TECHNICAL MEMO 2013-021

O'Donnell Wind Turbines Noise Evaluation
Kingston, MA

Allan Beaudry
Michael Bahtiarian, INCE Bd. Cert.

April 23, 2013

NCE JOB No. J2013-035

Prepared for:
CHRIS SENIE & ASSOCIATES
5 East Main Street, 2nd Floor
Westborough, MA 01581
Attention, Mr. Chris Senie, Esq.

Prepared by:
NOISE CONTROL ENGINEERING, Inc.
799 Middlesex Turnpike
Billerica, MA 01821
978-670-5339
978-667-7047 (fax)
nonoise@noise-control.com (Email)

TABLE OF CONTENTS

0.0 EXECUTIVE SUMMARY

Noise Control Engineering, Inc. (NCE) was retained by a group of residential neighbors to perform sound measurements of the three O'Donnell wind turbines located in Kingston, Massachusetts. NCE performed these measurements at four residences surrounding the turbines from 11:00 pm on April 2, 2013 to approximately 2:00 am on April 3, 2013. In addition to these four neighbor locations, NCE performed measurements at a reference location to establish the ambient noise in the area. Multiple 60-second measurements were performed at each location using a Larson Davis sound level meter (SLM).

The noise regulation assessed in this evaluation is the Massachusetts Department of Environmental Protection (MADEP) regulation that prohibits any source of noise to be 10 decibels greater than the ambient at the subject property line. The ambient noise for this evaluation was established at a reference location distant from the turbine. In addition to the broadband limit, the MADEP regulation prohibits any pure tone condition defined as the sound level in any octave band greater than or equal to 3 dB above the two adjacent bands.

Using the average operational levels measured at the four residential locations and the average ambient levels measured at the reference location, NCE assessed compliance with the MADEP noise regulation. Of the four neighborhood locations, two were found to be in excess of this regulation with increases over the reference/background noise level of 12 and 16 decibels. NCE also calculated the increases of the maximum measured residential levels over the minimum measured reference levels. This worst-case assessment produced overages of 13 to 22 decibels above the reference background. The turbine induced noise is significantly above the MADEP regulation that only permits up to a 10 decibel increase. No pure tones were identified in any measurements.

Based on the above data, NCE concludes that the O'Donnell Wind Turbines are generating noise that is in excess of the MADEP broadband noise regulation.

1.0 INTRODUCTION

Noise Control Engineering, Inc. (NCE) was retained by a group of residential neighbors to perform noise measurements of the three O'Donnell wind turbines located in Kingston, Massachusetts. NCE performed these measurements at four residences surrounding the turbines from 11:00 pm on April 2, 2013 to approximately 2:00 am on April 3, 2013.

2.0 NOISE LIMITS

NCE assessed the measured sound pressure level (SPL) data to the noise limits given below in Sections 2.1 and 2.2. It should be noted for the record that SPL below any such limit whether town ordinance or state regulation, does not necessarily mean that annoyance of any persons will not occur. This has been documented in recent research papers, references [1] and [2].

2.1 Commonwealth of Massachusetts

The Commonwealth of Massachusetts noise regulation is given in 310 CMR 7.10, reference [3]. The Massachusetts Department of Environmental Protection (MADEP) has established the specifics of the regulation in a policy letter, reference [4], and a MADEP Noise Guideline, reference [5]. The noise regulation requires comparison of operational noise level (i.e. with the source of noise operating) to the ambient or background noise level (i.e. with the source of noise shut down). The MADEP regulation [2] has two parts. The first part prohibits any source of noise to be 10 decibels greater than the ambient. The second part prohibits any pure tone condition which is defined as the sound level in any octave band that is greater than or equal to 3 dB above the two adjacent bands. Both parts apply at the property line of the noise source or the nearest inhabited residence.

According to the MADEP guideline [5], the ambient (or background) noise level is defined as, "*the sound from all sources other than the particular sound of interest…The ambient sound measurement (A-weighted Noise Level) is taken where the offending sound cannot be heard or with the sound source shut off*". The ambient sound level is also measured as *"…the A-weighted sound level that is exceeded 90% of the time…"*. This value is technically referred to as the L90 sound pressure level (SPL). Given that the wind turbines could not be shut down during this survey the reference location method was used to establish a background noise level.

2.2 Town of Kingston, MA

The Town of Kingston Zoning By-Laws provides specific guidelines for the proper siting of wind turbines, reference [6]. Section 4.16.6.3 of the bylaws outlines the regulations regarding wind turbine noise and states the wind facility must conform to the MADEP regulations stated above. This includes the broadband ambient-dependent limit as well as the prohibition of a pure tone condition.

3.0 INSTRUMENTATION

All sound pressure level measurements were performed using a Larson Davis Model 831 Integrating Sound Level Meter (SLM). This instrument was field-calibrated using a Larson Davis CAL200 pistonphone calibrator prior to the survey. Both the SLM and the calibrator have been laboratory calibrated to NIST standards within the previous 12 months. A copy of the calibration certificates will be provided upon request.

The SLM was outfitted with a windscreen and was configured to sample noise levels for 60 second periods. Data was collected in overall A-weighted, C-weighted, and one-third octave band sound pressure levels (SPL) for the 60-second duration. Additionally, these three acoustic parameters were collected continuously at 20 millisecond intervals providing a time resolution of 0.02 seconds. The microphone was positioned on a tripod at a nominal height of five feet with a six-foot cable running to the SLM electronics. A photograph of the typical instrumentation configuration as used on-site is shown in Figure 1.

4.0 METHODOLOGY

This noise survey was performed in an attended manner by which the NCE engineer was present during all measurements. All measurements were taken serially by moving from location to location noted below in Section 4.1. The night of the survey was selected to be a night of appropriate wind conditions (above 10 mph) based on weather forecasts. The measurements were performed between the hours of 11pm and 2am to provide the lowest possible background noise. Neither the officials of the Town of Kingston nor the developer/operator of the three O'Donnell wind turbines had any advance notice of this noise survey.

4.1 Measurement Locations

The sound pressure level measurements were performed at four residential locations surrounding the turbine and one reference location. The reference location was chosen to be of similar distance to Route 3 as the residential locations but sufficiently distant from the turbines to ensure no contamination of ambient measurements. Table 1 provides a summary of the five measurement locations, distance to the nearest wind turbine, and the latitude/longitude. Figure 2 shows these five locations along with the locations of the three O'Donnell wind turbines and the single Town of Kingston owned wind turbine (for reference). Each residential measurement location is situated in proximity to at least two wind turbines.

TABLE 1: Noise Measurement Locations in Kingston, MA

SITE	DESCRIPTION	DISTANCE TO CLOSEST WIND TURBINE*	LATITUDE LONGITUDE
1	Resident – 28 Raboth Rd	Approx. 785 ft.	41° 58' 10.11" N 70° 43' 32.03" W
2	Resident – 44 Raboth Rd	Approx. 1,170 ft.	41° 58' 06.96" N 70° 43' 35.94" W
3	Resident – 299 Country Club Way	Approx. 1,675 ft.	41° 58' 34.31" N 70° 43' 52.46" W
4	Resident – 389 Country Club Way	Approx. 2,360 ft.	41° 58' 49.96" N 70° 43' 31.87" W
REF	Reference Location – Brooks Street & Elm Street	Approx. 5,870 ft.	41° 59' 18.73" N 70° 43' 07.57" W

* As determined using Google Earth. All distances are accurate within ±10 feet

4.2 Local Weather

Table 2 lists the hourly observed wind speed, wind direction, and temperature as measured at Plymouth Municipal Airport during the hours the noise measurements were performed. The airport is located in Plymouth, MA and is approximately four miles south of the measurement locations and is the closest location where detailed historical weather information is publicly available. It should also be noted that there were no measurements of wind shear (the difference between wind speeds at varying heights above the ground).

TABLE 2: Weather as Measured at Plymouth Municipal Airport

	10 PM	11 PM	12 AM	1 AM	2 AM	3 AM
	4/2/2013		*4/3/2013*			
Temperature (°F)	34	33	32	32	32	32
Wind Speed (mph)	12	10	8	12	13	16
Wind Direction	West	West	West	West	WSW	West

5.0 RESULTS

Three 60-second measurements were performed at each residential location and the reference location for multiple non-sequential visits throughout the testing period. Appendix A provides the detailed data including the time and SPL values for all of the measurements taken during this survey.

5.1 MADEP Broadband Regulation, Average Assessment

Table 3 presents the average of the measured L_{EQ} values for each location and compares the average measured L_{EQ} at the residential locations with the average L_{EQ} measured at the reference location. The presented values for the reference location are similarly an average of the multiple L_{EQ} values measured throughout the night. As the reference location was not influenced by any external transient noise during the measurement

period and the measurements were of short duration (60 seconds), the measured L_{EQ} was used instead of the L_{90} as the ambient noise metric. NCE reviewed the two metrics and the L_{90} was approximately 1 decibel lower.

Excesses to the MADEP regulation of the broadband limit were found at the two Raboth Road locations, Sites 1 & 2, with increases of 16 and 12 decibels over the ambient. Sites 3 & 4 also had significant increases over the ambient but lower than the MADEP threshold. These increases are calculated from the averaged data sets and are a nominal assessment of compliance. It should be noted that locations #1 and #2 were downwind of the turbines during the night of measurement. It is possible that with a change of wind direction, locations #3 and #4 would have similar results to those found at #1 and #2 below.

TABLE 3: Average Measured L_{EQ} for each Location and Reference/Background L_{EQ}, dB(A) relative to 20 µPa

SITE	DESCRIPTION	Average Operational SPL	Average Background SPL	dB above Background
1	Resident – 28 Raboth Road	48	32	+16
2	Resident – 44 Raboth Road	44		+12
3	Resident – 299 Country Club Way	39		+7
4	Resident – 389 Country Club Way	37		+5

5.2 MADEP Broadband Regulation, Worst Case Assessment

There has been much deliberation by the MADEP regarding what forms of data are used to compare wind turbine operational noise to ambient/background noise. A worst case assessment would come from subtracting the lowest of the background SPL data set from the highest of the operational SPL data set. This type of assessment was suggested by the MADEP in reference [7] except that it was recommended in terms of using the highest 1 hour data set that would have been obtained from a much longer evaluation. Table 4 provides the same data, but uses the maximum operational vs. the minimum background. In this case, three of the four locations exceed the broadband requirement with excesses to background from 13 to 22 decibels. It should be noted that location #4 is within 2 decibels of exceeding the MADEP regulation.

TABLE 4: Maximum Measured Operational L_{EQ} vs. Minimum Background L_{EQ} dB(A) relative to 20 µPa

SITE	DESCRIPTION	Maximum Operational SPL	Minimum Background SPL	dB above Background
1	Resident – 28 Raboth Road	51	29	+22
2	Resident – 44 Raboth Road	47		+18
3	Resident – 299 Country Club Way	42		+13
4	Resident – 389 Country Club Way	38		+9

5.3 MADEP Pure Tone Regulation

Graphs of the equivalent continuous (L_{EQ}) octave band SPL were plotted for each 60-second measurement event for each location. These data are provided in Figures 3 through 6. An examination clearly shows that there are no pure tones from the 31.5 to 8,000 hertz octave bands. It should be noted that this data does not go low enough in frequency to access infrasonic pure tones, nor does the MADEP require evaluation of infrasonic sound pressure levels.

5.4 Wind Turbine Acoustic Source Identification

As noted in Section 3, part of the 60-second data set included "time history" data with samples recorded every 20 millisecond (0.020 seconds). As noted in references [8] and [9], this data allows identification of the acoustic characteristic produced by wind turbines (i.e. the "woosh-woosh" sound) known as Aerodynamic Amplitude Modulation (AAM). NCE examined these data for all locations and found that the two locations closest to the wind turbine exhibited AAM as shown in Figures 7 and 8. NCE has determined that the AAM variations at both locations have a frequency of 0.7 to 1.0 Hertz (cycles/second) or period of 1 to 1.4 seconds[1]. This frequency and period is nominally the blade passage rate of the wind turbine. Appendix B provides a determination of the frequency and period from the measured data. The AAM is a striking characteristic or signature unique to wind turbines. Persistent evidence of AAM in a set of noise data is a reliable method for determining if a wind turbine is indeed the primary noise source.

An observation, made both onsite by the engineer and upon examination of the data, is that the AAM depth varied greatly with time as shown in Figure 9. Such variations can occur when two or more sources of sound have small variations in operating speed which results in the sources of sound reinforcing and canceling each other. This is a known effect within vibration and sound and is referred to as "beating". There is insufficient data to confirm the beating effect at this time. However, NCE believes this is a possible cause.

6.0 CONCULSIONS

Based on the above data, NCE concludes that the O'Donnell Wind Turbines are generating noise that is in excess of the MADEP broadband noise guideline. The nominal excesses are 12 to 16 decibels above the background and worst case excesses are 13 to 22 decibels above the background. These results are significantly above the MADEP regulation that only permits up to a 10 decibel increase. These results are not affected by the measurement accuracy of this Type 1 sound level meter, ±1½ dB and therefore, the results are uncontroverted. The data evaluated herein do not show any violation of the MADEP pure tone regulation.

[1] Frequency is equal to the reciprocal of the period, F = 1/T

REFERENCES

1. Nissenbaum, Michael A., Jeffery J. Aramini & Christopher D. Hanning, "Effects of industrial wind turbine noise on sleep and health, Noise & Health Journal, Volume 14, Issue 60, September-October 2012.
2. 11.Pedersen, Eja, "Health aspects associated with wind turbine noise – Results from three field studies", Noise Control Engineering Journal, Vol. 59, Issue 1, January - February 2012.
3. Commonwealth of Massachusetts Regulation, 310 CMR 7.10, Noise.
4. Commonwealth of Massachusetts, Executive Office of Environmental Affairs, Division of Air Quality Control, DAQC Policy #90-001, dated February 1, 1990.
5. Commonwealth of Massachusetts, Department of Environmental Protection, "Noise Guideline Document" , Produced by the Central Regional Office, Bureau of Waste Prevention, dated February 2003.
6. Town of Kingston, Massachusetts Zoning Bylaws, Revised November 1992 through April 2012.
7. Commonwealth of Massachusetts, Department of Environmental Protection, Letter to Town of Falmouth, Board of Health, "Falmouth BWP, Falmouth Wind Turbine Study" dated January 24, 2011.
8. Di Napoli, Carlo, "Wind turbine noise assessment in a small and quiet community in Finland", Noise Control Engineering Journal, Vol. 59, Issue 1, January-February 2011.
9. Leea, Seunghoon, Kyutae Kima, Wooyoung Choib and Soogab Leec, "Annoyance caused by amplitude modulation of wind turbine noise", Noise Control Engineering Journal, Vol. 59, Issue 1, January-February 2011.

FIGURE 1: Photograph of Larson Davis Model 831 on tripod during daytime (Typical configuration, photograph not taken at Kingston).

FIGURE 2: Aerial Map of Measurement and O'Donnell Wind Turbine Locations

*Wind direction noted by red arrows.

FIGURE 3: Octave band sound pressure level for all measurements at *Location #1: 28 Raboth Road*

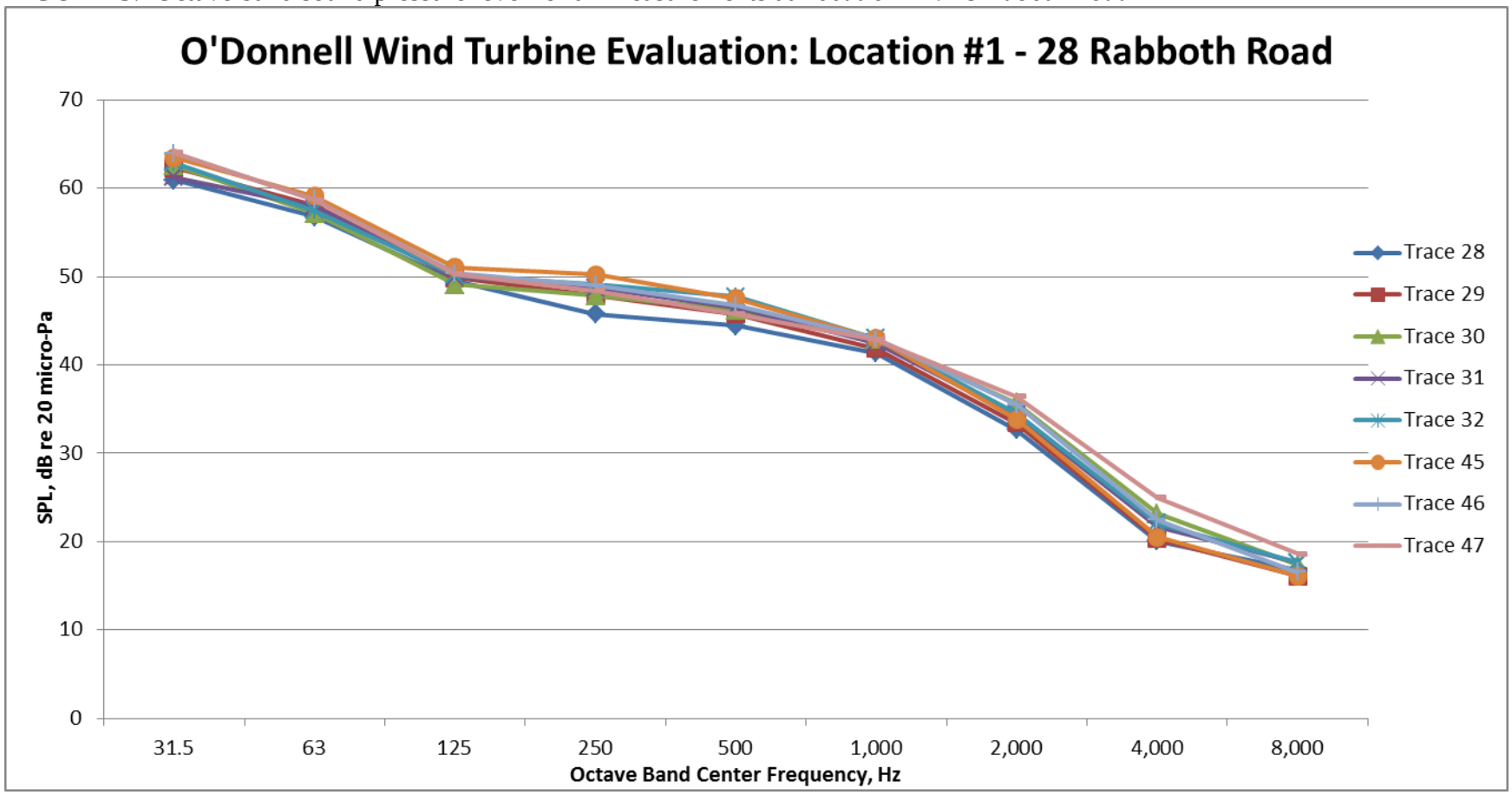


FIGURE 4: Octave band sound pressure level for all measurements at *Location #2: 44 Raboth Road*

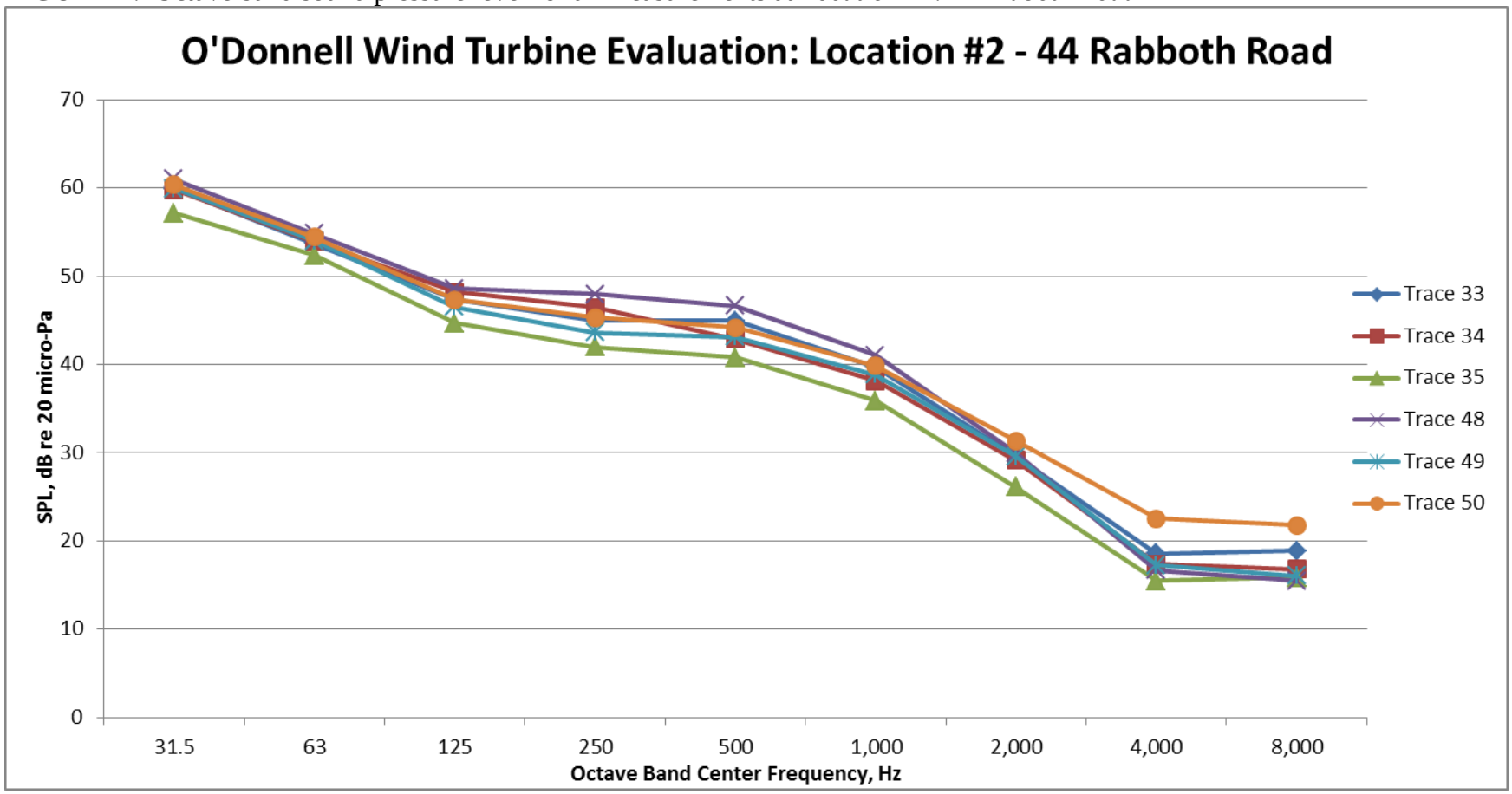


FIGURE 5: Octave band sound pressure level for all measurements at *Location #3: 229 Country Club Way*

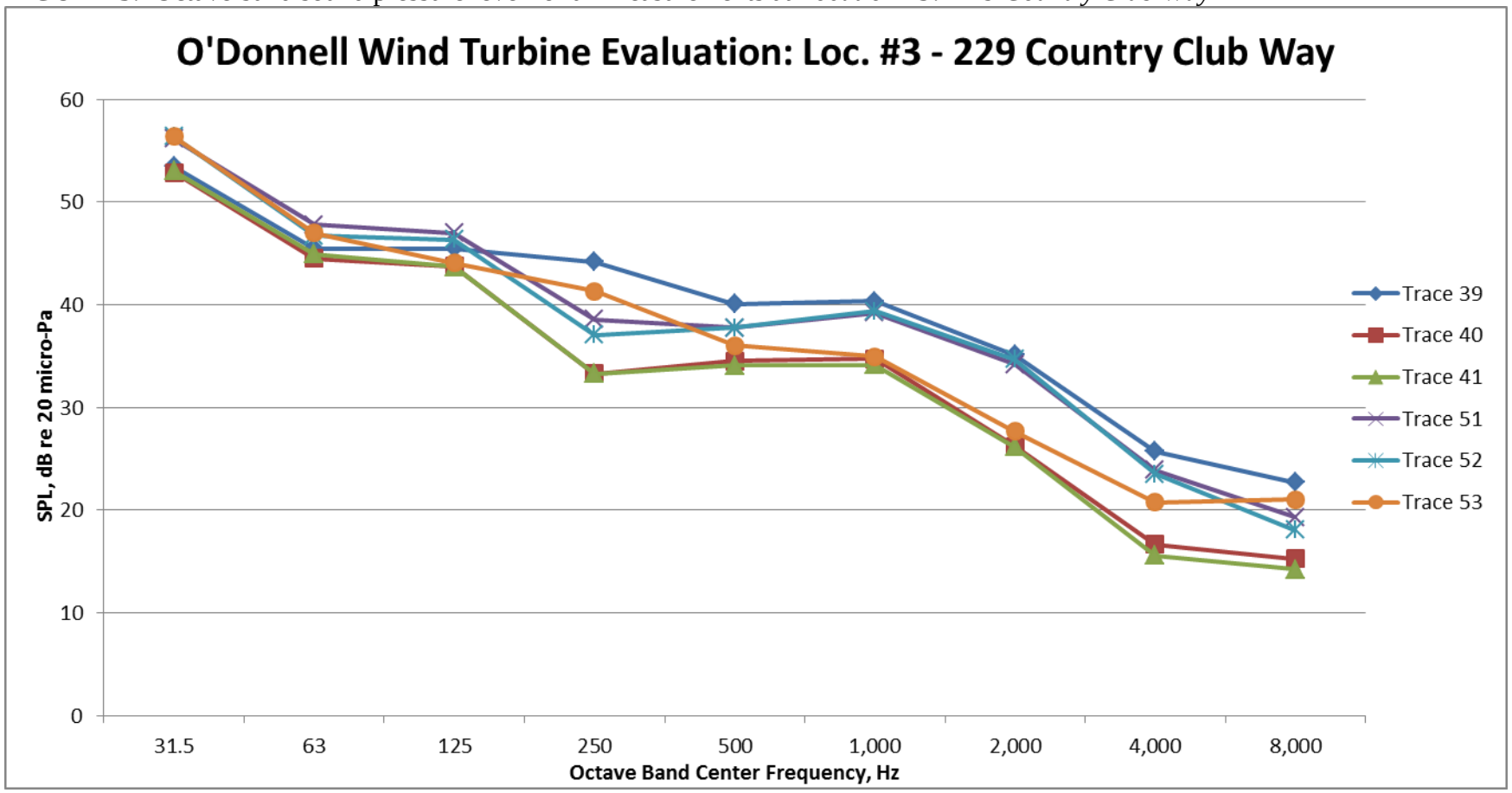


FIGURE 6: Octave band sound pressure level for all measurements at *Location #4: 389 Country Club Way*

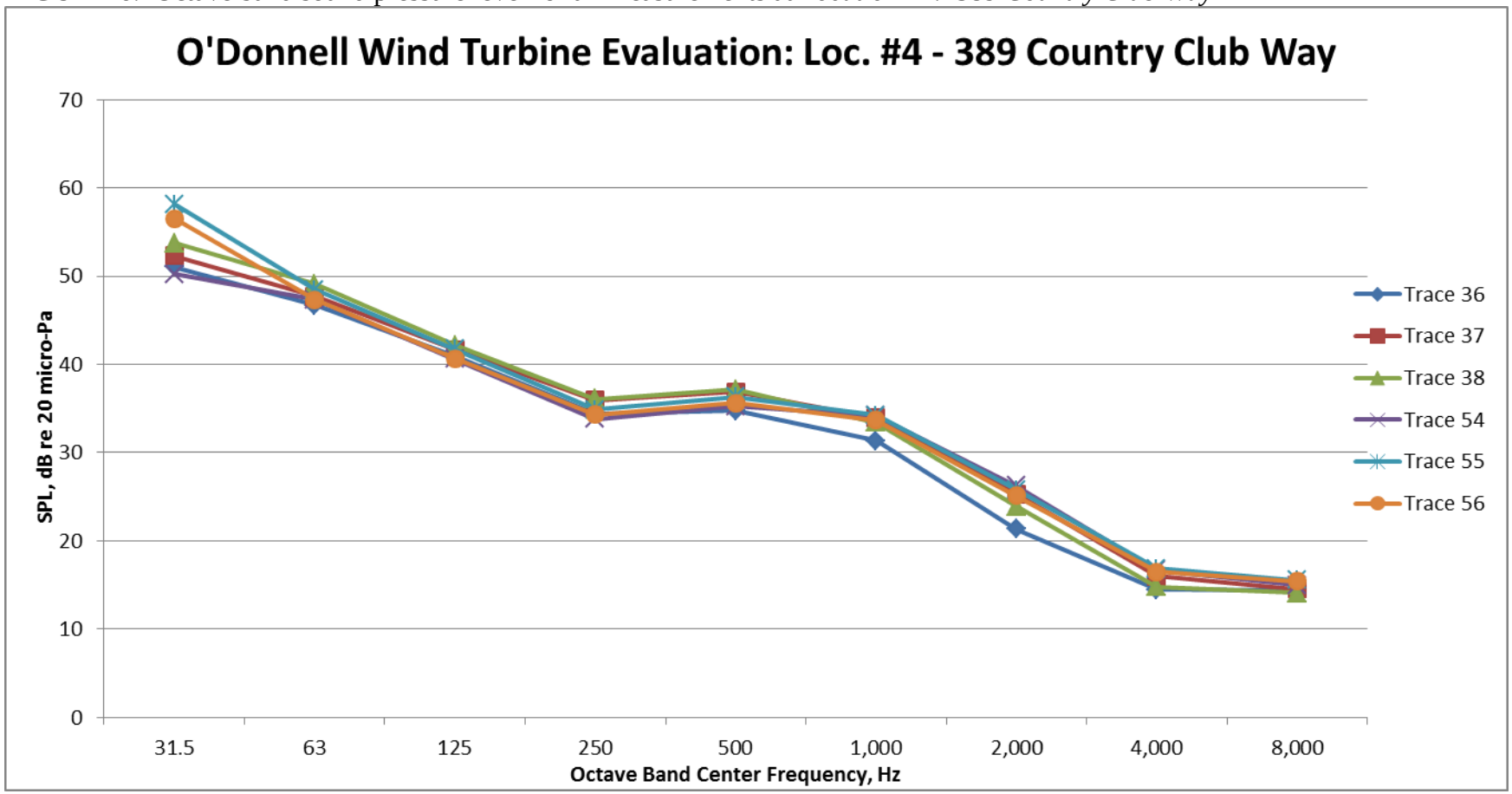


FIGURE 7: Time history data at location #1 vs. reference location

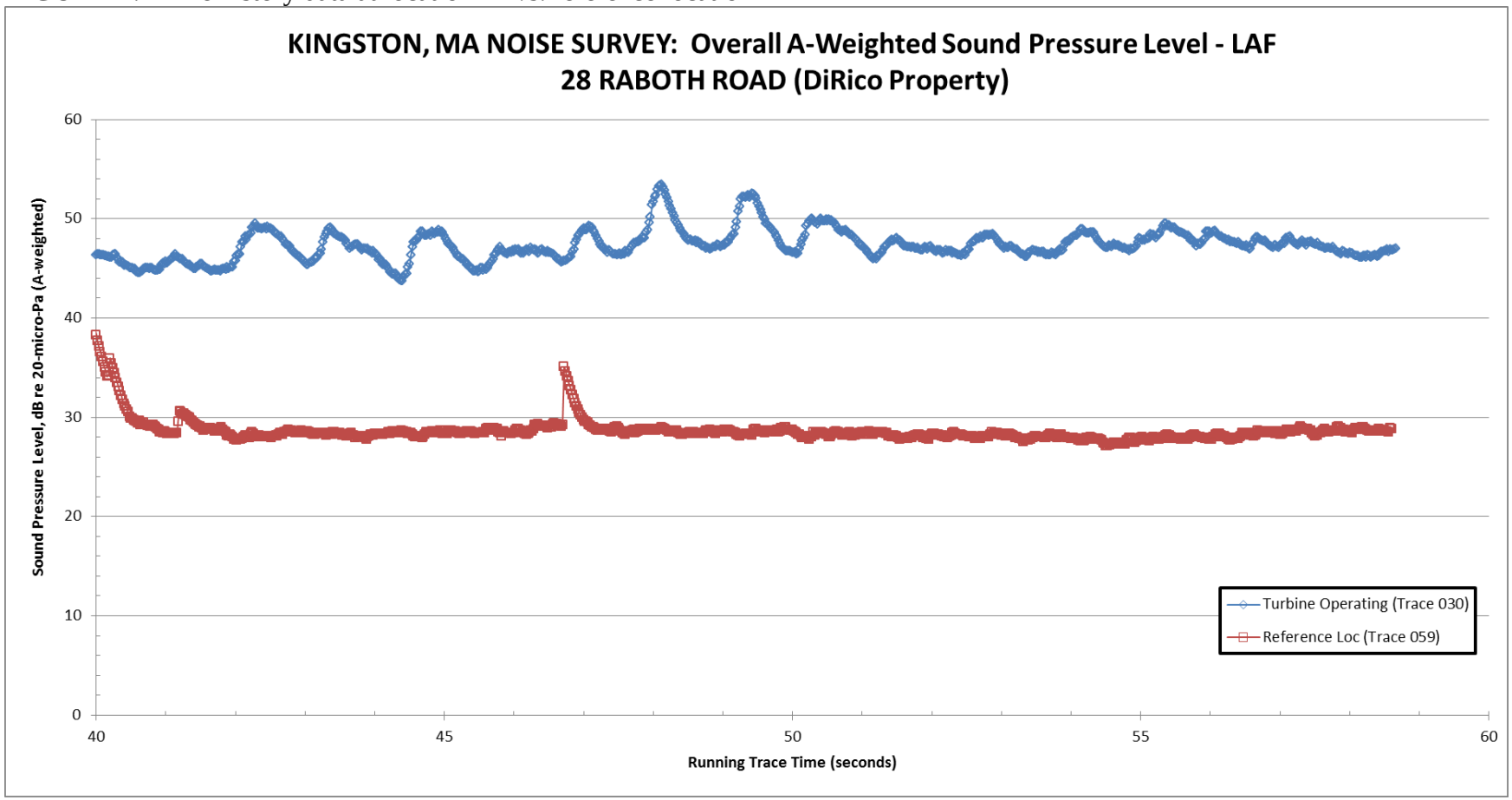


FIGURE 8: Time history data at location #2 vs. reference location

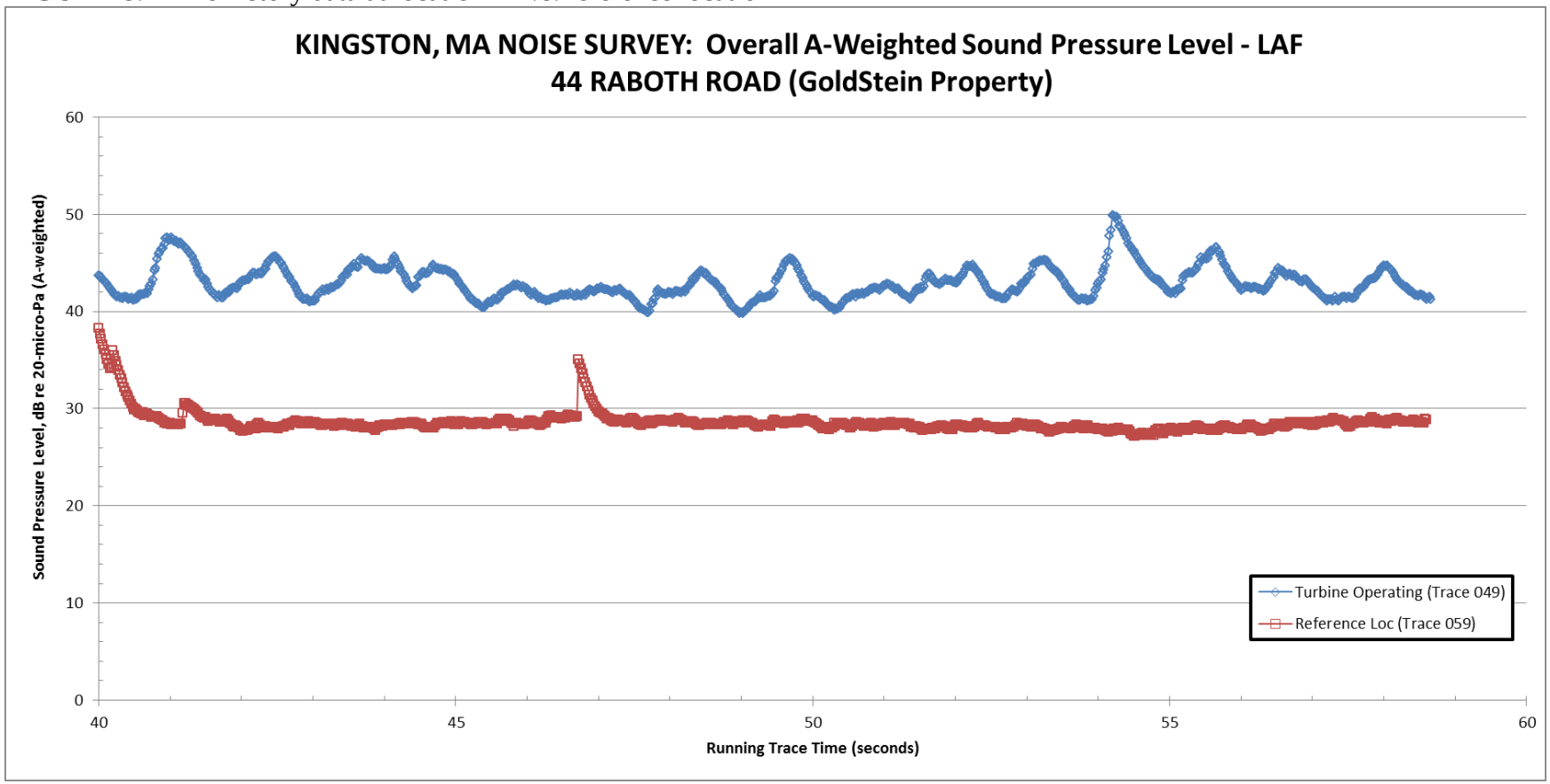
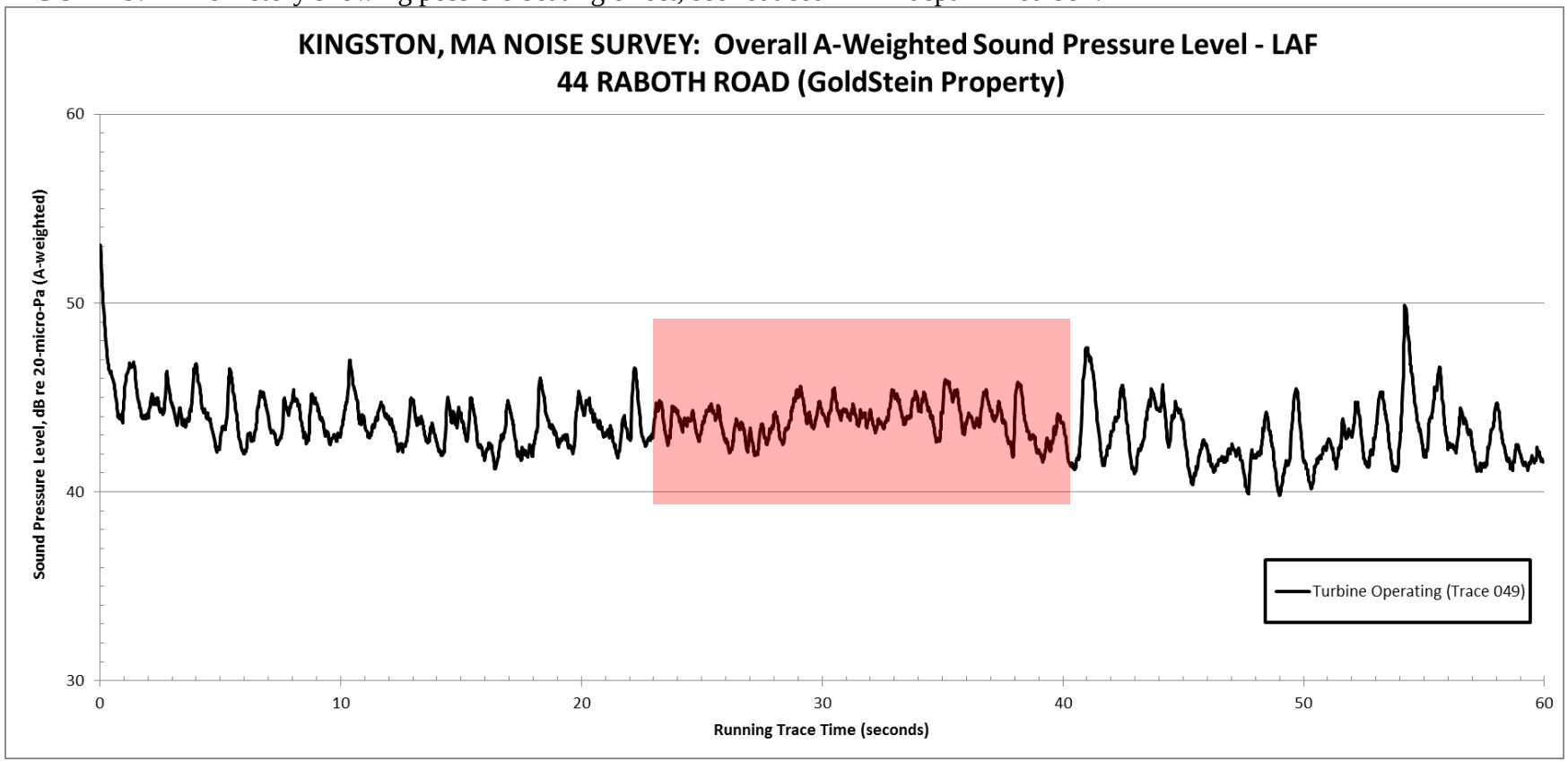


FIGURE 9: Time history showing possible beating effect, see reduced AAM depth in red box.



APPENDIX A

Detailed Survey Data;
Time & Sound Pressure Levels

TABLE A-1: Detailed Time & SPL Data Compilation

LD831 TRACE #	START DATE & TIME	LOC #	LOCATION	OVERALL LEQ, dB(A)	OCTAVE BAND DATA IN FIGURE	NOTES/COMMENTS
27	4/2/13 10:58 PM	n/a	SLM Calibration	94.0	n/a	Calibration
28	4/2/13 11:02 PM	1	28 Raboth Road	45.7	Figure 3	
29	4/2/13 11:04 PM	1	28 Raboth Road	46.8	Figure 3	
30	4/2/13 11:07 PM	1	28 Raboth Road	47.4	Figure 3	
31	4/2/13 11:09 PM	1	28 Raboth Road	47.4	Figure 3	
32	4/2/13 11:10 PM	1	28 Raboth Road	48.0	Figure 3	
33	4/2/13 11:21 PM	2	44 Raboth	44.9	Figure 4	
34	4/2/13 11:25 PM	2	44 Raboth	43.9	Figure 4	
35	4/2/13 11:26 PM	2	44 Raboth	41.3	Figure 4	
36	4/2/13 11:53 PM	4	389 Country Club	35.7	Figure 6	
37	4/2/13 11:54 PM	4	389 Country Club	37.9	Figure 6	
38	4/2/13 11:56 PM	4	389 Country Club	37.7	Figure 6	
39	4/3/13 12:08 AM	3	299 Country Club	43.8	Figure 5	Fan at adjacent house - data not used.
40	4/3/13 12:10 AM	3	299 Country Club	37.6	Figure 5	Fan at adjacent house off
41	4/3/13 12:12 AM	3	299 Country Club	37.2	Figure 5	Fan at adjacent house off
42	4/3/13 12:27 AM	Ref	Brooks & Elm Street	34.0	n/a	
43	4/3/13 12:29 AM	Ref	Brooks & Elm Street	32.8	n/a	
44	4/3/13 12:31 AM	Ref	Brooks & Elm Street	32.5	n/a	
45	4/3/13 12:48 AM	1	28 Raboth Road	48.3	Figure 3	
46	4/3/13 12:50 AM	1	28 Raboth Road	47.8	Figure 3	
47	4/3/13 12:52 AM	1	28 Raboth Road	47.5	Figure 3	
48	4/3/13 12:59 AM	2	44 Raboth Road	46.7	Figure 4	
49	4/3/13 1:00 AM	2	44 Raboth Road	43.7	Figure 4	
50	4/3/13 1:01 AM	2	44 Raboth Road	44.9	Figure 4	
51	4/3/13 1:25 AM	3	299 Country Club	42.4	Figure 5	Fan at adjacent house off
52	4/3/13 1:26 AM	3	299 Country Club	42.4	Figure 5	Fan at adjacent house off
53	4/3/13 1:27 AM	3	299 Country Club	39.2	Figure 5	Fan at adjacent house off
54	4/3/13 1:35 AM	4	389 Country Club	37.4	Figure 6	
55	4/3/13 1:37 AM	4	389 Country Club	37.9	Figure 6	
56	4/3/13 1:38 AM	4	389 Country Club	37.2	Figure 6	
57	4/3/13 1:46 AM	Ref	Brooks & Elm Street	31.4	n/a	
58	4/3/13 1:47 AM	Ref	Brooks & Elm Street	30.7	n/a	
59	4/3/13 1:48 AM	Ref	Brooks & Elm Street	28.7	n/a	
60	4/3/13 1:59 AM	n/a	Train Station	44.3	n/a	
61	4/3/13 2:12 AM	1	28 Raboth Road	48.9	Figure 3	
62	4/3/13 2:13 AM	1	28 Raboth Road	48.5	Figure 3	
63	4/3/13 2:14 AM	1	28 Raboth Road	50.5	Figure 3	
64	4/3/13 2:16 AM	1	28 Raboth Road	49.5	Figure 3	
65	4/3/13 2:19 AM	n/a	SLM Calibration	93.8	n/a	Calibration

APPENDIX B

Time History Frequency/Period
Determination

AAM Frequency Calculation for 28 Raboth Road based on Trace 30

Sample	Time at Peak, s	Period, s	Frequency, Hz
1	11.42		
	12.64	1.22	0.82
	13.68	1.04	0.96
	14.84	1.16	0.86
	16.00	1.16	0.86
2	42.28		
	43.34	1.06	0.94
	44.66	1.32	0.76
	45.8	1.14	0.88
	46.98	1.18	0.85
	48.1	1.12	0.89
	Min	1.04	0.76
	Max	1.32	0.96
	Average	**1.16**	**0.87**

AAM Frequency Calculation for 44 Raboth Road based on Trace 49

Sample	Time at Peak, s	Period, s	Frequency, Hz
1	2.76		
	3.96	1.2	0.83
	5.40	1.44	0.69
	6.68	1.28	0.78
	7.64	0.96	1.04
2	44.68		
	45.80	1.12	0.89
	47.04	1.24	0.81
	48.44	1.4	0.71
	49.68	1.24	0.81
	51.04	1.36	0.74
	Min	1.04	0.69
	Max	1.36	0.96
	Average	**1.25**	**0.81**