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Post Construction Sound Survey
Lake Winds Energy Park
Mason County, Michigan

Prepared for:

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1 INTRODUCTION

Howe Gastmeier Chapnik Limited ("HGC Engineering") was retained by Mason County to perform a post construction sound survey of the Lake Winds Energy Park ("wind farm") operated by Consumers Energy Company ("Consumers Energy") in Mason County, Michigan. The survey was initiated pursuant to a commitment by Consumers Energy relating to the zoning approvals for the project.

The wind farm is located in Mason County approximately 10 km southeast of the City of Ludington, 5 km east of Lake Michigan, and has been in operation since the winter of 2012. Figure 1 provides a key map of the area. The wind farm consists of 56 Vestas-American Wind Technology, 1.8 megawatt, wind turbine generators ("turbines"), model V100-1.8. The turbines have a hub height of 95 metres, a blade length of 49 metres, and a rotor diameter of 100 metres. The three-bladed turbines operate between wind speeds of 3 m/s and 20 m/s. Figure 2 shows a site plan for the wind farm while Figures 3a and 3b illustrate the turbine and measurement locations. The green crosses represent wind turbines, and the yellow and white circles represent the measurement locations. The measurement locations were selected to represent a variety of residences at typical distances from 300 to 600 meters to the closest wind turbines and, where possible, approximate the locations used for the ambient baseline study.

This survey is based principally on automated 10-minute A-weighted sound level measurements and supplemented with attended sound level measurements. The measurements were conducted over approximately a two week period from April 24 to May 10, 2013. Both the unattended and attended sound level measurements were conducted at a total of eight measurement locations within the wind farm area indicative of both pooled and unpooled properties.

Weather conditions, including wind speed and direction, were monitored and recorded for the duration of the measurement period at four locations. This data was supplemented with electric power production records and hub height wind data obtained from Consumers Energy as recorded through their turbine monitoring system.

2 METHODOLOGY

2.1 Criteria

Most sounds can contain a mixture of many frequencies simultaneously. The human ear varies in its sensitivity to sounds of different frequency. Therefore, sound levels are often measured using a frequency-weighted filter which emulates the frequency sensitivity of the human ear. The frequency-weighting is referred to as the "A-scale." Most instrumentation for measuring sound has the capability to weight all of the component frequencies of a sound, and sum them into a single number; sounds measured in this way are designated in units of A-weighted decibels [dBA]. A dBA spectral-sum sound pressure level is a reasonable single-number representation of the perceived overall loudness of a complex sound that contains multiple different frequencies. For this reason, most guidelines and limits for noise outdoors, such as the Mason County Zoning Ordinance, are specified in terms of a single-number dBA level.

The sound level criteria for the Lake Winds Energy Park are defined in Mason County Zoning Ordinance [1] Section 17.70(17.b.3) and Section 17.70(17.d) as 45 dBA (LA_{EQ}) at the property line of unpooled parcels, and 55 dBA (LA_{EQ}) at the dwelling of pooled parcels. These sound level limits are presented in terms of 10 minute energy equivalent average sound levels designated L_{EQ}, in units of dBA. Thus, where sound levels vary in loudness over a ten minute period, it is the average sound level rather than the maximum or minimum sound levels which is relevant. Furthermore, these sound level limits apply only to the sound level contribution from the turbines. However, any sound level measurement will contain both the sound contributed by the source under assessment, as well as sound from any ambient or background sound sources (e.g., road vehicles, air traffic, wind, frogs, insects, etc.). Thus, a sound level measurement cannot necessarily be compared directly to the sound level limits. Where significant background sound levels exist, some form of evaluation must be made to determine the sound level contribution of the source under assessment in the absence of background sounds.

Sound levels are sometimes usefully quantified by determining the ninetieth percentile (L_{90}) sound level. An L_{90} sound level represents the level exceeded 90% of the time during a measurement. L_{90} sound levels are useful as they allow some separation of steady sound from an overall aggregate measured sound level. This means that when a continuous sound such as the sound of an operating wind turbine generator is masked at times by a louder transient sound such as those caused by wind gusts, birds, vehicles, and animals, the L_{90} sound level tends to more accurately reflect the sound level contribution of the steady sound by itself than does the L_{EQ} sound level. On a technical note, the L_{90} sound levels represent the sound level contribution of steady sound sources, thus, the L_{90} will be underestimating the contribution of the wind turbine due to amplitude modulation at times when other background sounds are very low. In general the L_{90} is considered to be a good approximation of the contribution of the sound level impact from the turbines when they are audibly dominant most of the time, but with intermittent interference from louder sources. Put another way, when the L_{EQ} is much higher than the L_{90} (> 5dB) the turbines are not the primary source impacting the L_{EQ}. For this reason both the L_{EQ} and L_{90} values are reported in this survey.

It is important to note that the zoning approval does not require or imply that inaudibility of a sound source at a measurement location should be expected. In fact, even when the sound levels from a source are less than the numeric guideline limits, spectral and temporal characteristics of a sound regularly result in audibility. To be clear, wind turbines may be audible even when sound levels are below the set sound level limits.

2.2 Instrumentation

Four Bruel & Kjaer Integrating Sound Level Meters and four Norsonic N-140 Sound Level Meters were used for the unattended acoustic measurements. All of the meters recorded the 10 minute average L_{EQ} and L_{90}, but Norsonic meters were also able to record the 1/3 octave band spectrum and perform a one-minute audio recording every 10 minutes. The instruments are described in Table 1 below. The clocks of all instruments were synchronized with the turbine data collection system prior to the measurements.

Table 1: Instrumentation Used for Unattended Sound Level Measurements

Measurement Location ID	Residence Location	Instrument Make and Model	Instrument Serial Number
Location 1	Kistler Road	Bruel and Kjaer Type 2238 Sound Level Meter	2562612
Location 2	Kinney Road	Norsonic N-140 Integrating Sound Level Meter	1403362
Location 3	Hawley Road	Bruel and Kjaer Type 2238 Sound Level Meter	2684479
Location 4	Morton Road	Norsonic N-140 Integrating Sound Level Meter	1402334
Location 5	Hawley Road	Bruel and Kjaer Type 2238 Sound Level Meter	2664579
Location 6	Hawley Road	Norsonic N-140 Integrating Sound Level Meter	1403716
Location 7	Stiles Road	Norsonic N-140 Integrating Sound Level Meter	1404511
Location 8	Anthony Road	Bruel and Kjaer Type 2238 Sound Level Meter	2343948

Instruments that were used for the attended measurements are listed in Table 2 below.

Table 2: Instrumentation Used for Attended Sound Level Measurements

Instrument Make and Model	Instrument Serial Number
Bruel and Kjaer Type 2236 Sound Level Meter	1849429
Hewlett Packard Type 3569A Real Time Frequency Analyzer	3320A00214
Hewlett Packard Type 3569A Real Time Frequency Analyzer	3442A00141
Larson Davis LxT1 Integrating Sound Level Meter	0001724
Larson Davis Model 831 Integrating Sound Level Meter	0001865
Norsonic N-140 Integrating Sound Level Meter	1405028

Correct calibration of all acoustic instrumentation was verified using acoustic calibrators manufactured by Bruel and Kjaer. Calibration was carried out prior to the start of each measurement period and at the end of each measurement period. All instruments were equipped with their respective ½" diameter microphone. 175 mm diameter wind screens were used on all unattended microphones to minimize the contribution of direct wind noise on the microphone. The Norsonic N-140 Integrating Sound Level Meter (1405028) equipped with a Bruel and Kjaer type 4193 ½" diameter low frequency pressure-field microphone, was used for the attended infrasound measurements.

Wind speed, direction, were measured using the equipment summarized in Table 3 below. Additional meteorological data, such as rain, was recorded by the Davis weather stations at Locations 4 and 8.

Table 3: Instrumentation Used for Meteorological Measurements

Location ID	Measurement Location	Instrument Make and Model	Instrument Serial Number
Location 2	Kinney Road	NRG#40 Sine Anemometer with Campbell Scientific Data Logger	179500181113
Location 4	Morton Road	DavisVantage Pro2 Weather Station	3788A-6020
Location 6	Hawley Road	R.M.Young Wind Monitor with Campbell Scientific Data Logger	93557
Location 8	Anthony Road	DavisVantage Pro2 Weather Station	3788A-6312

3 RESULTS

3.1 Unattended Acoustic Measurements

The overall sound level data gathered by the automatic monitors at the eight measurement locations is presented in detail in Appendix A. For discussion purposes, Figures A1 through A8 illustrate the 10-minute L_{EQ} and L_{90} sound levels measured at the eight measurement locations in units of dBA, together with the numeric sound level limits. These figures also present the measured ground level wind speeds, and the hub height wind speed and power output of the closest turbine.

There were a number of periods of inclement weather (rain) which have been greyed out on Figures A1 through A8. These periods of inclement weather have not been considered in this survey as the weather was not suitable for sound level measurements. Additionally, the sound level meter data collected during the second week of monitoring at Location 5 did not align with the attended measurements and is therefore not considered valid. These periods have been noted in the Figures 5b and 5c including the use of a red filter.

As noted, the L_{90} sound level is often a better descriptor of the sound level contribution of a steady sound source than the L_{EQ} sound level. Where a steady sound is not masked by short duration events, such as vehicle pass-bys, the L_{EQ} and L_{90} sound level will be close to one another. Conversely, when short-duration or variable background sounds are the dominant noise source, and strongly mask any quieter steady industrial sounds, the difference between the L_{EQ} sound level and the L_{90} sound level will be large.

The unattended L_{EQ} and L_{90} sound level measurements conducted at the representative unpooled measurement locations indicate that, with the wind turbines at or close to full power, the sound level contribution from the wind turbines was generally close to the 45 dBA criteria. By simply considering the L_{EQ} and L_{90} sound levels, a case can be made that the turbines are above the limits for some ten minute periods, as there were periods when the turbines were operating at full capacity and both the L_{EQ} and L_{90} were above the applicable criteria. However, there are also periods when the turbines were operating at full capacity and both the L_{EQ} and L_{90} were below the criteria, in addition to periods when the turbines were not operating and yet the L_{EQ} and L_{90} were above the criteria (indicating high levels of background sound). As these examples illustrate, a comprehensive consideration of the turbine output, ground level wind speed, dominant noise source(s), and background sound is necessary to clearly determine if the limits are being exceeded. Consideration of the ground level wind speed is important, as generally when the ground level wind speed increases the ambient background sound level increases proportionally (due to wind in trees, brush, etc.). Therefore, although there are specific instances where the unattended L_{EQ} and L_{90} were above the applicable numerical criteria, these do not appear to represent a statistically significant portion of time and do not indicate a systemic exceedance.

The unattended L_{EQ} and L_{90} sound level measurements conducted at the representative pooled locations, with a criteria of 55 dBA, present the same trends as those measured at the unpooled locations. Although there are also specific instances where the unattended L_{EQ} and L_{90} were above the applicable numerical criteria, these do not appear to represent a statistically significant portion of time and do not indicate a systemic exceedance.

3.2 Attended Acoustic Measurements

During the measurement period a variety of attended measurements were conducted at the eight monitoring locations. Attended measurements allow the collection of sound data in conjunction with qualitative observations. These measurements have been plotted on Figures A1 through A8, and are used to provide an indication of the dominant sources of sounds and to verify the accuracy of the automatically monitored sound levels.

Appendix B summarizes the attended acoustic measurements which consider the frequency spectra and sound level characteristics of the measured sound levels. Attended sound level measurements at each measurement location were conducted during monitoring periods of 80-minutes, with the nearby turbines off for 40 minutes and on for 40 minutes. Attended measurements were conducted during both daytime and nighttime hours. The turbine shutdown and monitoring periods were scheduled with Consumers Energy approximately 24 hours in advance in an attempt to align with periods when the turbines would be operating at full capacity. However, due to generally low wind speeds during the two week period and transient weather conditions this was not always accomplished.

The observations and results of the attended measurements confirm that the wind turbines are routinely audible at the selected monitoring locations representative of both pooled and unpooled residences. The measured L_{EQ} and L_{90} values and corresponding wind conditions are summarized in Tables B1 through B8. Attended sound level measurements were conducted under hub height wind speeds ranging from less than 4 m/s to 11 m/s.

Of the attended sound measurements conducted at the eight representative locations, only one of the sixty-three L_{90} measurements exceeded the sound level criteria, while 18 of the 63 L_{EQ}

measurements exceeded the sound level criteria. However, in all instances when measured sound levels were greater than the 45 or 55 dBA criteria, the observations made during the sound level measurements generally indicated that the wind turbines were not the only dominant source of sound. Therefore, the sound levels recorded during the attended measurements indicate general compliance with the sound level limits.

The attended measurements also included an assessment of the sound levels as a function of frequency. Measurements of the sound were taken over the frequency spectrum 6.3 Hz to 10,000 Hz in one-third octave bands. Sample spectra in units of un-weighted decibels (dB) are included in Figures B1 to B3 in Appendix B. The spectra confirm that the sound from the wind turbines should be audible to most impacted persons, although no strong tones were noted. Note also that the increased levels around the 3150 Hz frequency band in the figures are consistent with frogs croaking, which was subjectively noted during the measurements, and are present regardless of turbine operation.

3.3 Infrasound Measurements

Infrasound is sound at low frequencies, and is not otherwise different from common higher-frequency sound. The International Organization for Standardization "ISO" defines infrasound as "sound or noise whose frequency spectrum lies mainly in the band from 1 Hz to 20 Hz." [2]

Natural sources of infrasound include wind and breaking waves; people are continually subject to sound at infrasonic frequencies. However, the human ear is not particularly sensitive to sound at these frequencies and humans are not generally subject to levels of infrasound sufficiently high enough to be able to detect its presence. As these sound levels are generally below human perception the results are presented in their un-weighted form and not their A-weighted form (which emulates the human ear's frequency sensitivity).

Various papers and reports dealing with low frequency noise in general, and investigations of low frequency noise produced by wind turbine generators in particular, have been published in recent years. These papers suggest various thresholds of perception below which infrasound is not generally discerned. The assessment of infrasound at measurement Location 3 has been based on the following thresholds of perception: Watanabe and Møller [3], Watanabe [4], ISO 389-7:2005 [2] and Yeowart and Evans [5].

Short duration measurements of sound at infrasonic frequencies were conducted at measurement Location 3. Short duration measurements were performed inside the resident's outbuilding (garage) to minimize the influence of wind gusts and car pass-bys, which tend to increase the levels of infrasound. The un-weighted measured sound spectra are illustrated in Figure C1. As shown in the figure, the infrasound levels at each frequency are higher by approximately 10 to 15 dB when the turbines are on, but remain well below the thresholds of perception.

4 CONCLUSIONS

HGC Engineering conducted a post construction sound survey at eight monitoring locations representing pooled and unpooled residences from April 24 until May 10, 2013. Both attended and unattended acoustic measurements were conducted over a wide range of wind and environmental conditions.

Observations made during the survey period indicate that the sound of the wind turbine generators was generally audible at the selected measurement locations, but to varying degrees. That being said, the zoning approval does not require inaudibility of a sound source at the measurement locations.

Unattended sound level monitoring was conducted over the two week period. The unattended L_{EQ} and L_{90} sound level measurements conducted at the representative unpooled and pooled measurement locations indicated that the sound level from the wind turbines under full or close to full power were generally close to their respective 45 or 55 dBA criteria. During these periods, consideration of the turbine output, wind speed, and background sound is necessary to clearly determine if the limits are being exceeded. Therefore, although there are instances where the unattended L_{EQ} and L_{90} were measured to be above the applicable numeric criteria, these do not represent a statistically significant portion of time and do not indicate a systemic exceedance.

The attended sound level measurements again indicated that the sound levels from the wind turbines were in general compliance with the sound level criteria. Further to this, spectra measurements do not show any significant tonality and demonstrate that the infrasound measurements are well below the perception threshold.

REFERENCES

1. Mason County. "Mason County Zoning Ordinance". Internet Document: www.masoncounty.net. Pp.176-178, 2012.

2. ISO 389-7:2005, "Acoustics- Reference zero for the calibration of audiometric equipment- Part 7: Reference threshold of hearing under free-field and diffuse-field listening conditions", 2005.

3. Watanabe, T., Møller, H., "Low frequency hearing thresholds in pressure field and in free field", *Journal of Low Frequency Noise and Vibration,* vol. 9, no. 3, pp. 106-115, 1991.

4. Watanabe, T., "Simultaneous masking and temporal masking of low frequency sound", presented at the 13th International Conference on Low Frequency Noise and Vibration and its Control, Tokyo Japan, 2008.

5. Yeowart, N.S. and Evans, M.J ., "Thresholds of audibility for very low frequency pure tones", *Journal of the Acoustical Society of America,* vol. *55,* no. 4, pp. 814-818, 1974.

6. Google Maps Aerial Imagery, Internet Application: *maps.google.com*