MEMO

TO: Melissa Schmit, Senior Permitting Specialist (Geronimo)

FROM: Eddie Duncan, INCE Bd. Cert.

DATE: September 26, 2017

SUBJECT: Crocker Wind Farm – Supplemental Information on Low Frequency & Infrasonic Sound Impacts

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In a recent information request regarding the Crocker Wind Farm application, the South Dakota Public Utility Commission (PUC) has requested supplemental information regarding low frequency noise and infrasound. The PUC has specifically requested an explanation of whether any impacts are anticipated from these types of sounds and why. This memorandum is in response to the request from the PUC. We will first define what low frequency and infrasonic sound is, and then we discuss them in the context of the proposed project.

Infrasound is sound pressure fluctuations at frequencies below about 20 Hz. Sound below this frequency is only audible at very high magnitudes. Low frequency sound is in the audible range of human hearing, that is, above 20 Hz, but below 100 to 200 Hz depending on the definition.

INFRASOUND

Low frequency aerodynamic impulsive sound is typically associated with downwind rotors on horizontal axis wind turbines. In this configuration, the rotor plane is behind the tower relative to the oncoming wind. As the turbine blades rotate, each blade crosses behind the tower's aerodynamic wake and experiences brief load fluctuations. This causes short, low-frequency pulses or thumping sounds. Large modern wind turbines, like that which is proposed for Crocker Wind, are "upwind", where the rotor plane is upwind of the tower. As a result, this type of low frequency sound does not exist in these turbines. Infrasound emissions from upwind turbines are much lower than the older downwind turbines, and are well below established infrasonic hearing thresholds.

As an example, Figure 1 shows the sound levels 350 meters (1,148 feet) from a wind turbine when the wind turbine was operating (T-on) and shut down (T-off) for wind speeds at hub height greater than 9 m/s. Measurements were made over approximately two weeks.[1] The red 90 dBG line is

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[1] RSG, et al., "Massachusetts Study on Wind Turbine Acoustics," Massachusetts Clean Energy Center and Massachusetts Department of Environmental Protection, 2016 – Graphic from RSG presentation to MassDEP WNTAG, March, 2016

shown here as the ISO 7196:1995 perceptibility threshold. As shown, the wind turbines generated measurable infrasound, but at least 20 dB below audibility thresholds.

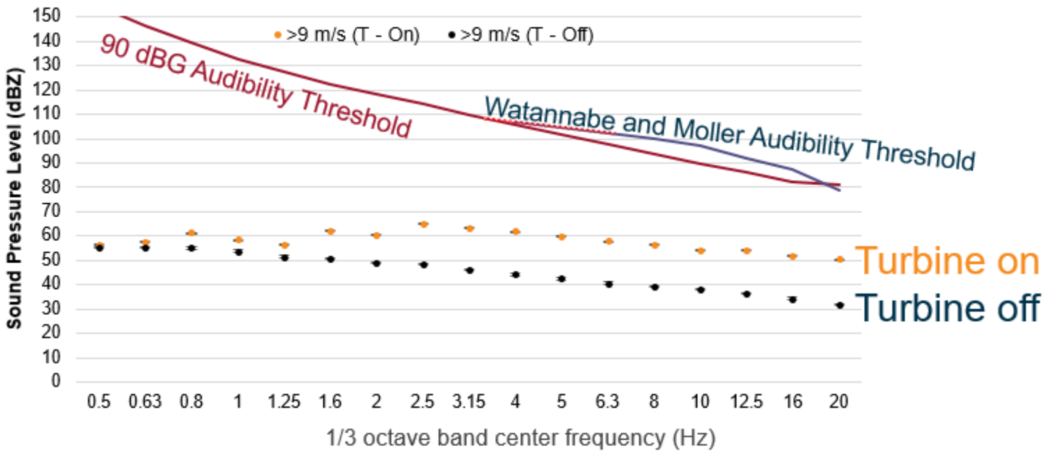

FIGURE 1: INFRASOUND FROM A WIND TURBINE AT 350 METERS (1,148 FEET) COMPARED WITH PERCEPTION THESHOLDS

Measurements of infrasound at distances from wind turbines typical of their nearest residential neighbors have consistently found that infrasound levels are below published audible human perception limits. O'Neal et al. measured sound from wind projects that used the GE 1.5 sle and Siemens SWT 2.3-93 model wind turbines. They found that at typical receptor distances away from a wind turbine, more than 1,000 feet away, wind turbine sound is typically audible starting at 50 Hz.[2]

Tachibana et al. measured sound levels from 34 wind projects around Japan over a three-year period.[3] They found that infrasound levels were "much lower than the criterion curve" proposed by Moorehouse et al.[4] RSG et al. studied infrasound levels at two wind turbine projects in the northeastern U.S. Both indoor and outdoor measurements were made.[1] Comparisons between turbine-on periods and adjacent turbine shutdown periods indicated the presence of wind-turbine-generated infrasound, but well below ISO 389-7[5] and Wattanabe et al.[6] perception limits. In their review of several wind turbine measurement studies (including O'Neal and Tachibana), McCunney et al. did not find evidence of audible or perceptible infrasound levels and typical residential distances from wind projects.[7]

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[2] O'Neal, R. et al. "Low frequency noise and infrasound from wind turbines." Noise Control Engineering J. 59 (2), 2011.
[3] Tachibana, et al. "Nationwide field measurements of wind turbine noise in Japan." Noise Control Engr. J. 62 (2) 2014.
[4] Moorehouse, A. T. "A procedure for the assessment of low frequency noise complaints." J. Acoust. Soc. Am. 126 (3) 2009
[5] *Acoustics -- Reference zero for the calibration of audiometric equipment -- Part 7: Reference threshold of hearing under free-field and diffuse-field listening conditions,* International Standards Organization, ISO 389-7:2005, last reviewed 2013
[6] Watanabe, T., and Moller, H., "Low frequency hearing thresholds in pressure field and in free field," *J. Low Freq. Noise Vib., Vol. 9(3), 106-115*
[7] McCunney, Robert, et al. "Wind Turbines and Health: A Critical Review of the Scientific Literature." *Journal of Occupational and Environmental Medicine.* 56(11). November 2014. pp. e108-e130.

Authors Salt, Pierpont, and Schomer have theorized that infrasound from wind farms can be perceived by humans and cause adverse reactions, even when it is below measured audibility thresholds.[8,9,10] Some of these theories have focused on the human vestibular system, hypothesizing that sub-audible infrasound could stimulate the vestibular system, upsetting the human body's manner of determining balance and causing symptoms such as dizziness, nausea, and headaches, along with disruptions in sleep. In response, McCunney et al. and Leventhall contend that there has been no demonstration that humans can perceive sub-audible infrasound, citing the relative insensitivity of the inner ear (where the vestibular system is located) to airborne sound and the presence of other low to moderate magnitude infrasound sources in the body and the environment.[11,12]

Yokoyama et al. conducted laboratory experiments with subjects exposed to synthesized infrasound from wind turbines. In one experiment, he filtered synthesized wind turbine sound to eliminate high frequency sound at ten different cutoff frequencies from 10 Hz to 125 Hz.[13] The results indicate that when all sound above 20 Hz was filtered out, none of the respondents could hear or sense the wind turbine sound. In a second experiment correlating the subject response of wind turbine sound to different frequency weighting schemes, they found that the subjective loudness of wind turbine sound was best described by the A-weighted sound level rather than other weightings that focused on low-frequency sound or infrasound.[14]

Hansen et al. compared subject response to infrasound and "sham" infrasound.[15] In one case, recordings of wind turbine noise, filtered to exclude sound above 53 Hz, were presented to subjects with the infrasonic content present, with only the infrasonic content present, and with the infrasonic content removed. Results showed that adverse response to the sound, was determined by the low frequency, not infrasonic content of the sound. A study by Walker, et al. found that feelings of nausea and annoyance were more correlated with audible range blade swish than infrasonic components.[16]

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[8] Salt, Alec and Hullar, Timothy. "Responses of the Ear to Low-Frequency Sounds, Infrasound, and Wind Turbines." *Hear Res.* 268(2010). pp. 12-21.
[9] Pierpont, Nina. "Wind Turbine Syndrome: A Report on a Natural Experiment." *K-Selected Books*: Santa Fe, New Mexico: 2009.
[10] Schomer, Paul, et al. "A Theory to Explain Some Physiological Effects of the Infrasonic Emissions at Some Wind Farm Sites." *J. Acoust. Soc. Am.* 137(3). March 2015. pp. 1357-1365.
[11] McCunney, Robert, et al. "Wind Turbines and Health: A Critical Review of the Scientific Literature." *Journal of Occupational and Environmental Medicine.* 56(11). November 2014. pp. e108-e130.
[12] Leventhall, Geoff. "Infrasound and the ear." *Fifth International Conference on Wind Turbine Noise*. Denver, Colorado: 28-30 August 2013.
[13] Yokoyama S., et al. "Perception of low frequency components in wind turbine noise." Noise Control Engr. J. 62(5) 2014
[14] Yokoyama et al. "Loudness evaluation of general environmental noise containing low frequency components." Proceedings of InterNoise2013, 2013
[15] Hansen, K, et al. "Perception and Annoyance of Low Frequency Noise Versus Infrasound in the Context of Wind Turbine Noise." *6th International meeting on Wind Turbine Noise*. Glasgow, Scotland: 20-23 April 2015.
[16] Walker, Bruce and Celano, Joseph. "Progress Report on Synthesis of Wind Turbine Noise and Infrasound." *6th International Meeting on Wind Turbine Noise*. Glasgow, Scotland: 20-23 April 2015.

Finally, research by Tonin, et al. found that response to infrasound was more determined by information the subject had received than the presence of infrasound in a sound signal.[17]

LOW FREQUENCY SOUND

Low frequency sound is primarily generated by the generator and mechanical components in the nacelle. Much of the mechanical sound has been reduced in modern wind turbines through improved sound insulation. Low frequency sound can also be generated by the blades at higher wind speeds when the inflow air is very turbulent. However, at these wind speeds, low frequency sound from the wind turbine blades is often masked by wind sound at the downwind receptors.

Low frequency sound is absorbed less by the atmosphere and ground than higher frequency sound. Our modeling takes into account frequency-specific ground attenuation and atmospheric absorption factors that takes this into account.

While infrasound from wind farms has not been shown to be audible by humans, infrasound and low-frequency sound can create noise-induced vibration in lightweight structures. ANSI 12.2-2008 Table 1 lists low frequency noise criteria to prevent "perceptible vibration and rattles in lightweight wall and ceiling structures."[18] These criteria are shown in Table 1. While these are interior levels, the equivalent exterior sound levels will be higher due to building noise reduction. [19, 20, 21] Outside to inside noise reduction is a function of sound frequency and whether windows are open or closed. The exterior sound level criteria for windows open are shown in Table 2.

TABLE 1: ANSI 12.2 SECTION 6 – INTERIOR SOUND LEVELS FOR PERCEPTIBLE VIBRATION AND RATTLES IN LIGHTWEIGHT WALL AND CEILING STRUCTURES

1/1 Octave Band Center Frequency	16 Hz	31.5 Hz	63 Hz
Clearly perceptible vibration and rattles likely	75 dB	75 dB	80 dB
Moderately perceptible vibration and rattle likely	65 dB	65 dB	70 dB

TABLE 2: EXTERIOR SOUND LEVELS FOR PERCEPTIBLE VIBRATION AND RATTLES IN LIGHTWEIGHT WALL AND CEILING STRUCTURES[19]

1/1 Octave Band Center Frequency	16 Hz	31.5 Hz	63 Hz
Clearly perceptible vibration and rattles likely	78 dB	81 dB	89 dB
Moderately perceptible vibration and rattle likely	68 dB	71 dB	79 dB

[17] Tonin, Renzo and Brett, James. "Response to Simulated Wind Farm Infrasound Including Effect of Expectation." *6th International Meeting on Wind Turbine Noise*. Glasgow, Scotland: 20-23 April 2015.
[18] "American National Standard Criteria for Evaluating Room Noise", American National Standards Institute ANSI/ASA S12.2-2008, Acoustical Society of America, (2008).
[19] O'Neal, R. et al. "Low frequency noise and infrasound from wind turbines." Noise Control Engineering J. 59 (2), 2011.
[20] RSG, et al. "Massachusetts study on wind turbine acoustics." Prepared for MassCEC and MassDEP, February 2016.
[21] Delta Electronics Light & Acoustics, *Low frequency noise from large wind turbines, Summary and conclusions on measurements and methods,* Danish Energy Authority, EFP-06 Project, 19 December 2008

Low frequency model results at the exterior of the worst-case receivers are provided in Table 3 for each turbine model. These model results are produced using the same methodology discussed in the Crocker Wind Farm Noise Compliance Report, dated 7/21/2017. As shown in the Table 3, the worst-case results for each turbine option are below the exterior criteria (see Table 2) to prevent "moderately perceptible vibration and rattle" in lightweight wall and ceiling constructions for all turbine models.

TABLE 3: LOW FREQUENCY MODEL RESULTS FOR THE WORST CASE RECEIVERS[22]

Turbine Model Run	Maximum Modeled Level (dB)	
	31.5 Hz	63 Hz
GE116	65	64
G126	63	59
V110	68	64
V136	63	62

Given the information presented in this memorandum, impacts due to infrasound and low-frequency sound are not anticipated.

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Director

[22] Sound emission data for the 16 Hz octave band is not available from the turbine manufacturers presented in Table 3.