frequently, a sizeable proportion of the population is highly annoyed and sleep-disturbed. There is evidence that the risk of cardiovascular disease increases.

<sup>1</sup> "Article 8:1. Everyone has the right to respect for his private and family life, his home and his correspondence." Although in the case against the United Kingdom the Court ruled that the United Kingdom Government was not guilty of the charges, the right to undisturbed sleep was recognized (the Court's consideration 96).

<sup>2</sup>  $L_{\text{night, outside}}$  in Table 5.4 and 5.5 is the night-time noise indicator ( $L_{\text{night}}$ ) of Directive 2002/49/EC of 25 June 2002: the A-weighted long-term average sound level as defined in ISO 1996-2: 1987, determined over all the night periods of a year; in which: the night is eight hours (usually 23.00 – 07.00 local time), a year is a relevant year as regards the emission of sound and an average year as regards the meteorological circumstances, the incident sound is considered, the assessment point is the same as for  $L_{\text{den}}$ . See *Official Journal of the European Communities*, 18.7.2002, for more details.



Below the level of 30 dB  $L_{\text{night, outside}}$ , no effects on sleep are observed except for a slight increase in the frequency of body movements during sleep due to night noise. There is no sufficient evidence that the biological effects observed at the level below 40 dB  $L_{\text{night, outside}}$  are harmful to health. However, adverse health effects are observed at the level above 40 dB  $L_{\text{night, outside}}$ , such as self-reported sleep disturbance, environmental insomnia, and increased use of somnifacient drugs and sedatives. Therefore, 40 dB  $L_{\text{night, outside}}$  is equivalent to the LOAEL for night noise. Above 55 dB the cardiovascular effects become the major public health concern, which are likely to be less dependent on the nature of the noise. Closer examination of the precise impact will be necessary in the range between 30 dB and 55 dB as much will depend on the detailed circumstances of each case.

A number of instantaneous effects are connected to threshold levels expressed in  $L_{\text{Amax}}$  (Table 5.1). The health relevance of these effects cannot be easily established. It can be safely assumed, however, that an increase in the number of such events over the baseline may constitute a subclinical adverse health effect by itself leading to significant clinical health outcomes.

Based on the exposure–effects relationship summarized in Table 5.4, the night noise guideline values are recommended for the protection of public health from night noise as below (Table 5.5).

Night noise guideline (NNG)	$L_{\text{night, outside}} = 40 \text{ dB}$	<b>Table 5.5</b> <b>Recommended night noise</b> <b>guidelines for Europe</b>
Interim target (IT)	$L_{\text{night, outside}} = 55 \text{ dB}$	

For the primary prevention of subclinical adverse health effects related to night noise in the population, it is recommended that the population should not be exposed to night noise levels greater than 40 dB of  $L_{\text{night, outside}}$  during the part of the night when most people are in bed. The LOAEL of night noise, 40 dB  $L_{\text{night, outside}}$ , can be considered a health-based limit value of the night noise guidelines (NNG) necessary to protect the public, including most of the vulnerable groups such as children, the chronically ill and the elderly, from the adverse health effects of night noise.

An interim target (IT) of 55 dB  $L_{\text{night, outside}}$  is recommended in the situations where the achievement of NNG is not feasible in the short run for various reasons. It should be emphasized that IT is not a health-based limit value by itself. Vulnerable groups cannot be protected at this level. Therefore, IT should be considered only as a feasibility-based intermediate target which can be temporarily considered by policy-makers for exceptional local situations.

All Member States are encouraged to gradually reduce the proportion of the population exposed to levels over the IT within the context of meeting wider sustainable development objectives. It is highly recommended to carry out risk assessment and management activities at local and national levels targeting the exposed population, and aiming at reducing night noise to the level below IT or NNG. IT and NNG can be used for health impact assessment of new projects (for example construction of roads, railways, airports or new residential areas) even before the achievement of IT, as well as for the risk assessment of the whole population. In the long run the NNG would be best achieved by control measures aimed at the sources along with other comprehensive approaches.

## 5.7 RELATION WITH THE GUIDELINES FOR COMMUNITY NOISE (1999)

The *Guidelines for community noise* (WHO, 1999) have been quoted a number of times in this paper, so one could rightfully ask what the relation is between the 1999 guidelines and the present NNG.

Impact of night-time exposure to noise and sleep disturbance is indeed covered in the 1999 guidelines, and this is the full statement (WHO, 1999):

“If negative effects on sleep are to be avoided the equivalent sound pressure level should not exceed 30 dBA indoors for continuous noise. If the noise is not continuous, sleep disturbance correlates best with  $L_{Amax}$  and effects have been observed at 45 dB or less. This is particularly true if the background level is low. Noise events exceeding 45 dBA should therefore be limited if possible. For sensitive people an even lower limit would be preferred. It should be noted that it should be possible to sleep with a bedroom window slightly open (a reduction from outside to inside of 15 dB). To prevent sleep disturbances, one should thus consider the equivalent sound pressure level and the number and level of sound events. Mitigation targeted to the first part of the night is believed to be effective for the ability to fall asleep.”

It should be noted that the noise indicators of the 1999 guidelines are  $L_{Aeq}$  and  $L_{Amax}$ , measured inside for continuous and non-continuous noise, respectively. The present night noise guidelines adopt an harmonized noise indicator as defined by Environmental Noise Directive (2002/49/EC):  $L_{night}$  measured outside, averaged over a year.

It should also be borne in mind that the 1999 guidelines are based on studies carried out up to 1995 (and a few meta-analyses some years later). Important new studies (Passchier-Vermeer et al., 2002; Basner et al., 2004) have become available since then, together with new insights into normal and disturbed sleep.

Comparing the above statement with the recommendations, it is clear that new information has made more precise statements possible. The thresholds are now known to be lower than  $L_{Amax}$  of 45 dB for a number of effects. The last three sentences still stand: there are good reasons for people to sleep with their windows open, and to prevent sleep disturbances one should consider the equivalent sound pressure level and the number of sound events. The present NNG allow responsible authorities and stakeholders to do this. Viewed in this way, the *Night noise guidelines for Europe* complements the 1999 guidelines. This means that the recommendations on government policy framework on noise management elaborated in the 1999 guidelines should be considered valid and relevant for the Member States to achieve the guideline values of this document.



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- Juvenal DJ (around AD 160) This is an excerpt from Reading About the World, Volume 1, edited by Paul Brians, Mary Gallwey, Douglas Hughes, Azfar Hussain, Richard Law, Michael Myers, Michael Neville, Roger Schlesinger, Alice Spitzer, and Susan Swan and published by Harcourt Brace Custom Books. Satire No. 3 (...*magnis opibus dormitur in urbe*...).
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## APPENDIX 1. GLOSSARY OF TERMS AND ACRONYMS

Term/acronym	Definition
Actimetry	The measurement of accelerations associated with the movement of an actimeter
ADHD	Attention-deficit hyperactivity disorder
Behavioural awakening	Awakening that is registered by the subject by means of a conscious action
BP	Blood pressure
CAP	Cyclic alternating patterns
EBD	Environmental burden of disease
END	Environmental Noise Directive (2002/49/EC)
EEG	Electroencephalogram, recording of electric activity in the brain
ECG	Electrocardiogram, recording of electric activity of the heart
EEG awakening	Transition from a state of sleep to a state of consciousness, as determined by a sleep EEG
Heart rate acceleration	A temporary rise in heart rate relative to the average heart rate assessed shortly before a noise event
HPA axis	Hypothalamus-pituitary-adrenal axis
ICSD	International Classification of Sleep Disorders
IHD	Ischaemic heart disease
Insomnia	Sleeping disorder consistent with an internationally accepted definition (see ICSD), which takes account of difficulty falling or staying asleep, the daytime implications and the duration of the problems
$L_{Aeq,T}$	Exposure to noise for the duration of a given time interval T (a 24-hour period, a night, a day, an evening) is expressed as an equivalent sound pressure level (measured in dB(A)) over the interval in question
$L_{Amax}$	Maximum outdoor sound pressure level associated with an individual noise event
$L_{night}$	Refers to the EU definition in Directive 2002/49/EC: equivalent outdoor sound pressure level associated with a particular type of noise source during night-time (at least 8 hours), calculated over a period of a year
Motility onset	The presence of movement in a short time interval, following an interval without movement
Mg	Magnesium
Motility	The presence of movement in a short time interval, as recorded on an actigram
OR	Odds ratio: the ratio of the odds of an event occurring in another group, or to a sample-based estimate of that ratio



Term/acronym	Definition
OSAS	Obstructive sleep apnoea syndrome
OTC	Over-the-counter (medicines sold without prescription)
Polysomnography	The measurement during a subject's time in bed of his or her brain activity by means of EEG, EOG and EMG. The technique involves the use of electrodes to record electrical potentials in the brain
REM	Rapid eye movement (sleep phase)
RR	Relative risk: a ratio of the probability of the event occurring in the exposed group vs. the control (non-exposed) group
SEL	Sound exposure level: equivalent outdoor sound pressure level associated with an individual noise event, with the equivalent level standardized at one second
Sleep disturbance	Disturbance of sleep by night-time noise, as perceived by a subject and described in a questionnaire response or journal entry
Sleep EEG	Graph created using data from EEG scanning during a subject's time in bed, showing the various stages of sleep as a function of time
Sleep fragmentation	Within a sleep period, the frequency and duration of intervals of wakefulness recorded on a sleep EEG or intervals of motility recorded on an actigram
Sleep latency	The length of time taken to fall asleep, i.e. the interval between the point at which a person begins trying to go to sleep or allowing him/herself to go to sleep and sleep inception time
Sleep stage change	Change from a deeper stage of sleep to a less deep stage, as determined by a sleep EEG
SMR	Standardized mortality ratios
SROBD	Sleep related obstructive breathing disorders
SWS	Slow-wave sleep (sleep phase)
UARS	Upper airway resistance syndrome



## APPENDIX 2. RELATIONS BETWEEN $L_{\text{NIGHT}}$ AND INSTANTANEOUS EFFECTS

### STATEMENT 1

Let  $f$  be a function of SEL that gives the expected number of instantaneous effects caused by a single event. With a given  $L_{\text{night}}$  and a given number of events  $N$ , the expected number of times that an effect occurs in the night,  $n$ , is maximal if all events have equal SEL, provided that  $f \cdot 10 \lg$  is increasing but negatively accelerated.

### STATEMENT 2

If

$$n_{\text{max}} = 10^{(L_{\text{night}} - \text{SEL} + 70.2)/10} \cdot f(\text{SEL}),$$

has a maximum over SEL and  $f$  is the quadratic function  $f(\text{SEL}) = a \text{ SEL}^2 + b \text{ SEL} + c$ , then the maximum occurs irrespective of  $L_{\text{night}}$  at

$$\text{SEL}_0 = 4.34 - A \pm ((A - 4.34)^2 - (c/a) + 8.68A)^{1/2},$$

where  $A = b/(2a)$ . (Only with + at the place of  $\pm$  the value will come in the realistic range of SEL)

### STATEMENT 3A

If the shape of the time pattern of the sound level has a block form, then  $\text{SEL} = L_{\text{Amax}} + 10 \lg(T)$ , where  $L_{\text{Amax}}$  is the maximum sound level (integrated over 1-s) and  $T$  is the duration of the noise event in seconds.

### STATEMENT 3B

If the sound level increases with rate  $a$  (in dB(A)/s) and after time point  $t = 0$  decreases with rate  $-a$ , then  $\text{SEL} \approx L_{\text{Amax}} - 10 \lg(a) + 9.4$ .

## APPENDIX 3. ANIMAL STUDIES ON STRESS AND MORTALITY

### INTRODUCTION

Is noise a health risk or does it just annoy? This basic question needs to be carefully answered when establishing night noise guidelines. No one will deny that in the case of high noise levels there is a risk of inner ear damage, but what about the moderate levels of environmental noise? To approach this rather difficult question, all available methods must be combined.

1. In animal experiments it is possible to assess the complete causal chain from noise exposure via physiological reactions and biological risk factors to morbidity or even mortality. However, a quantitative application of the results to humans is not possible. Instead, the method is useful in studying the pathomechanisms qualitatively.
2. Experiments on humans are, for ethical reasons, restricted to the study of reversible physiological reactions. But as long as there is no proof that reactions to chronically repeated noise exposures are increasing the risk of specific diseases, the results of such physiological studies are not considered conclusive.
3. Epidemiological studies have the advantage of investigating health effects which are particularly caused by chronic noise exposure although there is no possibility to control all influencing factors. Additionally, epidemiological studies have to be based upon biologically evident hypotheses.

A hypothetical model of noise-induced health effects is shown in Fig. 4.3 in Chapter 4, section 4.5.2 of this report. This model is based on the results of noise experiments with animals and humans. With animal experiments, the whole causal chain from noise exposure to health outcome can be traced as a direct pathway starting with a chronic high level noise exposure which, via endocrine stress reactions, leads, for example, to microcirculatory defects and to manifest hypertension.

Physiological experiments on humans have shown that noise of a moderate level acts via an indirect pathway and has health outcomes similar to those caused by high noise exposures on the direct pathway. The indirect pathway starts with noise-induced disturbances of activities such as communication or sleep. Since we are dealing with night noise guidelines, noise-induced sleep disturbances and any resulting persistent health effects are of primary interest here.

In physiological studies with experimentally changed noise exposure, the increase of arousals and of hormone excretion was studied in sleeping people. If this model is correct then in the cause-effect chain the arousal ought to precede the endocrine reactions. This order was derived from the different reaction times of the effects. While arousals appear within 1 second after a noise stimulus, hormones like catecholamines take several minutes, and cortisol about 10 minutes to be increased. This observation, together with the fact that arousals are evoked by equal or lower noise levels than the corresponding endocrine reactions, confirms the correctness of the model and leads to an important conclusion: noise exposure which does not evoke arousals in sleeping people will not induce adverse health effects.

This conclusion is essential with regard to night noise guidelines. However, the answers to the basic question as to whether certain health risks are connected with

environmental noise must be clarified by epidemiological studies based on noise experiments on both humans and animals.

## **TYPES OF ANIMAL STUDIES**

Noise has often been used as a stressor in animal studies. Even Selye (1953), who introduced the psychophysiological stress concept, used noise stimuli in his animal studies. Most of the modern animal studies testing the pharmacological effects of drugs are carried out with and without various stressors. The typical noise exposure is to short and very intensive sounds. One such example is the study of Diao et al. (2003) who exposed guinea pigs to 4 kHz octave band noise at 115 dB for 5 hours. But these experiments are of little value regarding the noise exposure types in question.

The same is true for another type of animal study concerned with the prevention of noise-induced health effects in wild and domestic animals (for review of the former kind see Fletcher, 1983). One example for the latter kind is the study of Geverink et al. (1998) on stress responses of pigs to transport and lairage sounds.

Since the subject of the present paper is noise-induced health effects in humans, the review addresses only those studies in which animals are used as a model for humans.

The animal model for aural effects in humans has been established in great detail, so that even quantitative transference of results from animals to humans is possible. However, inner ear damage generally occurs at much higher noise levels than the environmental levels under discussion in this paper. Therefore interest focuses on animal models with respect to extra-aural noise effects.

## **LIMITING ASPECTS OF ANIMAL MODELS**

Other than in studies on aural effects, the animal model does not allow quantitative comparisons in studies of extra-aural noise effects. It may, however, be used for the qualitative investigation of pathophysiological mechanisms following exposure to acute and very short sounds. But an animal model for long-term noise effects as caused by chronically repeated noise exposures needs careful planning. First it has to be ensured that stress reactions in both humans and animals when activated by noise exposure are qualitatively comparable. Secondly, the stress effects of chronic noise exposure have to be assessed in humans, and the animal models should be designed correspondingly. However, in the animal model, influences from cortical interconnections have to be excluded as a factor in these noise experiments. Naturally, one cannot expect to establish an animal model for indirect environmental noise effects which in humans may, for example, disturb activities such as verbal communication, which in turn may induce stress hormone increases.

## **STRESS HORMONES IN NOISE-EXPOSED ANIMALS**

### **HABITUATION**

In short-term experiments any kind of exposure to loud noise will cause acute increases of stress hormones. Long-term repeated noise exposure, however, will



cause a certain habituation in the animal. Periodic repetitions of identical noise bursts lead to almost complete habituation. This was probably the main reason why Borg (1981) found no adverse health effects in rats exposed for their whole lives to periodic noise pulses. Therefore, random series of noise pulses are now applied in most long-term studies.

Selye (1974) had already stated that not all stages of a stress response are noxious, especially in the case of mild or brief exposures. Since environmental noise is a mild stressor, adverse health effects are only to be expected under the condition that repeated noise exposures induce long-term stress hormone changes. According to the Allostatic Load Model (McEwen, 1998), the normal response to an environmental stressor such as noise is the physiological activation of the endocrine system enabling the body to cope with the stressor and, after the stress situation is terminated, to shut off the allostatic response.

### **J.D. HENRY'S MODEL OF BEHAVIOURAL STRESS EFFECTS**

On the basis of the available literature on stress effects in animals and humans, Henry (1992) developed a model with regard to different biological effects and health risks associated with different coping styles. He explains that the neuroendocrine response to various challenges and threats varies according to the type and degree of control a mammal can exert over it. This in turn is strongly determined by the animal's previous experience. In general, the sympathetic adrenomedullary system is preferentially activated when the animal displays an active response to escape from or deal with an environmental challenge. This is the fight/flight mode of stress response. The adrenocortical axis is preferentially activated as the subjects become immobile/passive when no control or threat of its loss is experienced. This is the conservation/withdrawal mode of response.

### **THE NOISE STRESS MODEL**

On the basis of noise effect studies in animals and humans (for review see Ising and Braun, 2000), a noise stress model was developed. It describes a differentiation of prevailing "stress hormones" under noise exposure. Predominantly adrenaline – and to a lesser degree noradrenaline – are released from the adrenal medulla as the normal response to novel noise stimuli of moderate intensity. Following long-term noise exposures of moderate intensity habituation will alter the response mode and predominantly noradrenaline is released. As a response to extremely intensive noise, near the inner ear pain threshold, predominantly cortisol is released from the adrenal cortex induced by increased releases of adrenocorticotrophic hormone (ACTH), especially in the case of unexpected noise.

The described differentiation will only be observed under special conditions. Unexpected exposure for three minutes to white noise at 75 dB leads, in dogs that are awake, to increased adrenal secretion of adrenaline and noradrenaline and – following a delayed increase in plasma ACTH – an increase in cortisol secretion (Engeland, Miller and Gann, 1990).

The cortisol response as described is valid for animals and humans in their active phases. During sleep, however, several studies in humans showed cortisol increases under exposure to traffic noise of moderate levels (Maschke, Arndt and Ising, 1995;



Evans et al. 2001; Ising and Ising, 2002; Ising et al., 2004). It was hypothesized that noise stimuli signalling a danger, for example the noise of an approaching lorry, will, during sleep, normally generate a defeat reaction, which includes the release of cortisol from the adrenal cortex. Appropriate studies with sleeping animals after conditioning them – for example with a specific noise stimulus followed by pain – should be carried out to test this hypothesis.

Rats were exposed for a period of 12 hours to low-altitude flight noise – reproduced electro-acoustically once per hour on average at stochastically fluctuating intervals ( $L_{Amax}$  125 dB, 10 dB downtime: 1 s,  $L_{eq}$ : 89 dB) (Ising et al., 1991; Ising, 1993). Adrenaline and noradrenaline excretions tended to decrease, whereas plasma cortisol increased significantly. Although in rats corticosterone is secreted rather than cortisol, we will simplify this paper by using cortisol for rats all the same. In this experiment, as well as in all others of our group, normally four rats were kept in one stainless steel cage, which was set on a funnel to collect their urine.

These results show that exposure to noise levels approaching or exceeding the pain threshold of the inner ear leads to endocrine reactions qualitatively different from those induced by less intensive noise.

The different endocrine reactions to acute and chronic noise exposure were studied in rats by Gesi et al. (2002b). They were exposed either to a single (6-hour) session of loud (100 dB(A)) noise, or to the same noise stimulus repeatedly every day for 21 consecutive days. Exposure to noise for 6 hours on one day induced parallel increases in dopamine, noradrenaline and adrenaline concentrations in tissue samples of the adrenal medulla. After 21 days of noise exposure, noradrenaline concentration was significantly higher than in controls, and that of adrenaline decreased significantly. Cortisol was not assessed in this study.

In another subchronic noise experiment, rats were exposed to irregular white noise at 90 dB for 3 and 9 hours per day during 18 and 8 days respectively (van Raaij et al., 1997). In rats with 3 hours of exposure per day the blood concentrations of adrenaline, noradrenaline and cortisol did not differ from controls. Exposure for 9 hours per day, however, resulted in significantly increased concentrations of noradrenaline and cortisol. At the end of the experiment all animals were subjected to restraint stress and their endocrine reactions were assessed. The authors sum up their findings as follows: these results indicate that chronic noise exposure at mild intensities induces subtle but significant changes in hormonal regulation.

The results of another experiment with different levels of random white noise pulses during 45 minutes per hour, 12 hours per day for 8 days demonstrate that cortisol responses to subchronic mild noise exposure do not monotonously increase with the noise levels (Bijlsma et al., 2001). While in rats exposed to 95 dB pulses plasma cortisol concentrations were raised twofold against controls, the exposure to 105 dB pulses did not increase cortisol significantly.

The time dependency of cortisol increase in the blood of rats under exposure to white noise (100 dB, 6 hours per day for 21 days) was examined by Gesi et al. (2001). The authors found a progressive increase in cortisol which reached a plateau 9 days from the beginning of exposure.

In summing up the results of these studies we can reach the following conclusions.

- Acute exposure to unexpected and novel noise of moderate intensities leads to activation of both the sympathetic adrenal-medullary system with increased secretion of adrenaline and noradrenaline, and the HPA axis with increased secretion of ACTH and of cortisol from the adrenal cortex.
- Under chronic exposure to unpredictable noise, adrenaline secretion is reduced to normal or subnormal values while noradrenaline and ACTH/cortisol concentrations remain increased.
- Extremely intensive unpredictable noise near the inner ear pain threshold triggers, in mammals that are awake, a defeat reaction with increases of ACTH/cortisol while the catecholamines adrenaline and noradrenaline remain normal or are slightly decreased.
- Chronic noise exposure at mild intensities will induce changes in hormonal regulation, if the individual threshold of allostasis is exceeded. A chronic allostatic load leads to subtle but significant changes in hormonal regulation, which are at present not fully understood.

### **EFFECTS OF PRENATAL NOISE EXPOSURE ON THE SENSITIVITY TO STRESS**

Pregnant rats were subjected to noise and light stress, three times weekly on an unpredictable basis throughout gestation (Weinstock et al., 1998). Blood concentrations of adrenaline, noradrenaline and cortisol at rest and after footshock were assessed. At rest cortisol was significantly increased in offspring of stressed rats in comparison to controls while adrenaline and noradrenaline did not differ in either of the groups. After footshock, noradrenaline was significantly higher in offspring of stressed rats, showing that prenatal stress can induce long-term changes in the sensitivity of the sympathicoadrenal system to stress.

Pregnant monkeys were repeatedly exposed to unpredictable noise during days 90–145 after conception (Clarke et al., 1994). Blood concentration of ACTH and cortisol were measured in offspring of stressed and control monkeys at rest and under four progressively stressful conditions. Prenatally stressed offspring showed higher ACTH than controls in all four stressful conditions while cortisol did not change under stress. These results indicate that prenatal stress may have long-term effects on the HPA axis regulation.

### **EFFECTS OF NOISE EXPOSURE ON CORTISOL AND THE IMMUNE SYSTEM**

The effect of acute noise stress on rats was studied by assessing blood concentrations of cortisol and total as well as differential leukocyte count (Archana and Namasivayam, 1999). A significant increase in cortisol and a significant decrease of total leukocyte counts were found.

Rats were exposed to “rock” music (80dB) for 24 hours (McCarthy, Quimet and Daun, 1992). In vitro stimulation of leukocyte subpopulations revealed several noise effects. Neutrophils and macrophages secreted significantly less superoxide anion and interleukin-1. Such effects may be detrimental to wound healing.



Pregnant rats were from gestation day 15 to day 21 daily exposed to the noise of a fire alarm bell ( $L_{Amax} = 85-90$  dB) delivered randomly for 1 hour (Sobrian et al., 1997). In developing offspring mitogen-specific alterations in lymphoproliferative activity and reduced immunoglobulin G levels were found at postnatal day 21.

Aguas et al. (1999) exposed a special breed of mice to low frequency noise – a model of noise – for three months as described below (Castelo Branco et al., 2003). These mice spontaneously developed an autoimmune disease at 6 months of age. Chronic low frequency noise exposure accelerated the expression of the autoimmune disease and affected the immune system, which was associated with kidney lesions and increased mortality.

#### *Embryotoxic effects*

Geber (1973) exposed pregnant rats day and night for three weeks to constantly changing sound mixtures between 76 and 94 dB for 6 minutes per hour, day and night, and demonstrated embryotoxic effects, notably calcification defects in the embryos.

Pregnant rats on a moderately magnesium deficient diet were exposed to noise during their active phase from 20.00 to 08.00 for three weeks (stochastically applied white noise impulses  $L_{Amax}$ : 87 dB,  $L_{eq}$ : 77 dB,  $t$ : 1 s duration) (Günther et al. 1981).

As compared to controls on the same diet, there was no difference in bone mineralization. The only significant effect was an increased fetal resorption rate.

The noise was changing in Geber's experiment but the noise level was comparable to the noise impulses stochastically applied by Günther et al. ( $L_{Amax} = 87$  dB). Since these impulses were more frequent, their stress effect was at least as strong as the noise exposure employed by Geber. Therefore the major factor that differentiated the two exposure types in causing a reduced mineralization of the rat skeletons (Geber, 1973) must have been the additional noise exposure during sleep.

Castelo Branco et al. (2003) studied Wistar rats born under low frequency noise exposure. The third octave level of the applied broadband noise was  $> 90$  dB for frequencies between 50 and 500 Hz. The broadband level was 109 dB(lin). The exposure schedule was chosen as a model for occupational noise: 8 hours per day, 5 days per week, and weekends in silence. Third generation rats born in low frequency noise environments were observed showing teratogenic malformations including loss of segments.

#### *Morphological alterations in the myocardium caused by acute noise*

Gesi et al. (2002a) reviewed the literature and stated that in experimental animals undergoing noise exposure, subcellular myocardial changes have been reported, especially at mitochondrial level; in particular, after 6 hours of exposure only the atrium exhibited significant mitochondrial alterations, whereas after 12 hours as well as subchronic exposure both atrium and ventricle were damaged.

Exposure of rats to 100 dB(A) noise for 12 hours caused a significant increase of DNA damage accompanied by ultrastructural alterations and increased noradrenaline concentrations in the myocardium (Lenzi et al., 2003). In another paper this group described an increase in mitochondrial calcium (Ca) influx caused by the same noise exposure. They described Ca accumulation at myocardial subcellular level. Summing up their results they wrote that: moreover, the present results joined with previous evi-

dence indicate that calcium accumulation is the final common pathway responsible for noise-induced myocardial morphological alterations (Gesi et al., 2000).

#### *Connective tissue proliferation*

Hauss, Schmitt and Müller (1971) described a proliferation of connective tissue in the myocardium of rats under acute exposure to noise.

On the basis of these results a noise exposure experiment was carried out of 5 weeks with day and night exposure to stochastically triggered bells ( $L_{Amax}$ : 108 dB,  $t$  (duration of one signal): 1 s,  $L_{eq}$ : 91 dB) (Ising, Noack and Lunkenheiner, 1974). We confirmed the results of Hauss, Schmitt and Müller (1971) using an electron microscope to demonstrate fibrosis in the interstitial tissue of the myocardium. Additionally electron dense areas (visible as black spots) located within bundles of collagen in the myocardium were observed. According to Selye (1962), these dark areas were most probably caused by high concentrations of calcium (Ca) carbonate or calcium phosphate deposits. This suggestion is consistent with the results of Gesi et al. (2000).

After publication of these findings, a reservation was correctly voiced that, as the noise exposure had not left intervals for sleep, it was not certain whether the myocardial damage was provoked by the noise stress as such or by a noise-induced lack of sleep. For this reason, all subsequent experiments provided for noise-free intervals of 8 to 12 hours during the rats' inactive phases to enable them to sleep.

Rats were exposed for 28 weeks to a random series of white noise impulses from 16.00 to 08.00 daily with an 8 hour rest in their inactive phase (Ising et al., 1979). The third octave spectrum of the noise was flat between 5 and 25 kHz and had a third octave level of 88 dB (lin) (broadband  $L_{Amax}$  = 97 dB(lin).  $L_{eq}$  = 87 dB(lin)). The duration of noise impulses was 4 seconds and the noise to pause ratio 1:10 on average. There was a small but significant increase in hydroxyproline as indicator of collagen in the rats' left myocardium. Electron micrographs showed, similar to the earlier experiment, collagen bundles in the otherwise empty interstitial space but no indication of calcium deposits.

#### *Respiratory effects*

Castelo Branco et al. (2003) studied respiratory epithelia in Wistar rats born under low frequency noise exposure and further exposed for up to 5403 hours during more than 2.5 years. The third octave level of the applied broadband noise was > 90 dB for frequencies between 50 and 500 Hz. The broadband level was 109 dB(lin). The exposure schedule was chosen as a model for occupational noise: 8 hours per day, 5 days per week and weekends in silence. Rats were gestated and born under the described noise exposure with additional exposures from 145 to 5304 hours. Transmission electron micrographs of the tracheal epithelium of rats exposed for 2438 hours revealed a subepithelial layer of hyperplastic collagen bundles, several of them exhibiting a degenerative pattern. The results indicate an increased proliferation as well as degenerative processes of collagen.

Castelo Branco et al. (2003) observed sheared cilia in the respiratory epithelia of Wistar rats born under and further chronically exposed to low frequency noise. As interpretation of their findings they stated that both mechanical and biochemical events may be responsible for this pattern of trauma.

#### *Electrolytes: Ca/Mg shift*

Acute exposure of rats to the fast rising overflight noise of low flying fighter planes



reaching levels of up to 125 dB(A) ) (Ising et al., 1991; Ising, 1993) resulted not only in an increase of cortisol but also in a decrease of intracellular magnesium (Mg) and an increase of Mg excretion.

In guinea pigs, acute stress – due to 2 hours of noise exposure (95 dB white noise) or to overcrowding in the cage – caused significant increases of serum Mg and decreases of erythrocyte Mg (Ising et al., 1986).

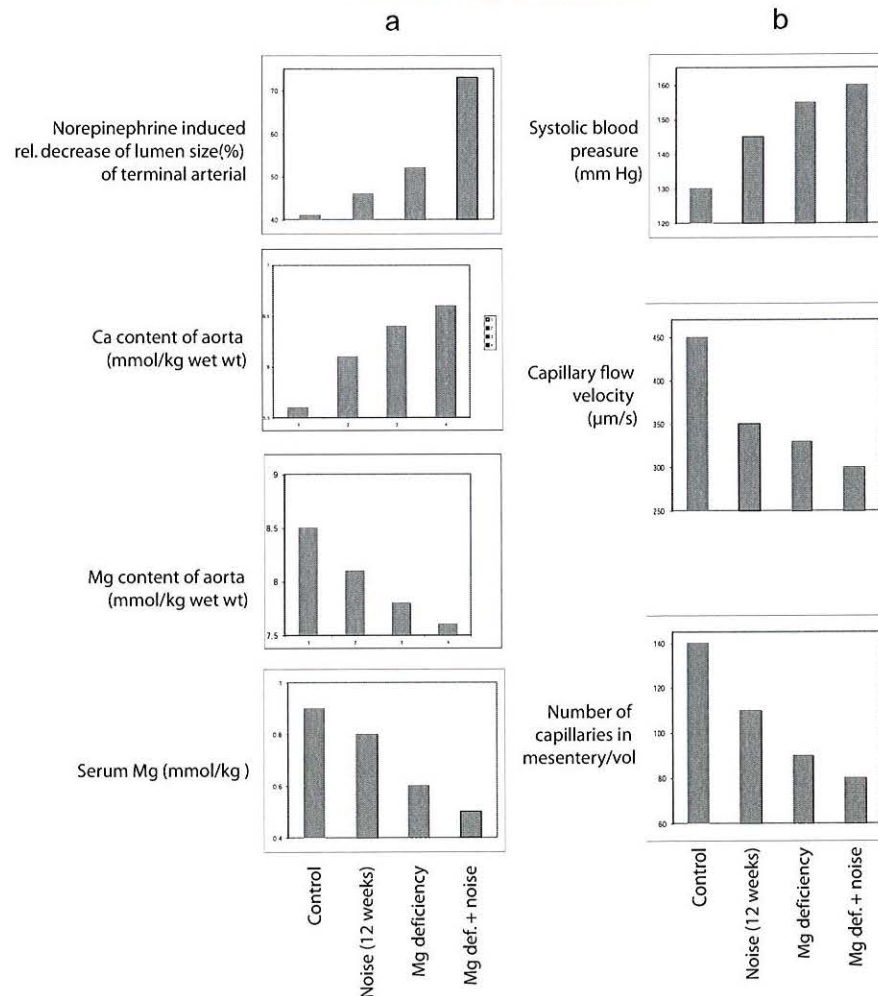
For chronic noise experiments an additional stress factor had been sought which would act synergistically with unwanted noise, since in the above described noise experiment, half a year of exposure led to but relatively mild health effects (Ising et al., 1979). The justification for using two stressors derives from the fact that humans have to cope with a whole range of more or less synergistic stress factors and not with noise alone.

Organic damage as a result of chronic stress is likely to occur only under the condition that the overall exposure to stress exceeds a certain tolerance level during a relatively long period of time (Selye, 1974). For technical reasons, the two options available to supply a suitable additional stress factor were the cold or a magnesium (Mg) deficiency. Both factors, like habitual noise, cause an increased noradrenaline secretion. For practical reasons different degrees of a magnesium-deficient diet were selected as an additional stress factor. Noise exposure was provided by electro-acoustically reproduced traffic noise of  $L_{Amax}$ : 86 dB,  $L_{eq}$ : 69 dB over 12 hours during the rats' active phase. For one group the noise level was slightly increased ( $L_{eq}$ : 75 dB). The experiment lasted 16 weeks (Günther, Ising and Merker, 1978). Magnesium deficiency combined with noise exposure led to dose-dependent increases in adrenaline and noradrenaline, which can be used to quantify the overall stress of the dietary treatment. As stress grew, the hydroxyproline (as an indicator of collagen) and calcium (Ca) content of the myocardium increased while the magnesium content decreased. Long-term stress therefore resulted in an intracellular Ca/Mg shift.

Altura et al. (1992) studied the relationship between microcirculation (measured several days after termination of noise exposure), hypertension and Ca/Mg shifts in vascular walls of noise-stressed rats on Mg deficient diets. Noise exposure during the first 8 weeks was set to an energy equivalent level of 85 dB(A) from 20.00 to 08.00. Noise impulses were randomly switched on at randomized peak levels of 80, 90 and 100 dB(A). During the final 4 weeks the equivalent noise level was elevated to 95 dB(A) and the daily exposure increased to 16 hours with an 8 hour rest during the animals' inactive phase. In aortic and port vein smooth muscle the Ca content increased with rising noise exposure, with decreasing Mg uptake, and with the combination of both together, while the Mg content decreased. Parallel to this the reactivity of terminal arterioles to noradrenaline was increased (Fig.1a).

Stress-induced Ca/Mg shifts in smooth muscle cells have the potential to increase the risk of hypertension and myocardial infarction (Ising, Havestadt and Neus, 1985). Stress increases the membrane permeability of catecholamine-sensitive cells, which in turn raises Ca influx into cells and liberates intracellular Mg. A depression of catecholamine-induced vasoconstriction by stress-dependent hypermagnesemia (excess serum Mg concentration) has been demonstrated experimentally. However, the benefit from this stress-depressing hypermagnesemia is obtained at the expense of increased renal Mg loss. In the long run, chronic stress combined with suboptimal Mg in diet will reduce the Mg release in acute stress situations, causing an increase of vasoconstriction and raising the risk of hypertension.

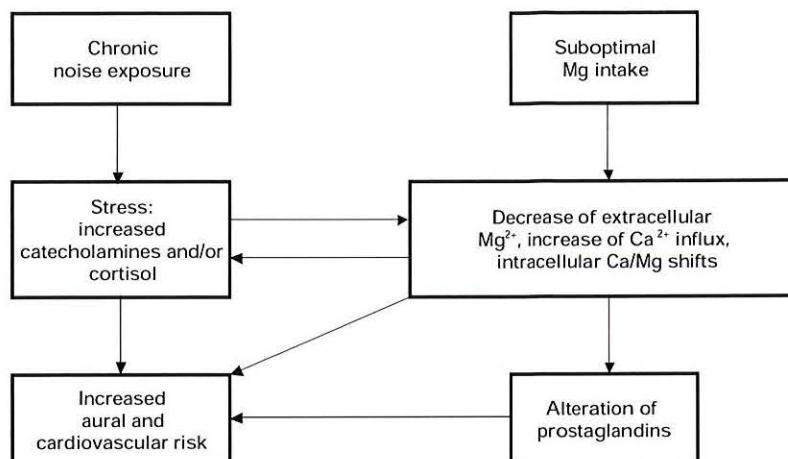
**Fig.1**  
**Effects of 12 weeks noise exposure, Mg deficient diet and the combination of both in Wistar rats. (a) Ca/Mg shifts in vascular smooth muscle, Mg concentration in blood and reactivity of arterioles to noradrenaline. (b) Systolic BP, capillary blood flow velocity and numbers of capillaries/volume.**



Source: Altura et al., 1992

Further analysis of the experimental results led to an interaction model between chronic stress and intracellular electrolyte shifts (Ising, 1981; Ising et al., 1986) (Fig.2). Chronic stress caused a loss of extracellular and intracellular Mg and an increase in intracellular Ca (Günther, Ising and Merker, 1978). A decrease of Mg was correlated with an increase in physiological noise sensitivity, that is, to more severe noradrenaline releases in animals and humans under noise exposure (Günther, Ising and Merker, 1978; Ising, Havestadt and Neus, 1985; Ising et al., 1986). There was a positive feedback mechanism between stress – caused by noise and other stressors – and intracellular Mg/Ca shifts, which may end in a *circulus vitiosus* and increase cardiovascular risks.

**Fig. 2**  
Interaction between stress and  
Ca/Mg shifts and its long term  
consequences



### *Hypertension*

Rothlin, Cerletti and Emmenegger (1956) exposed rats for 1.5 years, day and night, to 90 dB "audiogenic stress" and observed a raising of systolic BP values from 120 mm Hg to about 150 mm Hg. He used a cross-breed of Albino rats and wild Norwegian rats since Albino rats did not develop hypertension under noise exposure. After termination of exposure the BP returned to normal.

Albino rats were exposed to noise during their whole lifespan (for review see Borg, 1981) to periodic noise impulses of 80 and 100 dB. This periodic exposure had no detrimental health effects, which can be understood on the basis of the work of Glass, Singer and Friedmann (1969). Unpredictable noise presentation was shown to cause lasting cortisol increases in rats in contrast to periodic exposure to 100 dB, which led to adaptation (De Boer, van der Gugten and Slangen, 1989). The unpredictability of a noise is a decisive precondition of long-term stress effects.

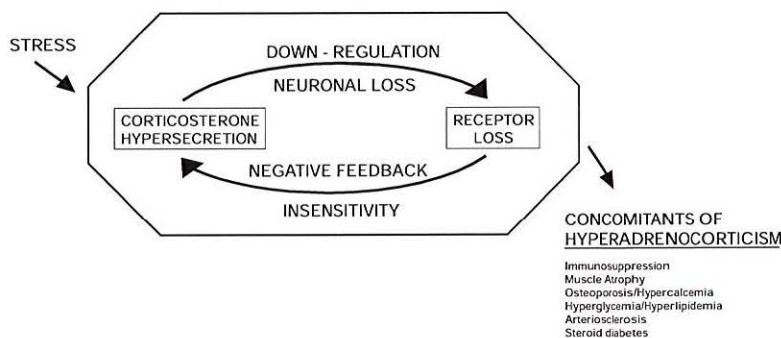
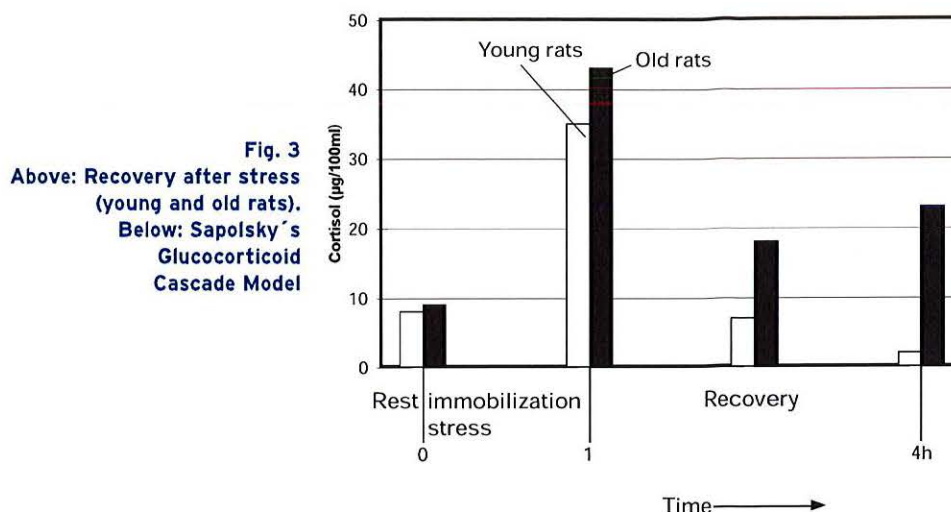
Exposure of primates to traffic noise for 10 hours per day during 9 months led to a significant BP increase, which persisted during 3 weeks after termination of exposure (Peterson et al., 1981). A replication of this experiment with a different species of primates failed to show an increase of their BP (Turkkan, Hienz and Harris, 1983).

In the above-mentioned experiment of Altura et al. (1992), exposure to unpredictable noise impulses led within 12 weeks to irreversible changes of microcirculation and an increase of systolic BP (Fig. 1b). The observed rarefaction of capillaries in the mesentery can be interpreted as an indicator of accelerated ageing of the circulatory system.

### *Ageing and lifespan*

The cortisol response and recovery after immobilization stress was compared in young and old rats. The results are demonstrated in Fig. 3 together with Sapolsky's Glucocorticoid Cascade Model (Sapolsky, Krey and McEwen, 1986). The stress response of young and old rats is more or less the same. However, while the young rats recover immediately after termination the old ones recover only in part.





Therefore, acute stress leads, in old animals, to considerably prolonged cortisol increases. On the other hand, chronically repeated stress activates the HPA axis and can cause cortisol receptor losses even in younger animals, a process generally developing only in old age. Finally, chronic cortisol hypersecretion may occur along with follow-up health defects.

Aguas et al. (1999) exposed a special breed of mice to the above described model of occupational low frequency noise for three months. Chronic low frequency noise exposure accelerated the expression of the autoimmune disease and was associated with kidney lesions and increased mortality.

Chronic noise exposure of animals on a suboptimal Mg diet led to increases of connective tissue and calcium and decreases of Mg in the myocardium (Günther, Ising and Merker, 1978). These changes were correlated with noradrenaline changes. Since they are also correlated with normal ageing, the noise stress induced changes may be interpreted as accelerated ageing (Ising, Nawroth and Günther, 1981). Even the lifespan was reduced in rats on an Mg deficient diet, and was further dose-dependently reduced in combination with noise exposure (see Table 1).



**Table 1**  
**Effects of noise exposure combined with**  
**dietary Mg-deficiency in rats**

Treatment		Effect				
4 months	3 months	Urine		Myocardium		Death rate
Mg in diet	Noise	Noradrenaline	Adrenaline	Hydroxyproline	Ca	Mg
	$L_{eq}/L_{Amax}$	( $\mu\text{g/g Cre}$ )		(mg/g dry wt.)	(mg/g d.w.)	(mg/g d.w.)
control	ambient	$18 \pm 4$	$12 \pm 2$	$3.0 \pm 0.1$	$3.0 \pm 0.2$	$37.5 \pm 0.8$
suboptimal	ambient	$23 \pm 4$	$18 \pm 2$	$3.0 \pm 0.1$	$3.5 \pm 0.5$	$38.0 \pm 1.7$
suboptimal	69/86 dB	$37 \pm 11$	$16 \pm 2$	$3.0 \pm 0.1$	$4.3 \pm 0.2$	$37.9 \pm 1.3$
deficient	ambient	$98 \pm 17$	$20 \pm 5$	$3.9 \pm 0.1$	$6.2 \pm 0.7$	$31.2 \pm 1.4$
deficient	69/86 dB	$129 \pm 19$	$41 \pm 10$	$4.6 \pm 0.1$	$6.7 \pm 0.6$	$29.8 \pm 1.8$
deficient	75/86 dB	$172 \pm 26$	$60 \pm 15$	$5.6 \pm 0.9$	$8.0 \pm 0.9$	$26.8 \pm 0.8$

Adrenaline and noradrenaline excretion was measured during the fourth week of noise exposure; death rate is related to the 4-month period of Mg treatment; all other parameters were determined at the end of the experiment (mean values  $\pm$  S.E.). Noise has the potential to cause stress reactions which are enhanced by suboptimal magnesium intake. Chronic noise-induced stress accelerates the ageing of the myocardium and thus increases the risk of myocardial infarction. The involved pathomechanisms include increases of catecholamines and/or cortisol under acute noise exposure and an interaction between endocrine reactions and intracellular Ca/Mg shifts.

## WHAT CAN BE LEARNED FROM ANIMAL STUDIES ABOUT NOISE EFFECTS IN HUMANS?

The effects of low frequency noise – the “vibroacoustic disease” – were studied primarily in humans (for review see Castello Branco and Alves-Pereira, 2004).

In this context, the amygdalar contribution to conditioned fear learning, revealed for normal human subjects, has to be mentioned. Longer lasting activation of the HPA axis, especially abnormally increased or repeatedly elevated cortisol levels may lead to disturbances of the hormonal balance and even severe diseases in man (Spreng, 2000).

Catecholamines induce various detrimental effects on the heart (Ceramuzynski, 1981). Additionally, magnesium deficiency causes alterations of serum lipids (Weglicki et al., 1993), cytokines (Rayssiguier, 1990) and prostaglandines (Nigam, Averdunk and Günther, 1986), in particular an increase of thromboxan, which is released from thrombocytes (Neumann and Lang, 1995) and several other cell types and – in turn – thromboxan A2 can aggregate thrombocytes. All these alterations may increase the risk of myocardial infarction.

Beside these cardiovascular stress effects, chronically increased cortisol may induce

neuronal degeneration and thus accelerate the ageing also of the brain (Sapolsky, Krey and McEwen, 1986), not only in rats but in humans as well (Sapolsky, 1994).

The importance of Ca/Mg shifts was confirmed by post mortem studies of hearts from victims of IHD (Elwood et al. 1980). The tissue samples were taken from areas of the myocardium not affected by the infarction and the results were stable after controlling for several confounders. The results are shown in Table 2. With normal ageing Ca increases and Mg decreases in the myocardium. This process is accelerated in myocardial infarction patients, which indicates an accelerated ageing of these peoples' heart muscle under the pathogenic influences that lead to myocardial infarction.

**Table 2**  
**Age dependency of myocardial Ca and Mg**  
**contents in ischaemic heart disease (IHD)**

IHD deaths and non IHD deaths. (Mean Value  $\pm$  SD, numbers in brackets)

	Group	Age < 45years	45-64 years	$\geq$ 65 years
Ca [ $\mu$ g/g]	Non IHD	43 $\pm$ 15 (175)	50 $\pm$ 14 (281)	57 $\pm$ 22 (155)
		48 $\pm$ 10 (48)	53 $\pm$ 17 (389)	58 $\pm$ 21 (188)
	IHD	183 $\pm$ 28	173 $\pm$ 34	178 $\pm$ 30
		170 $\pm$ 29	157 $\pm$ 30	156 $\pm$ 27
Mg [ $\mu$ g/g]	Non IHD	0.24	0.29	0.32
	IHD	0.28	0.34	0.37

Another factor which decreases Mg and increases Ca (Hofecker, Niedermüller and Skalicky, 1991) and collagen (Caspari, Gibson and Harris; 1976, Anversa et al., 1990; Gibbons, Beverly and Snyder, 1991) in the myocard is normal ageing (Ising, Nawroth and Günther, 1981). Therefore, it is plausible that the age-dependent decrease of Mg in hearts of IHD victims was about double of that in age-matched non-IHD deaths. This is therefore an indication that age- and stress-dependent electrolyte changes exist in humans and may be correlated with an increased risk of IHD.

Long-term experiments with Mg-deficient and noise-stressed rats showed that connective tissue and Ca in the myocardium increased with age while Mg decreased. Hence, stress caused by noise or cold is enhanced by suboptimal Mg intake and accelerates the ageing of the heart and decreases the lifespan (Heroux, Peter and Heggteit, 1977; Ising, Nawroth and Günther, 1981; Günther, 1991).

Since coronary arteriosclerosis increases strongly with age (Lakatta, 1990) a biologically older heart is at a higher risk of IHD and of myocardial infarction. The interaction process described seems to be one of the pathomechanisms by which chronic noise stress increases the risk of myocardial infarction.

Several of the risk factors described in the literature to explain the correlation of work stress with myocardial infarction have been found to be increased under noise-induced stress as well, that is, increases of BP and total cholesterol.

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## APPENDIX 4. NOISE AND SLEEP IN CHILDREN

### FACTORS THAT MODIFY AUDITORY AROUSAL THRESHOLDS IN CHILDREN

By the time that most studies were conducted in infants, it had become progressively evident that arousal and awakening thresholds are influenced by a variety of factors. These significantly modify the response to ambient noise of sleeping infants. Some factors inhibit the arousal response, while others enhance the response.

#### PRENATAL AND PERINATAL FACTORS

##### *Age of gestation*

In 97 healthy infants, auditory awakening thresholds decreased significantly from the 44th to the 60th week after conception (Kahn, Picard and Blum, 1986). Awakening thresholds were defined as the infant opening their eyes and/or crying. Mean awakening thresholds dropped from 98.5 $\pm$ 11 at the 44th week after conception to 83 dB(A) by the 60th week after conception.

##### *Cigarette smoke*

To evaluate the effects of cigarette smoke on polygraphic arousal thresholds, 26 newborns were studied with polygraphic recordings for one night: 13 were born to mothers who did not smoke, and 13 were born to mothers who smoked (over 9 cigarettes per day) (Franco et al., 1999). Another group of infants with a median post-natal age of 12 weeks were also studied: 21 born to non-smoking mothers and 21 born to smoking mothers. The auditory arousal thresholds of the infants of both age groups were measured with the use of auditory challenges of increasing intensity, administered during REM sleep. More intense auditory stimuli were needed to induce arousals in newborns ( $p=.002$ ) and infants ( $p=.044$ ) of smokers than in infants of non-smokers (mean value of 84 $\pm$ 11 dB(A) for smokers and 81.6 $\pm$ 20 for non-smokers). Behavioural awakening (infants opening their eyes and/or crying) occurred significantly less frequently in the newborns of smokers ( $p=.002$ ) than of non-smokers.

It was concluded that newborn and infants born to smoking mothers had higher arousal thresholds to auditory challenges than those born to non-smoking mothers. From the present findings, it appeared that the impact of exposure to cigarette smoke occurred mainly before birth.

#### POSTNATAL FACTORS

The following postnatal factors modify arousal from sleep.

##### *Sleep stage*

In infants, auditory stimuli have generally indicated increased responses during active as compared with quiet sleep (Busby, Mercier and Pivik, 1994).



### *Time of the night*

In 31 infants, the arousal thresholds decreased across the night (mean value of  $67 \pm 12.5$  dB(A) in the first part of the night, for  $51 \pm 3.5$  in the third part of the night;  $p = .017$ ) (Franco et al., 2001). Similar findings had been reported in adult subjects (Rechtschaffen, Hauri and Zeitlin, 1966).

### *Body position during sleep*

To investigate whether prone or supine sleeping was associated with a different response threshold to environmental stimuli, 25 3-month-old healthy infants with a median age of 9 months were exposed to an auditory challenge while sleeping successively prone or supine (Franco et al., 1998). Three infants were excluded from the study because they awoke while their position was being changed. For the 22 infants included in the analysis, more intense auditory stimuli were needed to arouse the infants in the prone position (median of 70 dB(A), range values 50 to more than 100 dB(A)) than in the supine position (median of 60 dB(A), range values 50–90 dB(A)) ( $p = .011$ ). Arousal thresholds were higher in the prone than in the supine position in 15 infants, unchanged in 4 infants and lower in the prone position in 3 infants ( $p = .007$ ). It was concluded that infants show higher arousal thresholds to auditory challenges when sleeping in the prone position than when sleeping in the supine position. The findings could not readily be explained. The difference in arousal thresholds could be related to difference in chest wall mechanoreceptor responses, or differences in BP and/or central baroreceptors responses.

### *Ambient room temperature*

Two groups of healthy infants with a median age of 11 weeks were recorded polygraphically during one night: 31 infants were studied at  $24^\circ\text{C}$  and 31 infants at  $28^\circ\text{C}$ . To determine their arousal thresholds, the infants were exposed to white noises of increasing intensities during REM and non-REM sleep (Franco et al., 2001). The arousal thresholds decreased across the night in the infants sleeping at  $24^\circ\text{C}$  ( $p = .017$ ). The finding was not found for the infants sleeping at  $28^\circ\text{C}$ . When analysing the arousal responses according to time of the night, it was found that the auditory thresholds were significantly higher at  $28^\circ\text{C}$  ( $75 \pm 19$  dB(A)) than at  $24^\circ\text{C}$  ( $51 \pm 3.5$  dB(A)) between 03.00 and 06.00 ( $p = .003$ ). These findings were only seen in REM sleep.

### *Sleeping with the head covered by bedclothes*

To evaluate the influence of covering the face of sleeping infants with a bed sheet, 18 healthy infants with a median of 10.5 weeks (range 8–15 weeks) were recorded polygraphically for one night (Franco et al., 2002). They slept in their usual supine position. During sleep, a bed sheet was gently placed on their face for 60 minutes. With the face free or covered by the sheet, the infants were exposed to white noises of increasing intensities during REM and non-REM sleep. Compared to with their face free, during the periods when their faces were covered, the infants had increases in pericephalic ambient temperature ( $p < .001$ ), increases in REM sleep ( $p = .035$ ) and body movements ( $p = .011$ ) and a decrease in non-REM sleep ( $p < .001$ ). Respiratory frequency was increased in both REM ( $p = .001$ ) and non-REM ( $p < .001$ ) sleep. With their face covered, the infants had higher auditory arousal thresholds (mean of  $76 \pm 23$  dB(A)) than with their face free (mean of  $58 \pm 14$  dB(A)) ( $p = .006$ ). The difference was seen in REM sleep only. A positive correlation was found between pericephalic temperature and arousal thresholds in REM sleep ( $r = .487$ ;  $p = .003$ ).

### *Short sleep deprivation*

Following short sleep deprivation, a study reported that in infants there was no measurable change in arousal propensity by auditory stimuli (1 kHz pure tone, delivered in the midline of the cot, from 73 dB and increased in 3 dB steps to 100 dB)

during quiet sleep (Thomas et al., 1996). Another study was undertaken to evaluate the influence of a brief period of sleep deprivation on sleep and arousal characteristics of healthy infants (Franco et al., submitted). Thirteen healthy infants with a median age of 8 weeks (range 7–18 weeks) were recorded polygraphically during a morning nap and an afternoon nap in a sleep laboratory. They were two hours sleep-deprived, either in the morning or in the afternoon before being allowed to fall asleep. Six infants were sleep-deprived before the morning nap and seven before the afternoon nap. During each nap, the infants were exposed to white noises of increasing intensities in REM sleep to determine their arousal thresholds. Following sleep deprivation, the infants tended to have less gross body movements during sleep ( $p = .054$ ). They had a significant increase in obstructive sleep apnoeas ( $p = .012$ ). The infants' auditory arousal thresholds were significantly higher following sleep-deprivation (mean of  $76 \pm 13.5$  dB(A)) than during normal sleep (mean of  $56 \pm 8.4$  dB(A)) ( $p = .003$ ) and during REM sleep. It was concluded that short-term sleep deprivation in infants is associated with the development of obstructive sleep apnoeas and a significant increase in arousal thresholds.

#### *Pacifiers and breastfeeding*

Fifty-six healthy infants were studied polygraphically during one night: 36 infants used a pacifier regularly during sleep; 20 never used a pacifier (Franco et al., 2000). Thumb users or occasional pacifier users were not included in the study. The infants were recorded at a median age of 10 weeks (range 6–19 weeks). To evaluate their auditory arousal thresholds, the infants were exposed to white noise of increasing intensity during REM sleep. Polygraphic arousals occurred at significantly lower auditory stimuli in pacifier-users than in nonusers (mean of  $60 \pm 11.6$  with pacifiers, for  $71 \pm 15.3$  without pacifier;  $p = .010$ ). Compared to non-users, pacifier-users were more frequently bottle-fed than breastfed ( $p = .036$ ).

Among infants sleeping without a pacifier, breastfed infants had lower auditory thresholds than bottle-fed infants (mean of  $67.7 \pm 13.0$  breastfed, for  $77.7 \pm 17.5$  bottle-fed;  $p = .049$ ). The question of how a pacifier contributes to protect the sleeping infant might be best explained by the observed loss of the pacifier early after sleep onset. This could contribute to disruption of the infant's sleep and favour arousals.

## CONCLUSIONS

Various factors modify auditory arousal responses from sleep in healthy infants. Some inhibit arousals while others enhance the response. To evaluate the effect and dose-effect relationship on children therefore requires the careful determination of confounders that may bias studies and lead to conflicting results.

Additional confounders should be added to the list of factors that modify arousal thresholds. These include past experience with the stimulus (Rechtschaffen, Hauri and Zeitlin, 1966), or the presence of meaning in the noise as both of them are of critical importance in determining the persistence of physical reactions to the noise (McLean and Tarnopolsky, 1977). These are the reasons which lead most sleep/wake researchers to use white noises to stimulate the sleeping child.

Knowledge of these variables does little to clarify the physiological determinants of the awakening response, because knowledge of how such variables are related to possible physiological determinants is little better than that of the awakening response itself (Rechtschaffen, Hauri and Zeitlin, 1966).



These findings however, underline the significant dose-response relationship between ambient noise and arousal or awakening from sleep in infants.

## **NOISE AND SLEEP FOR DIFFERENT STAGES OF DEVELOPMENT**

### **THE FETUS**

The human fetus spends most of its time in a state equivalent to sleep, similar to that recorded in newborn infants. The healthy fetus in utero was shown to react to external noises. This is the result of the development of the human cochlea and peripheral sensory end organs. These complete their normal development by 24 weeks of gestation. Sound is well transmitted into the uterine environment. Ultrasonographic observations of blink/startle responses to vibroacoustic stimulation are first elicited at 24–25 weeks of gestation, and are consistently present after 28 weeks, indicating maturation of the auditory pathways of the central nervous system (Committee on Environment Health of the American Academy of Pediatrics, 1997). The fetus reacts to 1–4 seconds of 100–130 dB of 1220–15000 Hz sound. The hearing threshold (the intensity at which one perceives sound) at 27–29 weeks of gestation is approximately 40 dB and decreases to a nearly adult level of 13.5 dB by 42 weeks of gestation, indicating continuing postnatal maturation of these pathways.

Teratogenic effects have been described in animals prenatally exposed to noise (Committee on Environment Health of the American Academy of Pediatrics, 1997). These were associated with higher levels of cortisol and corticotropin hormones in the exposed animals. No such effects could be demonstrated in humans, in whom studies on the relation between exposure to noises during gestation and shortened gestation or lower birth weights were inconclusive or conflicting. It is possible that in these studies, noise could be a marker of other risk factors (Committee on Environment Health of the American Academy of Pediatrics, 1997). In conclusion, most studies on the effects of noise on perinatal health have been criticized as being hampered by serious methodological limitations, both in terms of the measurement of exposure and outcome, and failure to control for other known determinants of the outcomes under investigation. The lack of properly controlled studies makes it difficult to draw conclusions about what effects ambient noise has on perinatal outcomes (Morrell, Taylor and Lyle, 1997).

### **NEWBORN INFANTS**

A large number of investigations have been concerned with the responses of sleeping newborn infants to acoustic signals. Many of the studies arise from a large and general interest in child development as well as from a need for hearing tests for infants (Mills, 1975).

Infant incubators produce continuous noise levels of between 50 and 86 dB(lin) (American Academy of Pediatrics, 1974). Oxygen inlets produced an additional 2 dB (lin). Slamming of incubator doors and infant crying produced 90 to 100 dB(A)

(American Academy of Pediatrics, 1974). It was shown that inside incubators, background noise level is about 50 dBA and can reach 120 dBA (Committee on Environment Health of the American Academy of Pediatrics, 1997). Much of the energy is located below 500 Hz, between 31 and 250 Hz (Mills, 1975).

Ambient noise appears to influence the quantity and quality of the sleep of newborns. Some newborns appear to be particularly responsive to ambient noises. Sleeping premature, anoxic, or brain-damaged infants detect intruding sounds better than sleeping healthy or term babies (Mills, 1975).

Newborn infants spend most of their time sleeping. Some studies have documented hearing loss in children cared for in intensive care units (Committee on Environment Health of the American Academy of Pediatrics, 1997). Noise and some ototoxic drugs act synergistically to produce pathological changes of the inner ears of experimental animals (neomycin, kanamycin, sodium salicylate). The relationship with the infant's clinical condition and associated treatments has, however, not yet been clearly defined. Infants exposed to sound levels of incubators are usually premature, on drugs and in very poor health. Moreover, the exposures are continuous. A weak infant could spend weeks sleeping in such a noise level without rest periods away from noise (Mills, 1975).

High noise levels may be associated with other types of responses. In young infants, sudden loud (of approximately 80 dB) environmental noise induced hypoxaemia.

Noise reduction was associated in neonates with increases in sleep time, in particular in quiet sleep (Committee on Environment Health of the American Academy of Pediatrics, 1997). It also resulted in fewer days of respiratory support and oxygen administration. Premature infants cared for with noise reduction had a better maturation of electroencephalograms.

A Committee on Environmental Health of the American Academy of Pediatrics (1997) concluded that high ambient noise in the neonatal intensive care unit (NICU) changed the behavioural and physiological responses of infants. For all the above observations and considerations, sound in infant intensive care units should be maintained at under 80 dB(A) (Graven, 2000). Among other recommendations, paediatricians were encouraged to monitor sound in the NICU, and within incubators, where a noise level greater than 45 dB is of concern.

## INFANTS (1 MONTH TO 1 YEAR OLD)

Some studies of the effect of external noises on the sleep/wake reactions of infants were conducted in their natural home environment. The reactions of babies to aircraft noise were studied by means of electroplethysmography (PLG) and EEG (Ando and Hattori, 1977). The recordings were done in the morning, in the infants' sleeping rooms. The infants were exposed to recorded noise of a Boeing 727 at take-off. The noise was presented at 70, 80 and 90 dB(A) at peak level at the position of the babies' heads. The subjects who had not been awakened by exposure to aircraft noise were exposed to music (Beethoven's Ninth Symphony) at levels of 70, 80 and 90 dB(A). The frequency ranged between 100 Hz and 10 kHz. It was found that the babies whose mothers had moved to the area around the Osaka International Airport before conception (Group I; n=33) or during the first five months of pregnancy (Group II; n=17) showed little or no reaction to aircraft noise. In contrast,



babies whose mothers had moved closer to the airport during the second half of the pregnancy or after birth (Group III;  $n=10$  or IV;  $n=3$ ) and the babies whose mothers lived in a quiet living area (Group V;  $n=8$ ) reacted to the same auditory stimuli. The babies in groups I and II showed differential responses depending on whether the auditory stimuli were aircraft noise or music. Abnormal PLG and EEG were observed in the majority of babies living in an area where noise levels were over 95 dB(A). It was concluded that the difference in reactivity to aircraft noise may be ascribed to a prenatal difference in time of exposure to aircraft noise. The reactions diminished after the sixth month of life in groups I and II, and the ninth month in groups III to V. This phenomenon may be explained as habituation to aircraft noise after birth. However, in all groups, no habituation occurred for a noise level over 95 dB(A) (Ando and Hattori, 1977). This study was criticized, as the authors did not adjust for several important determinants of birth weight, such as prematurity and the mother's age, weight, smoking status or socioeconomic status (Morrell et al., 1997).

Noise levels may be constantly high in paediatric units. The mean noise levels measured in a centre of a surgical recovery room were 57.2 dB(A), while those measured at the patients' heads were 65.6 dB(A) (American Academy of Pediatrics, 1974). In a medical unit (6-bed wards containing 5 infants between 3 and 17 months) peak sound levels were recorded on the pillow of the cot for 12 min (Keipert, 1985). Infant crying produced 75–90 dB(A) and a beeper around 76–78 dB(A). Peak noise levels recorded at the nurses' station were about 78 dB(A) for telephone, 80 for infant crying, public address system, adult talking, and up to 90 dB(A) for child talking (Keipert, 1985).

In a study conducted on infants exposed to 50–80 dB(lin) in the range of 100–7000 Hz (American Academy of Pediatrics, 1974), a level of 70–75 dB(lin) for 3 minutes led to obvious disturbance or awakening in two thirds of the children. All infants awakened after 75 dB(lin) for 12 minutes.

In other studies conducted on the effects of awakening and arousal, it was shown that white noise intensity was significantly lower when it elicited polygraphically scored arousals than when it induced awakenings (Franco et al., 1998).

## **TODDLERS PREADOLESCENTS (8–12 YEARS OLD) ADOLESCENTS (13–18 YEARS OLD)**

Developmental variations in auditory arousal thresholds during sleep were investigated in four groups of normal male subjects: children ( $n=6$ ; 5–7 years old), preadolescents ( $n=10$ ; 8–12 years old), adolescents ( $n=10$ ; 13–16 years old), and young adults ( $n=10$ ; 20–24 years old) (Busby, Mercier and Pivik, 1994). Arousal thresholds were determined during non-REM and REM sleep for tones (3-s, 1500 Hz pure tones delivered in an ascending series of increasing intensity, 5 dB increments beginning at 30 dB SPL (sound pressure level) re 0.0002 dynes/cm<sup>2</sup> until awakening or maximum intensity of 120 dB) presented via earphone insert on a single night following two adaptation nights of undisturbed sleep. Age-related relationships were observed for both awakening frequency and stimulus intensity required to effect awakening, with awakenings occurring more frequently in response to lower stimulus intensities with increasing age. In children, 43.1% of stimuli induced awakenings, in preadolescents 54.8%, adolescents 72% and adults 100% ( $X^2=60.37$ ;  $p<.001$ ). Partial arousals (brief EEG desynchronization and/or EMG activity with the subjects returning to sleep) occurred in 9.8% of children, 4.8% of preadoles-

cents, 12.2% of adolescents, 0% of adults. Although stimulus intensities required for awakening were high and statistically equivalent across sleep stages in non-adults, higher intensity stimulus was required in stage 4 relative to stage 2 and REM sleep. Frequency of awakening increased with age, whereas stimulus intensities required to effect these awakenings decreased with age. These relationships were maintained for individual sleep stages. These results confirm previous observations of marked resistance to awakening during sleep in preadolescent children and suggest that processes underlying awakening from sleep undergo systematic modification during ontogenic development. The observed resistance to elicited awakening from sleep extending up to young adulthood implies the presence of an active, developmentally related process that maintains sleep (Busby, Mercier and Pivik, 1994).

In another study, children aged 5–7 years were shown to be 10–15 dB less sensitive to pure tones than adults aged 22–30 (Mills, 1975). Another report on male hyperactive and normal children aged 8–12 showed that these children were awakened with auditory stimulus intensity levels of up to 123 dB SPL, much higher than values reported for adults (range of 50–85 dB) (Busby, Mercier and Pivik, 1994).

In a study on four children (two males), aged 5–8 years old on the effects of simulated sonic booms (68 dB(A) near the subjects' ears), 94.1% of the subjects showed no change, 5.9% had shallower sleep, but none aroused or had behavioural awakening. In general, the frequency of arousal or behavioural awakenings and of sleep stage changes increased with age (up to 75 years) (Lukas, 1975).

In a prospective longitudinal investigation, which employed non-exposed control groups, effects of aircraft noise prior to and subsequent to inauguration of a new airport as well as effects of chronic noise and its reduction at an old airport (6–18 months after relocation), were studied in 326 children aged 9–13 years (Bullinger et al., 1999). The psychological health of children was investigated with a standardized quality of life scale as well as with a motivational measure. In addition, a self-report noise annoyance scale was used. In the children studied at the two airports over three time points, results showed a significant decrease of total quality of life 18 months after aircraft noise exposure as well as motivational deficits demonstrated by fewer attempts to solve insoluble puzzles in the new airport area. Parallel shifts in children's attributions for failure were also noted. At the old airport parallel impairments were present before the airport relocation but subsided thereafter (Bullinger et al., 1999).

In some studies, the effects of ambient noise on autonomic responses could be demonstrated in children. In children aged 6–12 years exposed to intermittent traffic noise during 4 nights (at a rate of 90 noises per hour; peak intensity of the noise, 45, 55 and 65 dB(A) varied semi-randomly) and 2 quiet nights. Heart rate was affected and relatively higher in noise during REM and stage 2 than during delta sleep (Muzet et al., 1980, in Abel, 1990).

## CONCLUSIONS

Several studies on the extra-auditory effects of ambient noise on sleeping children were summarized in Table 1. In relation to ambient noise, specific changes were reported in both sleep quality and quantity. Some of the effects were shown to have a dose-response relationship. Several limitations to the present report should be discussed. Firstly, no one knows



whether the inference that is often made that the effects of noise might develop with a longer exposure time (Abel, 1990) is correct. Serious cardiorespiratory or autonomic changes, such as increases in BP could only develop following a long time exposure starting from childhood. This, in fact, has never been documented, nor has the extent of variability between subjects due to difference in susceptibility. Secondly, there is no information to evaluate whether adaptation to ambient noise could limit the effects observed during short-term experiments. Thirdly, as the existing research data are applicable to generally healthy children, no one knows how the reported findings could be applied to ill children, children receiving medical treatment or very young premature infants. Finally, as most studies were conducted in laboratory controlled environments, no one knows the correlation between these studies and the effects of noise in the home. The multifactorial effects of the environment on sleep and arousal controls could be much more complex than expected. One might predict that, similarly as for adults, the effects of noise on the child's sleep and health are very complicated and depend upon the spectrum and level of the noise, temporal aspects of the noise, psychological responses to the noise and the nature of the evaluation technique. The complexity of the conditions related to sleep/wake controls was illustrated by the review of confounding factors affecting auditory arousal thresholds.

Despite these limitations, it can be concluded that, based on the evidence available, the extra-auditory effects of noise could be pervasive, affecting the children's physical and psychological well-being. Changes in sleep quantity and quality together with autonomic reactions are seen when a child is exposed to ambient noise during sleep. Ambient noise exerts a dose-effect relationship on changes in sleep/wake behaviours. These reflect modifications induced within the brain of the sleeping child. It remains, however, to be determined what pervasive effects long-term exposure to ambient noise has on the child's development, health and well-being. Evidence should also be defined to support an enforcement of strategies for noise reduction at the source as suggested by some studies. Noise-induced health effects on children, a clinical and public health concern, should be evaluated by further studies.

No.	dB(A)	% responses	Type of responses	Reference
1	80	70	Neonates motor response	Steinschneider 1967
2	60	5	Neonates startle response	Gädeke et al., 1969
70	10			
80	20			
100	60			
3	60	7	Neonates startle response	Ashton 1967
65	10			
70	40			
4	80	70	Child awake	Semczuk 1967
5	100	70	Child awake	Busby, Mercier and Pivik 1994
6	100	76	Preadolescent awake	
7	100	86	Adolescent awake	
8	60	100	Adult	
9	120	72	Infant awake	Kahn, Picard and Blum, 1986
10	75	75	Infant awake	Gädeke et al., 1969

**Table 1**  
**Arousal and**  
**awakening in**  
**children**  
**a review of**  
**the literature**

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Environmental noise is a threat to public health, having negative impacts on human health and wellbeing. This book reviews the health effects of night time noise exposure, examines dose effects relations, and presents interim and ultimate guideline values of night noise exposure. It offers guidance to policy-makers in reducing the health impacts of night noise, based on expert evaluation of scientific evidence in Europe.

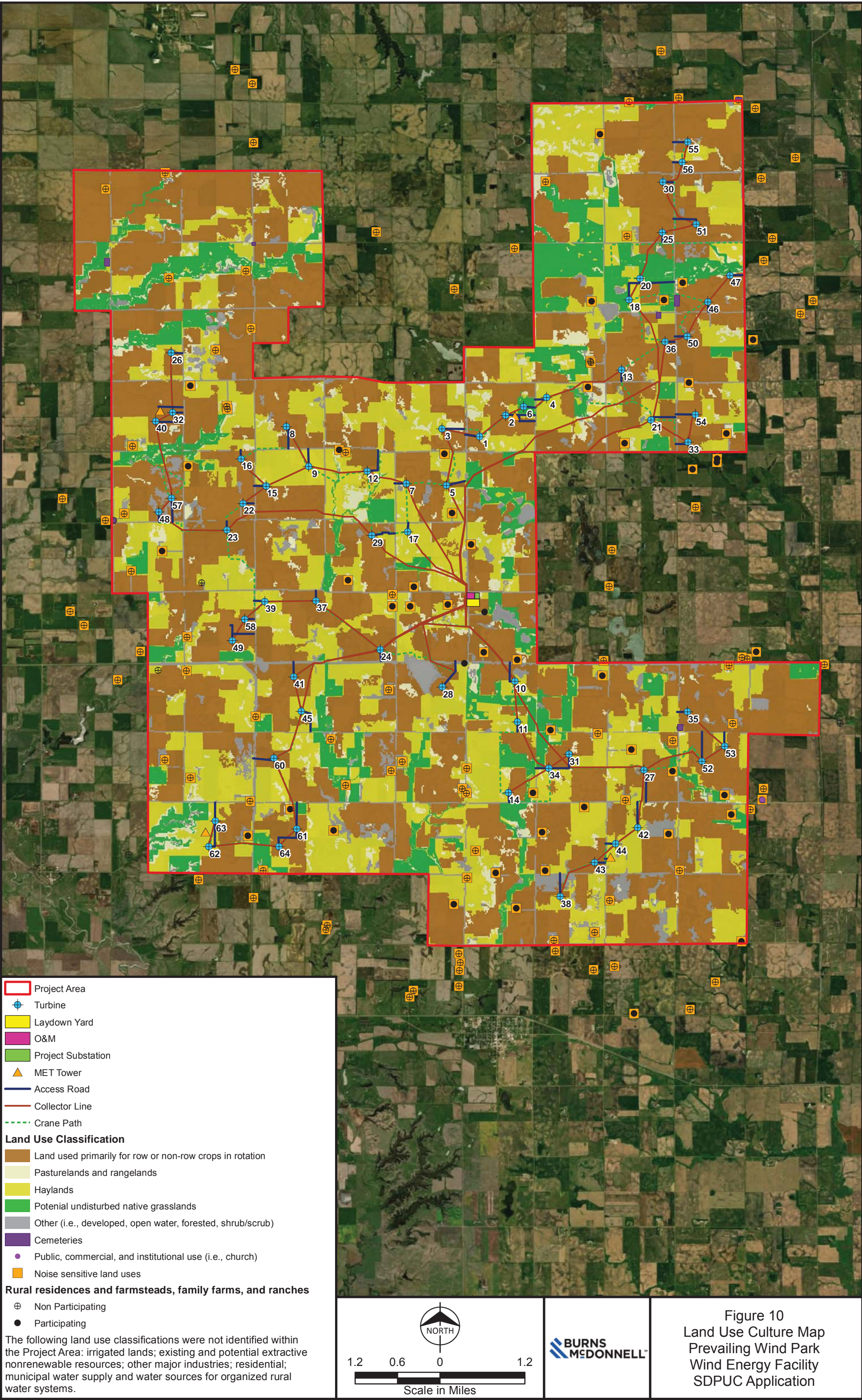


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**BEFORE THE PUBLIC UTILITIES COMMISSION  
OF THE STATE OF SOUTH DAKOTA**

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**EL18-026 - IN THE MATTER OF THE  
APPLICATION BY PREVAILING  
WIND PARK, LLC FOR A PERMIT OF  
A WIND ENERGY FACILITY IN BON  
HOMME COUNTY, CHARLES MIX  
COUNTY AND HUTCHINSON  
COUNTY, SOUTH DAKOTA, FOR THE  
PREVAILING WIND PARK PROJECT**

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\* **APPLICANT'S UPDATED RESPONSES**  
\* **TO STAFF'S DATA REQUESTS NOS. 2-**  
\* **13, 2-14 and 2-16**  
\* **EL18-026**  
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Below please find Applicant's Updated Responses to Staff's Data Requests Nos. 2-13, 2-14 and 2-16 to Applicant.

**2-13) Referring to the Sound Study (Appendix M), would it be necessary to include the existing Beethoven Wind Project in the model to capture the cumulative noise impacts to receptors in or near the Project Area? If not, please explain why.**

Chris Howell: I performed an analysis of the sound created by the Beethoven Wind Project turbines and the Prevailing Wind Park, which is enclosed as Attachment 2-13. The Analysis shows that the modeled sound from the existing Beethoven Wind farm exceeds 45 dBA at one receptor – REC 129. The modeled sound for REC 129 from the Beethoven Wind Farm is 46.2 dBA. When the two wind farms are modeled together, the sound at REC 129 is 46.3 dBA, showing that the Project would contribute only .1 dBA of sound. This added amount is acoustically negligible.

Updated Response (Chris Howell): After responding to this data request, Prevailing Wind Park decided to use a taller hub height for the GE 3.8-137 turbine and identified nine additional occupied residences in the Project area. I have reviewed my analysis in Attachment 2-13 and confirm that the predicted sound levels would be no greater than modeled in that analysis. The taller hub height results in similar or slightly lower sound levels at receptors due to the increased distance between the nacelles and receptors.

**2-14) Referring to the Shadow Flicker Study (Appendix N), please explain if shadow flicker from the Beethoven project wind turbines in addition to the Prevailing Wind Park wind turbines could cause receptors to experience greater than 30hrs of shadow flicker per year.**

Aaron Anderson: No. I evaluated shadow flicker at the Beethoven project wind turbines and the Prevailing Wind Park. No receptor that will experience shadow flicker from the Prevailing Wind Park would also experience shadow flicker from the Beethoven project.

Updated Response (Aaron Anderson): After responding to this data request, Prevailing Wind Park decided to use a taller hub height for the GE 3.8-137 turbine and identified nine additional

occupied residences in the Project area. I assessed shadow flicker within 10 rotor diameters of the GE 3.8-137 with the taller hub height and confirmed that there was no receptor that would experience shadow flicker from the Prevailing Wind Park and shadow flicker from the Beethoven project.

**2-16) What is the modeled noise level and shadow flicker at the Gramkow-Vesper Cemetery located at the intersection of 409th Ave. and 298th St. near turbine 35?**

Chris Howell: The noise level of the Project at the Gramkow-Vesper Cemetery is 43.2 dBA for the GE 3.8-137 model.

Aaron Anderson: The shadow flicker level of the Project at the Gramkow-Vesper Cemetery is approximately 5 hours per year for the GE 3.8-137 model.

Updated Responses (Aaron Anderson for shadow flicker and Chris Howell for sound): The following cemeteries were identified in the Project area. The predicted sound and shadow flicker levels are provided in the table below and are based on the GE 3.8-137 model with the 111.5 – meter hub height.

<b>Name</b>	<b>ID</b>	<b>dBA</b>	<b>Shadow Flicker hours/year</b>
Zion Cemetery (REC-119)	DK-09	29.7	0.00
New Salem Cemetery (REC-152)	DK-15	-	0.00
St. Paul's Cemetery (REC-153)	DK-18	20.8	0.00
Name not shown on maps. (REC-151)	DK-35	42.0	Approximately 18
Zion Cemetery (REC-150)	DK-36	42.6	Approximately 30
Presbyterian-Bohemian Cemetery (REC-149)	DK-69	33.8	7.35
Gramkow-Vesper (REC-140)	JK-22	43.2	5.27
Danzig Cemetery (REC-111)	JK-59	30.7	0.00

Dated this 8th day of October, 2018.

By: /s/ Lisa M. Agrimonti

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**BEFORE THE PUBLIC UTILITIES COMMISSION  
OF THE STATE OF SOUTH DAKOTA**

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**EL18-026 - IN THE MATTER OF THE  
APPLICATION BY PREVAILING  
WIND PARK, LLC FOR A PERMIT OF  
A WIND ENERGY FACILITY IN BON  
HOMME COUNTY, CHARLES MIX  
COUNTY AND HUTCHINSON  
COUNTY, SOUTH DAKOTA, FOR THE  
PREVAILING WIND PARK PROJECT**

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\*  
\* **APPLICANT’S UPDATED RESPONSES**  
\* **TO INTERVENORS’ DATA REQUESTS**  
\* **EL18-026**  
\*  
\*

Below please find Applicant’s Updated Responses to Intervenor’s Data Requests to Applicant.

- 1-2) Produce all manuals, guides, information sheets, studies, reports, and like documents that refer or relate to the turbine model selected for the Project, namely the GE 3.8-137.**

Lisa Agrimonti: Prevailing Wind Park objects to this request to the extent that it seeks information and/or documents not in the possession, custody, or control of Prevailing Wind Park, or that are confidential. Prevailing Wind Park further objects to this request because it is overbroad and vague in its request for “like documents.” Subject to and without waiving this objection, Prevailing Wind Park further responds:

Peter Pawlowski: sPower Development Company LLC (“sPower”) has a copy of the safety manual for the GE 3.8-137 turbine model that is subject to a confidentiality agreement. sPower is in contact with General Electric to determine under what circumstances the document may be disclosed in this docket. Additional information about the GE turbine can be found on General Electric’s publicly available website. See <https://www.ge.com/renewableenergy/wind-energy/turbines/3mw-platform>.

Updated Response (Lisa Agrimonti): See Attachment 1-2 (Technical Documentation Wind Turbine Generator Systems All Onshore Types). Prevailing Wind Park also has two additional responsive documents for the proposed turbine: an operating manual and a safety manual which are subject to a non-disclosure agreement. General Electric has advised that the two documents are proprietary and contain trade secret data that would advantage its competitors if disclosed. General Electric has consented to Prevailing Wind Park submitting the documents to the South Dakota Public Utilities Commission provided they are treated as confidential trade secret information pursuant to, and in accordance with, ARSD 20:10:01:39-20:10:01:45 and SDCL 1-27-1.5. The confidential documents also may be provided to counsel for Intervenor’s marked “**Attorneys’ Eyes Only**” to be reviewed by counsel of record in this matter, but may not be further disclosed or disseminated. Documents designated as “**Attorneys’ Eyes Only**” may not be disclosed to any intervenor or any other third party without the written consent of Prevailing Wind Park.

**1.4 Produce all studies, reports, and like documents that refer or relate to ice-throw from turbines.**

Lisa Agrimonti: Prevailing Wind Park objects to this request to the extent that it seeks information and/or documents not in the possession, custody, or control of Prevailing Wind Park, or that is confidential. Prevailing Wind Park further objects to this request because it is overbroad and vague in its request for “like documents.” Subject to and without waiving this objection, Prevailing Wind Park further responds:

Peter Pawlowski: See response to 1-2.

Updated Response (Peter Pawlowski). See also Attachment 1-2.

**1-11) State the number of participating residences located within (a) 1,000 feet of a turbine; (b) 2,000 feet of a turbine; (c) 1/2 mile of a turbine; (d) 1 mile of a turbine; and (e) 2 miles of a turbine.**

Bridget Canty: As shown in the Application:

(a) There are 0 participating residences within 1,000 feet of a proposed turbine location;

(b) There are 5 participating residences within 2,000 feet of a proposed turbine location;

(c) There are 21 participating residences within ½ mile of a proposed turbine location;

(d) There are 40 participating residences within one mile of a proposed turbine location; and

(e) There are 45 participating residences within two miles of a proposed turbine location.

Updated Response (Bridget Canty): Prevailing Wind Park reverified the number of occupied residences within the Project area and within .5 miles of the Project area. Based on that review, part (e) is updated to 47 participating residences within two miles of a proposed turbine location.

**1-12) State the number of non-participating residences located within (a) 1,000 feet of a turbine; (b) 2,000 feet of a turbine; (c) 1/2 mile of a turbine; (d) 1 mile of a turbine; and (e) 2 miles of a turbine.**

Bridget Canty: As shown in the Application:

(a) There are 0 non-participating residences within 1,000 feet of a proposed turbine location;

- (b) There is 1 non-participating residence within 2,000 feet of a proposed turbine location;
- (c) There are 10 non-participating residences within ½ mile of a proposed turbine location;
- (d) There are 46 non-participating residences within one mile of a proposed turbine location; and
- (e) There are 82 non-participating residences within two miles of a proposed turbine location.

Updated Response (Bridget Canty):Prevailing Wind Park reverified the number of occupied residences within the Project area and within .5 miles of the Project area. Based on that review, part (e) is updated to 87 non-participating residences within two miles of a proposed turbine location.

Dated this 5th day of October, 2018.

By: /s/ Lisa M. Agrimonti

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# 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.....5

2 Falling Objects.....5

3 Tower Collapse.....5

4 Ice Shedding and Ice Throw .....5

5 Blade Failure.....5

6 Industry Best Practices.....6

7 Setback Considerations .....7



## 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  $\frac{1}{2}$  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 <sup>1</sup> , with a minimum setback distance of 170 meters	<ul style="list-style-type: none"> <li>- Public use areas</li> <li>- Residences</li> <li>- Office buildings</li> <li>- Public buildings</li> <li>- Parking lots</li> <li>- Public roads               <ul style="list-style-type: none"> <li>- Moderately or heavily traveled roads if icing is likely</li> <li>- Heavily traveled multi-lane freeways and motorways if icing is not likely</li> </ul> </li> <li>- Passenger railroads</li> </ul>
All turbine sites (tower collapse): 1.1 x tip height <sup>1</sup>	<ul style="list-style-type: none"> <li>- Public use areas</li> <li>- Residences</li> <li>- Office buildings</li> <li>- Public buildings</li> <li>- Parking lots</li> <li>- Heavily traveled multi-lane freeways and motorways</li> <li>- Sensitive above ground services<sup>2</sup></li> </ul>
All turbine sites (rotor sweep/falling objects): 1.1 x blade length <sup>3</sup>	<ul style="list-style-type: none"> <li>- Property not owned by wind farm participants<sup>4</sup></li> <li>- Buildings</li> <li>- Non-building structures</li> <li>- Public and private roads</li> <li>- Railroads</li> <li>- Sensitive above ground services</li> </ul>

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

**PERMIT CONDITIONS JOINTLY PROPOSED BY APPLICANT AND STAFF**

Prevailing Wind Park, LLC, Docket No. EL18-026

1. Applicant will obtain all governmental permits which reasonably may be required by any township, county, state or federal agency, or any other governmental unit for construction and operation activity of the Project prior to engaging in the particular activity covered by that permit. Copies of any permits obtained by Applicant shall be sent to the Commission.
2. Applicant shall construct, operate, and maintain the Project in a manner consistent with (1) descriptions in the Application, (2) Application supplements, (3) responses to any data requests, (4) the Final Decision and Order Granting Permit to Construct Wind Energy Facility, Attachment A-Permit Conditions, (5) any applicable industry standards, (6) any permits issued by a federal, state, or local agency, and (7) evidence presented by Applicant at the evidentiary hearing.
3. Applicant shall complete the Western Area Power Administration (WAPA) environmental review process as required by the National Environmental Policy Act. Further, Applicant shall comply with and implement any requirements or commitments set forth in the WAPA NEPA review. The Applicant expects environmental review to be composed of an Environmental Assessment and that Applicant would be required to comply with applicable mitigation measures set forth in the Upper Great Plains Wind Energy Programmatic Environmental Impact Statement.
4. Applicant agrees that the Commission's complaint process as set forth in ARSD Chapter 20:10:01 shall be available to landowners and other persons sustaining or threatened with damage as the result of Applicant's failure to abide by the conditions of the Permit or otherwise having standing to seek enforcement of the conditions of the Permit. Participating landowners are free to use the complaint process free from retribution or consequence regardless of any private easement term to the contrary.
5. At least 14 days prior to commencement of construction, Applicant shall provide each participating and non-participating landowner in the Project Area with the following information:
  - a) A copy of the Final Decision and Order Granting Permit to Construct Wind Energy Facility;
  - b) Detailed safety information describing:
    - 1) Reasonable safety precautions for existing activities on or near the Project;
    - 2) Known activities or uses that are presently prohibited near the Project, and
    - 3) Other known potential dangers or limitations near the Project;



- c) Construction/maintenance damage compensation plans and procedures;
  - d) The Commission's address, website, and phone number;
  - e) Contact person for Applicant, including name, e-mail address, and phone number.
6. In order to ensure compliance with the terms and conditions of this Permit pursuant to SDCL 49-41B-33, it is necessary for the enforcement of this Order that all employees, contractors, and agents of Applicant involved in this Project be made aware of the terms and conditions of this Permit.
7. Except as otherwise provided in the Permit Conditions, Applicant shall comply with all mitigation measures set forth in the Application and Applicant's responses to Commission staff data requests. Material modifications to the mitigation measures shall be subject to prior approval of the Commission.
8. Applicant will negotiate road use agreements with Bon Homme County, Hutchinson County and Charles Mix County, and all affected townships, if required. Applicant will follow the terms of all road use agreements. Applicant shall take appropriate action to mitigate wind-blown particles created throughout the construction process, including but not limited to implementation of dust control measures such as road watering, covering of open haul trucks when transporting material subject to being windblown, and the removal of any soils or mud deposits by construction equipment when necessary.
9. Applicant shall comply with the following conditions regarding road protection:
- a) Applicant shall acquire all necessary permits authorizing the crossing of federal, state, county, and township roads.
  - b) Applicant shall coordinate road closures with federal, state, and local governments and emergency responders.
  - c) Applicant shall implement a regular program of road maintenance and repair through the active construction period to keep paved and gravel roads in an acceptable condition for residents and the public.
  - d) After construction, Applicant shall repair and restore deteriorated roads resulting from construction traffic or compensate governmental entities for their repair and restoration of deteriorated roads, such that the roads are returned to their preconstruction condition.
  - e) Within 180 days of completing construction and reclamation of the Project, Applicant shall submit documentation to the Commission identifying that the roads were repaired in accordance with this Condition 8 and to the satisfaction of affected townships and counties. If the townships or counties will not provide such documentation, then Applicant shall provide a report to the Commission on the outstanding road repair issues and how those issues will be resolved.

- f) Privately owned areas used as temporary roads or crane paths during construction will be restored to their preconstruction condition, except as otherwise requested or agreed to by the landowner.
  - g) Should Applicant need to widen any existing roadways during construction of the Project, Applicant shall return the roadways back to original width after completion of the Project, unless agreed upon otherwise with the federal, state, county, or township entities, or the landowner.
  - h) Applicant shall use appropriate preventative measures to prevent damage to paved roads and to remove excess soil or mud from such roadways.
- 10. Applicant shall provide signage that identifies road closures and disturbances resulting from the Project in accordance with the most recent editions of the Manual on Uniform Traffic Control Devices as published by the Federal Highway Administration.
  - 11. Applicant shall promptly report to the Commission the presence of any critical habitat of threatened or endangered species in the Project area that Applicant becomes aware of and that was not previously reported to the Commission.
  - 12. 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 SHPO and the Commission of the reasons that complete avoidance cannot be achieved in order to coordinate minimization and/or treatment measures.
  - 13. Applicant agrees to develop an unanticipated discovery plan for cultural resources and follow SDCL 34-27-25, 34-27-26, and 34-27-28.
  - 14. Applicant shall file the final cultural resources report with the Commission prior to construction. If any potential adverse impacts to NRHP unevaluated, listed, or eligible cultural resources are identified in the final cultural resources report, Applicant shall file with the Commission a report describing the SHPO-approved planned measures to ameliorate those impacts.
  - 15. Applicant shall provide the Stormwater Pollution Prevention Plan (SWPPP) to the Commission when Applicant has a final design for the Project. The SWPPP will outline the water and soil conservation practices that will be used during construction to prevent or minimize erosion and sedimentation. The SWPPP will be completed before submittal of an application for a National Pollutant Discharge Elimination System (NPDES) general permit for construction activities. All contractors to be engaged in ground disturbing activities will be given a copy of the SWPPP and requirements will be reviewed with them prior to the start of construction.
  - 16. Applicant shall repair and restore areas disturbed by construction or maintenance of the Project. Except as otherwise agreed to by the landowner, restoration shall 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.
17. Applicant shall work closely with landowners or land management agencies, such as the NRCS, to determine a plan to control noxious weeds.
18. Applicant shall stage construction materials in a manner that minimizes the adverse impact to landowners and land users as agreed upon between Applicant and landowner or Applicant and the appropriate federal, state, and/or local government agency. All excess construction materials and debris shall be removed upon completion of the Project, unless the landowner agrees otherwise.
19. In order to mitigate interference with agricultural operations during and after construction, Applicant shall locate all structures, to the extent feasible and prudent, to minimize adverse impacts and interferences with agricultural operations, shelterbelts, and other land uses or activities. Applicant shall take appropriate precautions to protect livestock and crops during construction. Applicant shall repair all fences and gates removed or damaged during construction or maintenance unless otherwise agreed with the landowner or designee. Applicant shall be responsible for the repair of private roads damaged when moving equipment or when obtaining access to the right-of-way.
20. Applicant shall bury the underground collector system at a minimum depth of four feet, or deeper if necessary, to ensure the current land use is not impacted.
21. Applicant shall repair or replace all property removed or damaged during all phases of construction, including but not limited to, all fences, gates, and utility, water supply, irrigation or drainage systems. Applicant shall compensate the owners for damages or losses that cannot be fully remedied by repair or replacement, such as lost productivity and crop and livestock losses. All repair, replacement and/or compensation described above shall be in accordance with the terms and conditions of written agreements between Applicant and affected landowners where such agreements exist.
22. Applicant shall, in the manner described in its written agreement with a landowner, indemnify and hold the landowner harmless for loss, damage, claim, or actions resulting from Applicant's use of the easement, including any damage resulting from any release, except to the extent such loss, damage claim, or action results from the negligence or

willful misconduct of the landowner or his employees, agents, contractors, invitees, or other representatives.

23. Applicant may make turbine adjustments of 250 feet or less from the turbine locations identified in the Application without prior Commission approval, so long as specified noise and shadow flicker thresholds are not exceeded, cultural resource impacts and documented habitats for listed species are avoided, and wetland impacts are avoided or are in compliance with applicable U.S. Army Corps of Engineers (USACE) regulations. Prior to implementing the turbine adjustment, Applicant will file in the docket an affidavit demonstrating compliance with the limitations set forth above. Any turbine adjustment that does not comply with the aforesaid limitations would be considered a "material change," and Applicant shall file a request for approval of the "material change" prior to making the adjustment pursuant to the following approval process:
  - Applicant will file with the Commission and serve on the official Service List a request for approval of the adjustment that includes:
    - An affidavit describing the proposed turbine adjustment, the reason for the adjustment, the reason the adjustment does not comply with one or more turbine flexibility limitations set forth above, and information regarding compliance with all other applicable requirements; and
    - A map showing both the approved location and the proposed adjustment (in different colors);
  - Once received, the information would be reviewed by Commission staff, and Commission staff will have 10 calendar days within which to request further Commission review.
  - If no further review is requested, Applicant may proceed with the adjustment.
  - If further review is requested, the Commission will issue a decision regarding Applicant's request at its next available regularly scheduled Commission meeting, subject to notice requirements, after the request for further review is made by Commission staff.
24. Applicant may adjust access roads, the collector system, the operations and maintenance facility, the Project substation, and temporary facilities, so long as they are located on land leased for the Project, cultural resources and documented habitats for listed species are avoided, and wetland impacts are avoided or are in compliance with applicable USACE regulations.
25. If the Project causes interference with radio, television, or any other licensed communication transmitting or receiving equipment, Applicant shall take all appropriate action to minimize any such interference and shall make a good faith effort to restore or provide reception levels equivalent to reception levels in the immediate areas just prior to construction of the Project. This mitigation requirement shall not apply to any dwellings or other structures built after completion of the Project.



26. Applicant will provide Global Positioning System (GPS) coordinates of structure locations to affected landowners at any time during the life of the Project. Coordinates will be provided in writing to landowners within 30 days of a request.
27. [Sound Condition]
28. Applicant shall install turbine control equipment on the Project's turbines that allows for individual turbines to be shut down as necessary to ensure that shadow flicker does not exceed 30 hours per year and/or 30 minutes per day at non-participating residencies. Applicant shall also take steps to mitigate shadow flicker concerns at any residence that could experience shadow flicker levels above 30 hours per year or 30 minutes per day.
29. Not less than 30 days prior to commencement of construction work in the field for the Project, Applicant will provide to Commission staff the following information:
  - a) the most current preconstruction design, layout, and plans;
  - b) a sound level analysis showing compliance with the applicable sound level requirements;
  - c) a shadow flicker analysis showing the anticipated shadow flicker levels will not exceed 30 hours per year and/or 30 minutes per day at any non-participating residence and an affidavit from the Applicant identifying the turbine numbers that will be operationally controlled in order to meet the shadow flicker requirements; and
  - d) such additional Project preconstruction information as Commission staff requests.
30. Within 90 days after the Project's commercial operation date, Applicant shall submit a report to the Commission that provides the following information:
  - a) as-built location of structures and facilities, including drawings clearly showing compliance with the setbacks required by state and local governments and the voluntary commitments set forth in Table 9-2 of the Application;
  - b) the status of remedial activities for road damage, landowner property damage, crop damage, environmental damage, or any other damage resulting from Project construction activities; and
  - c) a summary of known landowner complaints and Applicant's plan for resolving those complaints.
31. For purposes of this Project and the commitments herein, "residences," "businesses," and "public buildings" shall include only those that are in existence and in use as of the date of the Commission's order issuing a permit. "Business" shall not include agricultural uses.
32. Applicant shall seek input from local emergency response personnel to properly and effectively coordinate an emergency response plan consistent with local resources and response abilities. Upon completion of construction, a Project operation emergency

response plan shall be provided to Commission staff to make available to the general public on the Commission's website.

33. Prior to the construction of the Project, Applicant will notify public safety agencies by providing a schedule and the location of work to be performed within their jurisdiction. The agencies contacted will include the South Dakota Department of Public Safety, the sheriff in Hutchinson, Charles Mix and Bon Homme counties and the Office of Emergency Management in Hutchinson, Charles Mix and Bon Homme counties.
34. Applicant agrees to undertake two years of independently-conducted post-construction avian mortality monitoring for the Project, and to provide a copy of the report to the USFWS, GFP, and the Commission.
35. The Bird and Bat Conservation Strategy (BBCS) developed for the Project shall be implemented during construction and operation of the Project.
36. At least thirty days prior to commencement of construction, Applicant shall submit the identity and qualifications of a public liaison officer to the Commission for approval to facilitate the exchange of information between Applicant, including its contractors, and landowners, local communities, and residents, and to facilitate prompt resolution of complaints and problems that may develop for landowners, local communities, and residents as a result of the Project. Applicant shall file with the Commission its proposed public liaison officer's credentials for approval by the Commission prior to the commencement of construction. After the public liaison officer has been approved by the Commission, the public liaison officer may not be removed by Applicant without the approval of the Commission. The public liaison officer shall be afforded immediate access to Applicant's on-site project manager, its executive project manager, and to the contractors' on-site managers and shall be available at all times to Commission staff via mobile phone to respond to complaints and concerns communicated to the Commission staff by concerned landowners and others. As soon as Applicant's public liaison officer has been appointed and approved, Applicant shall provide contact information for him/her to all landowners in the Project area and to law enforcement agencies and local governments in the vicinity of the Project. The public liaison officer's contact information shall be provided to landowners in each subsequent written communication with them. If the Commission determines that the public liaison officer has not been adequately performing the duties set forth for the position in this Order, the Commission may, upon notice to Applicant and the public liaison officer, take action to remove the public liaison officer. The public liaison's services shall terminate ninety days after the Project commences commercial operations, unless the appointment is extended by order of the Commission.
37. If the Project is decommissioned, Applicant will follow Section 24 of the Application, and the decommissioning plan attached to the Supplemental Direct Testimony of Daniel Pardo. The Commission shall be notified prior to any decommissioning action.
38. Applicant will use two methods to detect icing conditions on turbine blades: (1) sensors that will detect when blades become imbalanced or create vibration due to ice accumulation; and (2) meteorological data from on-site permanent meteorological towers, on-site anemometers, and other relevant meteorological sources that will be used to determine if ice accumulation is occurring. These control systems will either automatically shut down the turbine(s) in icing conditions (per the sensors) or Applicant

will manually shut down turbine(s) if icing conditions are identified (using meteorological data). Turbines will not return to normal operation until the control systems no longer detect an imbalance or when weather conditions either remove icing on the blades or indicate icing is no longer a concern. The Applicant will pay for any documented damage caused by ice thrown from a turbine.

39. Applicant shall utilize an Aircraft Detection Lighting System if approved by the Federal Aviation Administration.
40. At least 30 days prior to construction Applicant shall file a plan with the Commission for Commission approval that provides a decommissioning escrow account. The plan shall provide as follows:
  - a) The escrow account is funded by the turbine owner annually at a rate of \$5,000 per turbine per year for the first 10 years, commencing no later than the commercial operation date.
  - b) Beginning in year ten following commercial operation of the project and each fifth year thereafter, the turbine owner shall submit the Commission an estimated decommissioning date, if established, and estimated decommissioning costs and salvage values. Based on the verification of the information in the filing the Commission may require additional funding in order to match the estimated amount needed for decommissioning.
  - c) All interest earned by the account remains in the account.
  - d) An account statement is provided annually to the Commission and becomes a public record in this docket.
  - e) The escrow account obligations will be those of Prevailing Wind Park and the escrow agreement shall include terms providing that the agreement binds Prevailing Wind Park's successors, transferees, and assigns. Also, a sale of project assets would be expected to include the associated Permit which would require Commission approval per SDCL § 49-41B-29.
  - f) The escrow account agent shall have an office located in South Dakota.
  - g) The escrow agreement shall be subject to the laws of South Dakota and any disputes regarding the agreement shall be venued in South Dakota.
  - h) To minimize the risk that the escrow account would be subject to foreclosure, lien, judgment, or bankruptcy, the escrow agreement will be structured to reflect the follow factors:
    - 1) That Prevailing Wind Park agreed to the creation of the escrow account;
    - 2) Prevailing Wind Park exercises no (or the least amount possible of) control over the escrow;
    - 3) The initial source of the escrow;

- 4) The nature of the funds put into the escrow;
  - 5) The recipient of its remainder (if any);
  - 6) The target of all its benefit; and
  - 7) The purpose and its creation.
- i) Account funds are to be paid to the project owner at the time of decommissioning to be paid out as decommissioning costs are incurred and paid.
  - j) If the project owner fails to execute the decommissioning requirement found in section 40 of the Conditions, the account is payable to the landowner who owns the land on which associated project facilities are located as the landowner incurs and pays decommissioning costs.
41. The terms and conditions of the Permit shall be made a uniform condition of construction, subject only to an affirmative written request for an exemption addressed to the Commission. A request for an exemption shall clearly state which particular condition should not be applied to the property in question and the reason for the requested exemption. The Commission shall evaluate such requests on a case-by-case basis, which evaluation shall be completed within 60 days unless exigent circumstances require action sooner.



**Applicant's Proposed Conditions**

Prevailing Wind Park, LLC, Docket No. EL18-026

27. The Project, exclusive of all unrelated background noise, shall not generate a long-term average sound pressure level (equivalent continuous sound level, Leq), 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, of more than 45 dBA within 25 feet of any residence, or 50 dBA if the owner of the residence has signed a waiver or granted an easement. Applicant shall, upon Commission formal request, conduct field surveys or provide post-construction monitoring data verifying compliance with specified noise level limits using applicable American National Standards Institute (ANSI) methods. If the long-term average level exceeds 45 dBA at any residence, or 50 dBA where the owner of the residence has signed a waiver or easement, then the Applicant shall take whatever steps are necessary in accordance with prudent operating standards to rectify the situation. Sound monitoring will not be repeated in a representative area during any five-year period unless operational or maintenance changes result in a reasonable assumption of higher turbine sound levels.
29. Not less than 30 days prior to commencement of construction work in the field for the Project, Applicant will provide to Commission staff the following information:
  - a. the most current preconstruction design, layout, turbine model, and plans;
  - b. a sound level analysis showing compliance with the applicable sound level requirements;
  - c. a shadow flicker analysis showing the anticipated shadow flicker levels will not exceed 30 hours per year and/or 30 minutes per day at any non-participating residence and an affidavit from the Applicant identifying the turbine numbers that will be operationally controlled in order to meet the shadow flicker requirements;
  - d. such additional Project preconstruction information as Commission staff requests; and
  - e. should Applicant decide at a later point to use a different turbine model, it shall provide the information required in parts a-d above.

**PUBLIC UTILITIES COMMISSION  
OF THE STATE OF SOUTH DAKOTA**

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**IN THE MATTER OF THE  
APPLICATION BY PREVAILING  
WIND PARK, LLC, FOR A WIND  
ENERGY FACILITY PERMIT FOR  
THE PREVAILING WIND PARK  
PROJECT**

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**CERTIFICATE OF SERVICE**

**EL18-026**

Bridget Duffus, of Fredrikson & Byron, P.A., hereby certifies that on the 8th day of October, 2018, a true and correct copy of the following documents and this Certificate of Service were served electronically on the persons listed below:

- A3-2 - Updated Shadow Flicker Analysis
- A10-2 - Updated Sound Study
- A20-1 - Applicant's Responses to Staff's Fifth Set of Data Requests
- A20-2 - Applicant's Responses to Staff's Sixth Set of Data Requests
- A22-2 - Intervenor Gregg Hubner, Marsha Hubner, Paul Schoenfelder, and Lisa Schoenfelder's Responses to Applicant's Second Set of Data Requests
- A22-3 - Intervenor Gregg Hubner, Marsha Hubner, Paul Schoenfelder, and Lisa Schoenfelder's Responses to Applicant's Third Set of Data Requests
- A24 - Intervenor Kelli Pazour's Responses to Applicant's First Set of Data Requests
- A25 - Intervenor Karen Jenkins' Responses to Applicant's First Set of Data Requests
- A27 - Intervenor Sherman Fuerniss' Responses to Staff's Second Set of Data Requests
- A28 - Intervenor Gregg Hubner, Marsha Hubner, Paul Schoenfelder, and Lisa Schoenfelder's Responses to Staff's Second Set of Data Requests
- A29 – Figure 10
- A30 – Applicant's Supplemental Responses to Staff's Data Requests
- A31 – Applicant's Updated Responses to Intervenor's Data Requests
- A32 – Permit Conditions Jointly Proposed by Applicant and Staff
- A33 – Applicant's Proposed Conditions

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/s/ Bridget Duffus

Bridget Duffus

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