Washington State Department of Transportation

Memorandum

March 14, 2019

TO: Mark Norman

FROM: Jim Laughlin (206) 440-4643

SUBJECT: Keechelus Lake Underwater Background Sound Measurement Results – Technical Memorandum.

Underwater Noise Levels

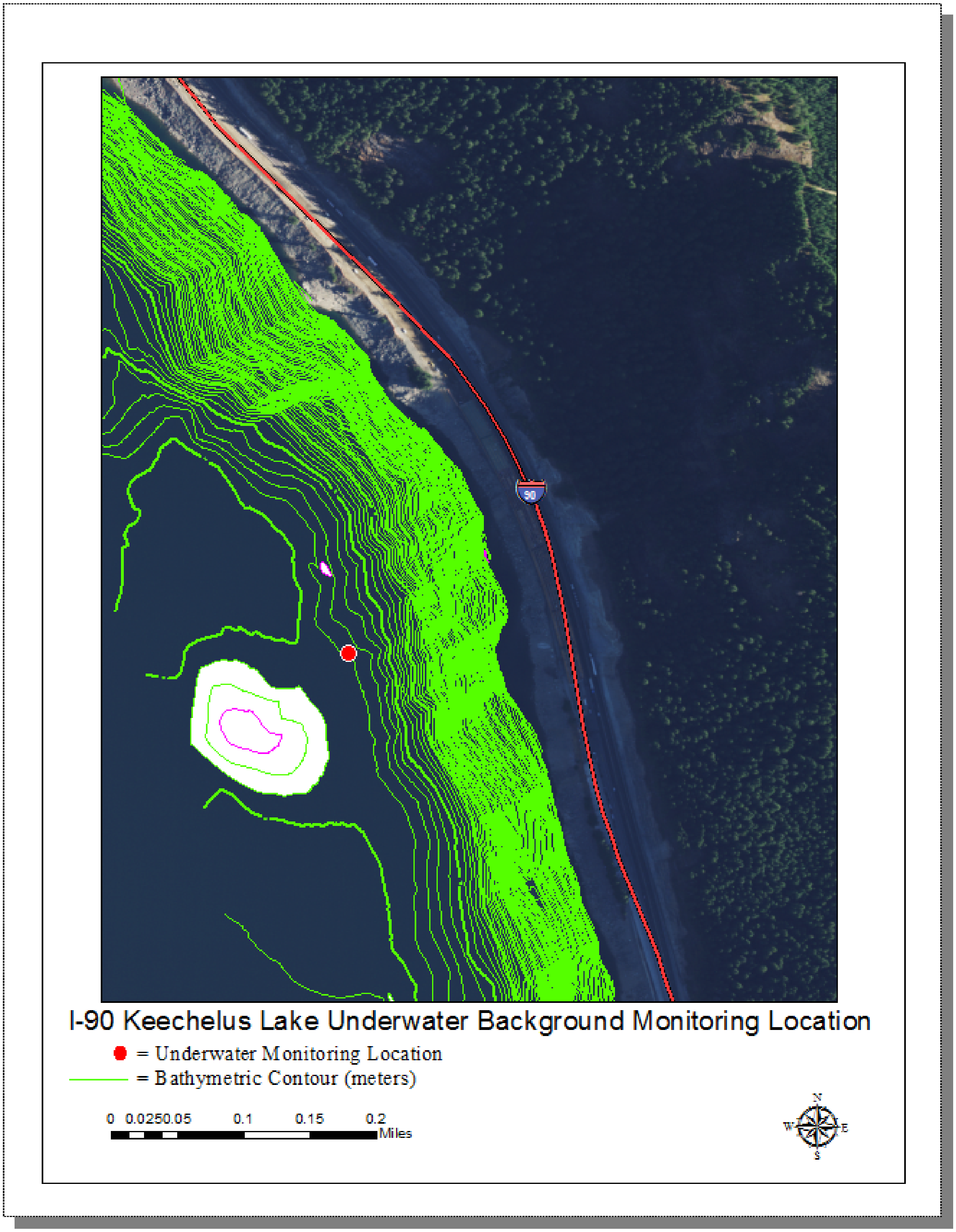
This memo summarizes the background sound levels measured in Keechelus Lake in an effort to determine site specific underwater background sound levels. Three days of data were collected between July 18, 2016 and July 21, 2016 in Keechelus Lake (Figure 1). Three full 24-hour cycles (e.g., 6AM to 6AM) were analyzed as part of this report from 9:54 AM on Monday July 18th through 10:54 AM on Thursday July 21st. Given the small size, rural location of the lake, and relatively infrequent boat usage on Keechelus Lake the dominant noise source in the lake during this recording period was rock drilling generating sound through the rock and into the lake.

No frequency weighting (*e.g.*, A-weighting or C-weighting) was applied to the underwater acoustic measurements presented in this report. Underwater sound levels quoted in this report are given in decibels relative to the standard underwater acoustic reference pressure of 1 micro Pascal.

One hydrophone was deployed with the Autonomous Multichannel Acoustic Recorder (AMAR) approximately 10 feet from the bottom and 1,600 feet from the eastern shore of the lake. The water depth was 226 feet where the AMAR was deployed. The AMAR had a nylon sleeve or 'sock' over the cage which protects the hydrophone. The sock protects the hydrophone from any potential flow noise that could become an issue at current speeds above 1 meter per second. The current frequency range for the AMAR is 20 Hz to 20 kHz.

Broadband, 20 Hz to 20 kHz, 30-second Root Mean Square (RMS) noise levels were calculated for each 30-seconds recorded with a 50% overlap window during the three 24-hour continuous recordings that were analyzed as part of this report.

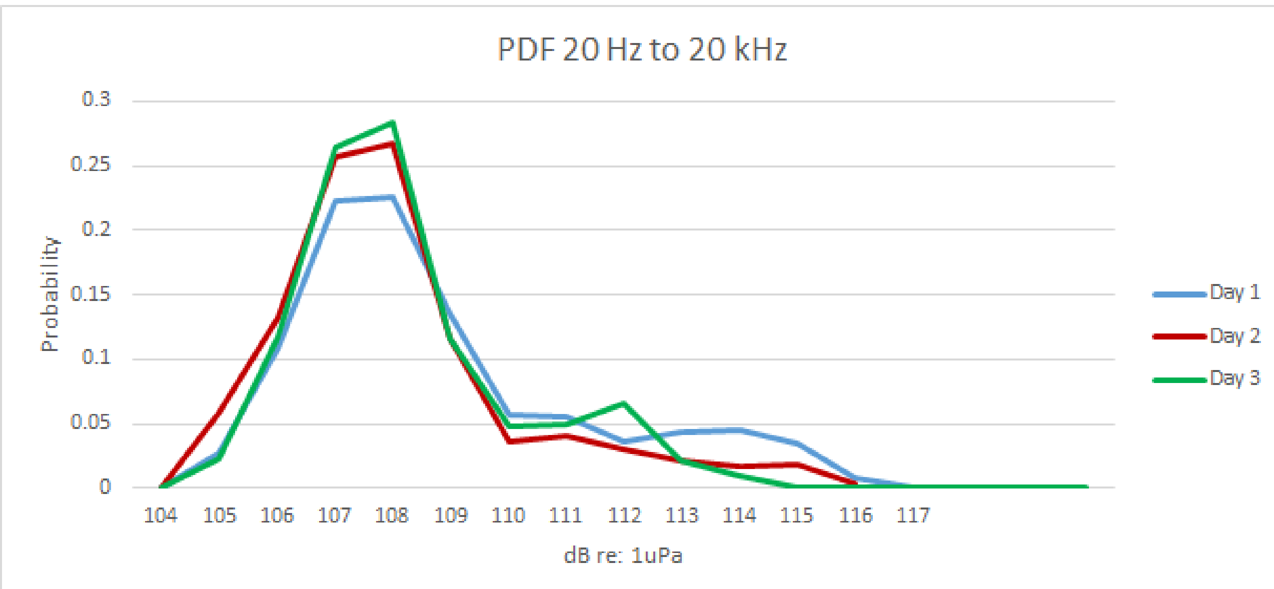
Figure 1: Location of the Autonomous Multichannel Acoustic Recorder (AMAR) deployment at Keechelus Lake (white areas indicate small underwater hills).



Keechelus Lake is a freshwater lake, therefore, it was unnecessary to analyze functional hearing groups using the marine mammal weighting functions associated with pinnipeds and cetaceans. The 50th percentile from the CDF plot reflects the average background sound level in Keechelus Lake.

Background noise levels during the daytime are relatively quiet and primarily consist of occasional rain events and small outboard motorboats and during this recording rock drilling north of I-90. Root Mean Square (RMS) background noise levels are reported in terms of the 30-second average continuous sound level and have been computed from the Fourier transform of pressure waveforms in 30-second time intervals. The distribution of the data is approximately log-normal however there is some variability in the daily distributions of the data (Figure 2).

Figure 2: Probability Density Function (PDF) for the 20 Hz to 20 kHz analysis on a daily (24-hr) basis.

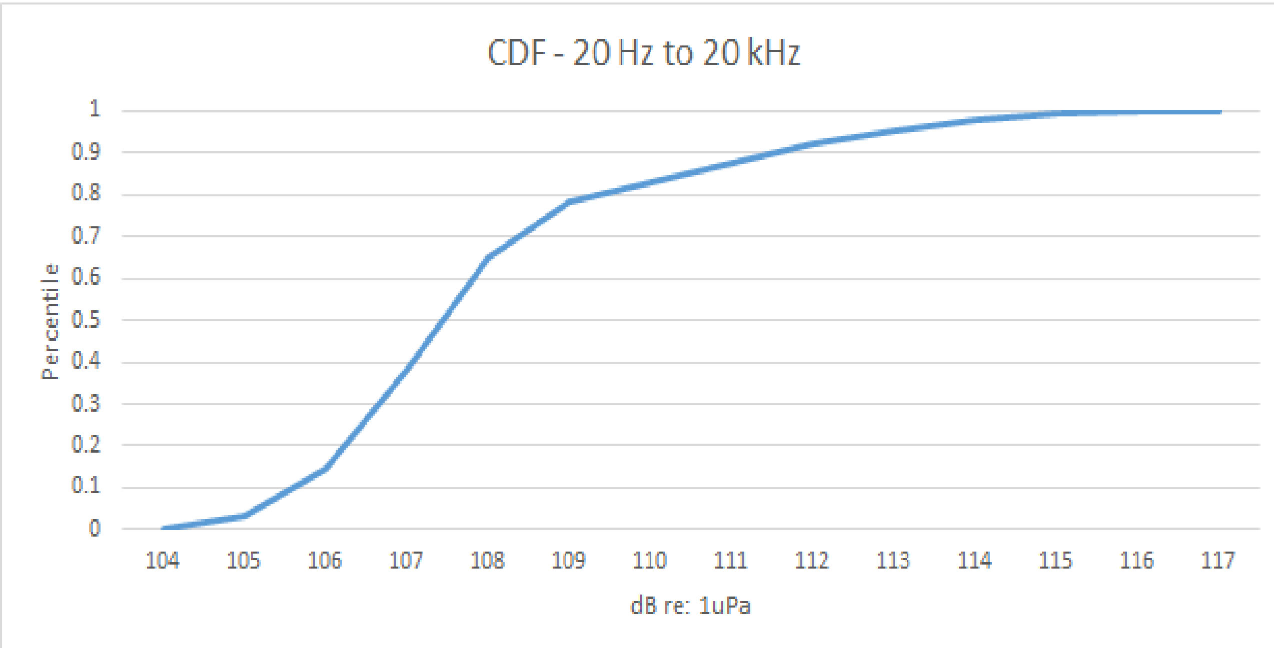


Once it was determined that the data was approximately log-normally distributed, the data for all three days were then plotted as a Cumulative Distribution Function following the 2009 NOAA guidance on analyzing background sound levels. A CDF plot for the full frequency range is shown in Figure 3. The figure shows the typical sigmoid or 'S' shape. The overall average background sound level is approximated with the 50th percentile on the plot.

The background sound levels for all frequencies measured between 20 Hz and 20 kHz ranged between 104 dB and 119 dB with the 50th percentile occurring at 107 dB (Figure 3). The overall average background sound levels are summarized in Table 1.

This is roughly consistent with other studies conducted in freshwater habitats. Wysocki et al., 2007 measured underwater sound levels in Lake Lunz (Pleschinger See) in Austria to be 79 dB. They found that in general freshwater habitats where there little or no water movement have background sound levels that are less than 100 dB.

Figure 3: Cumulative Distribution Function (CDF) for the 20 Hz to 20 kHz analysis for all three days.



The PDF and CDF were also analyzed separately for measurements recorded during the daytime hours only (between 6:00 AM and 6:00 PM) and are shown in Figures 4 and 5. The PDF values during the daytime are generally higher than the 24-hour PDF values.

Figure 4: Probability Density Function (PDF) for the 20 Hz to 20 kHz analysis on a daytime only basis.

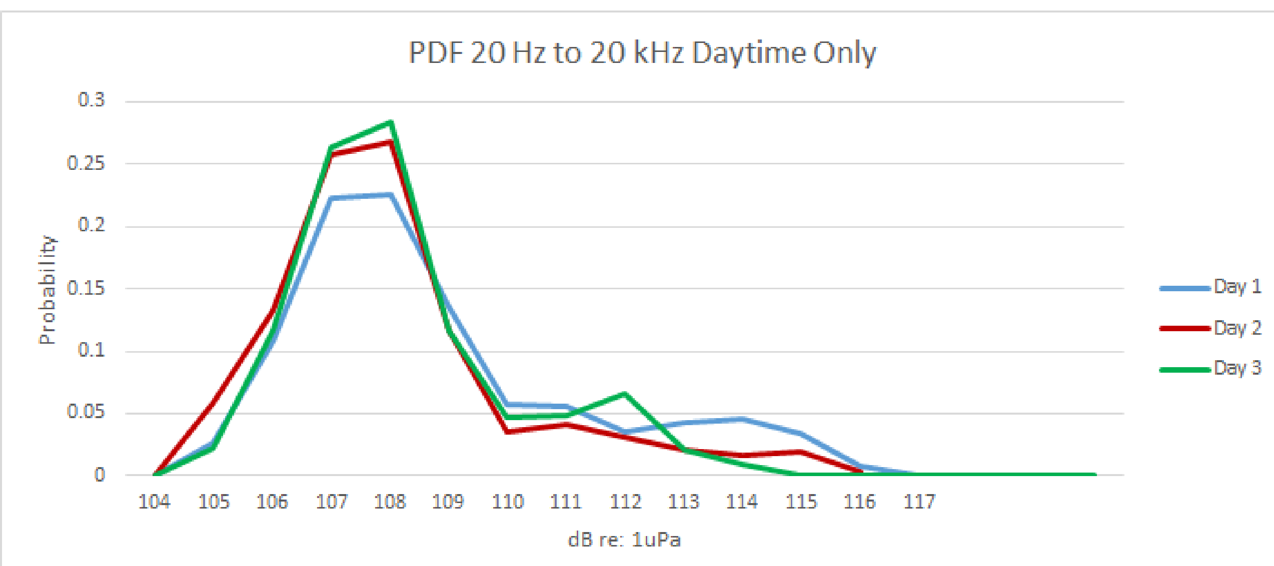
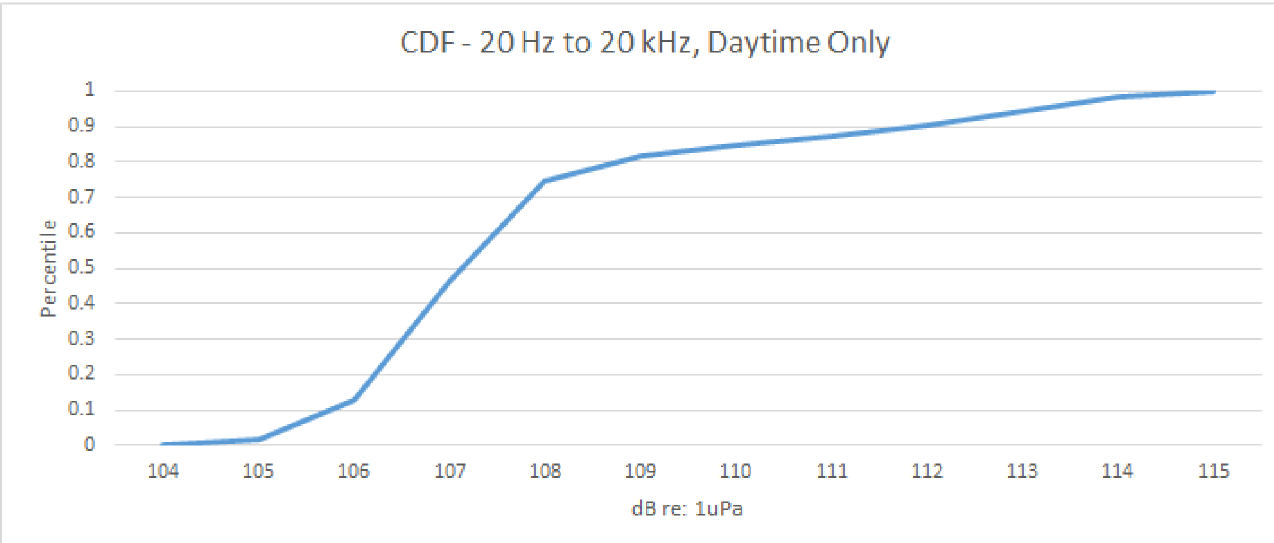


Figure 5: Cumulative Distribution Function (CDF) for the 20 Hz to 20 kHz analysis for all three days during daytime hours only.



The background sound levels for all frequencies measured between 20 Hz and 20 kHz for daytime ranged between 104 dB and 119 dB with the 50th percentile occurring at 107 dB (Figure 5). The overall average background sound levels are summarized in Table 1. During daytime hours, rock drilling at the nearby construction immediately north of I-90 can be heard in the underwater recordings.

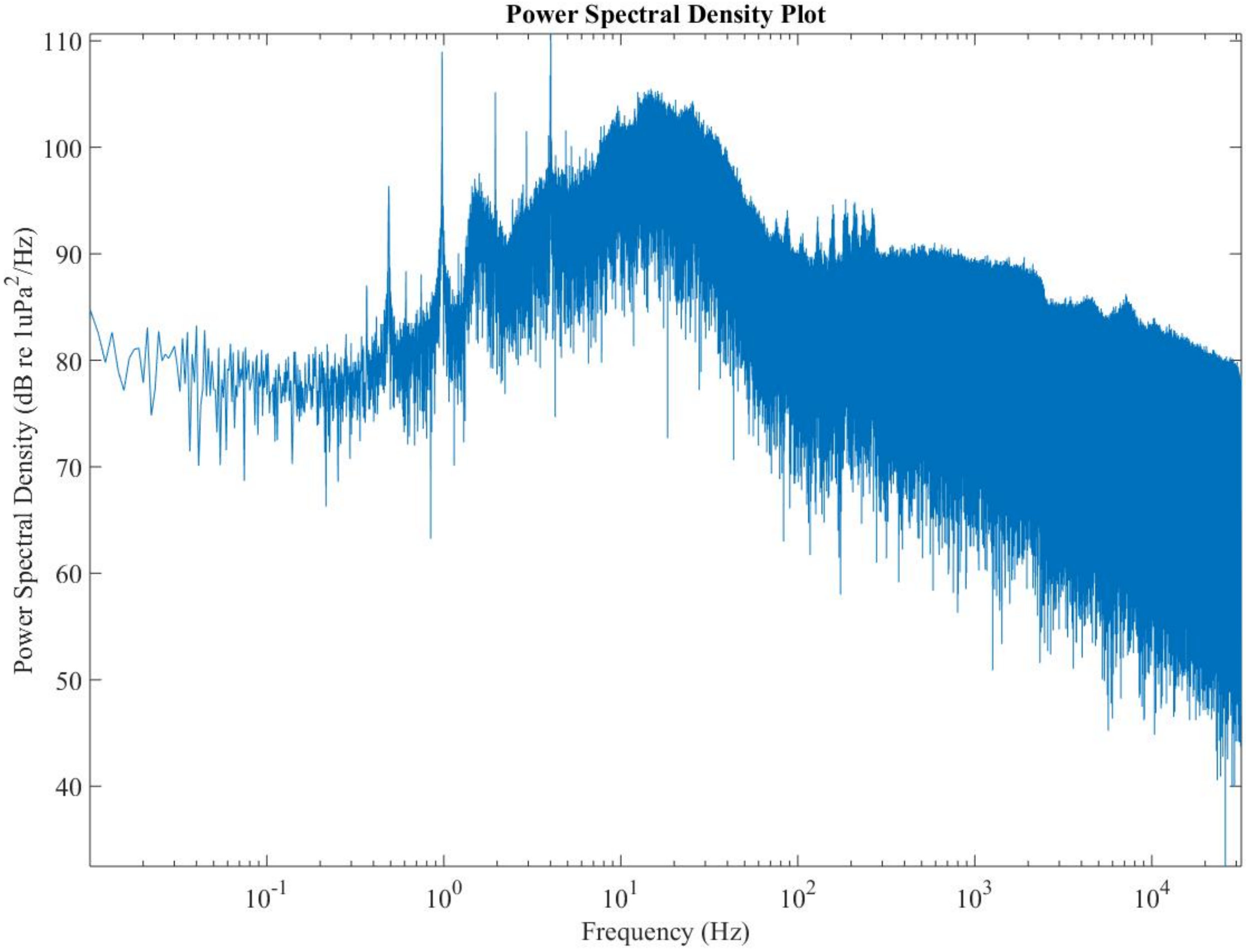
Table 1: Summary table of average overall underwater background noise levels (CDF 50th percentile) in Keechelus Lake.

Period	50% Cumulative Density Function (CDF)
72-hour	107 dB
Daytime Only	107 dB

The data were plotted using a Fast Fourier Transformation (FFT) for this report to evaluate the frequency distribution of the background noise levels (Figure 6). A Fourier analysis converts a signal from its original domain (typically time or space) to a representation in the frequency domain and vice versa. FFT provides a more detailed look at the frequency distribution of the signal.

Figure 6 shows that there was a peak in the signal between approximately 12 kHz and 15 kHz. This peak is produced by the rock drilling occurring during the daytime hours to drill holes to place the explosives.

Figure 6: FFT analysis of the broadband 20 Hz to 20 kHz frequencies for the 72-hour period in Keechelus Lake.



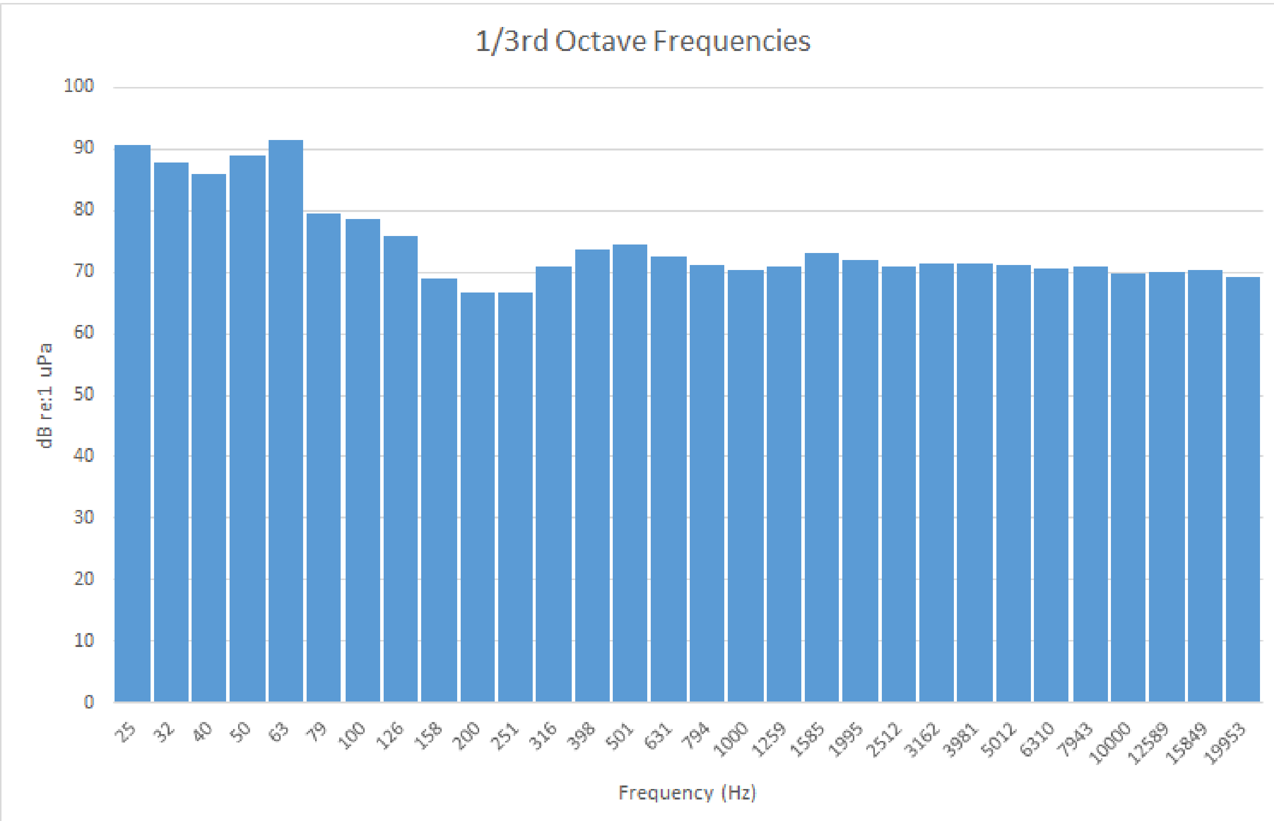
The data were also plotted in 1/3-octave bands for the entire 72-hour recording analyzed for this report to evaluate the frequency distribution of the background noise levels. One-third octave band analysis offers a more convenient way to look at the composition of the sound and is an improvement over the spectral density plots. One-third octave bands are frequency bands whose upper limit in hertz is $2^{1/3}$ (1.26) times the lower limit. The width of a given band is 23% of its center frequency. For example, the 1/3-octave band centered at 100 Hz extends from 89 to 112 Hz, whereas the band centered at 1000 Hz extends from 890 to 1120 Hz. The 1/3-octave band level is calculated by integrating the spectral densities between the band frequency limits. Conversion to decibels is

= 10*LOG (sum of squared pressures in the band)

Sound levels are often presented in 1/3-octave bands because the effective filter bandwidth of hearing systems is roughly proportional to frequency and often about 1/3-octave. In other words, a fish's perception of a sound at a given frequency will be strongly affected by other sounds within a 1/3-octave band around that frequency. The overall level (summing all frequencies) of a broadband sound exceeds the level in any single 1/3-octave band.

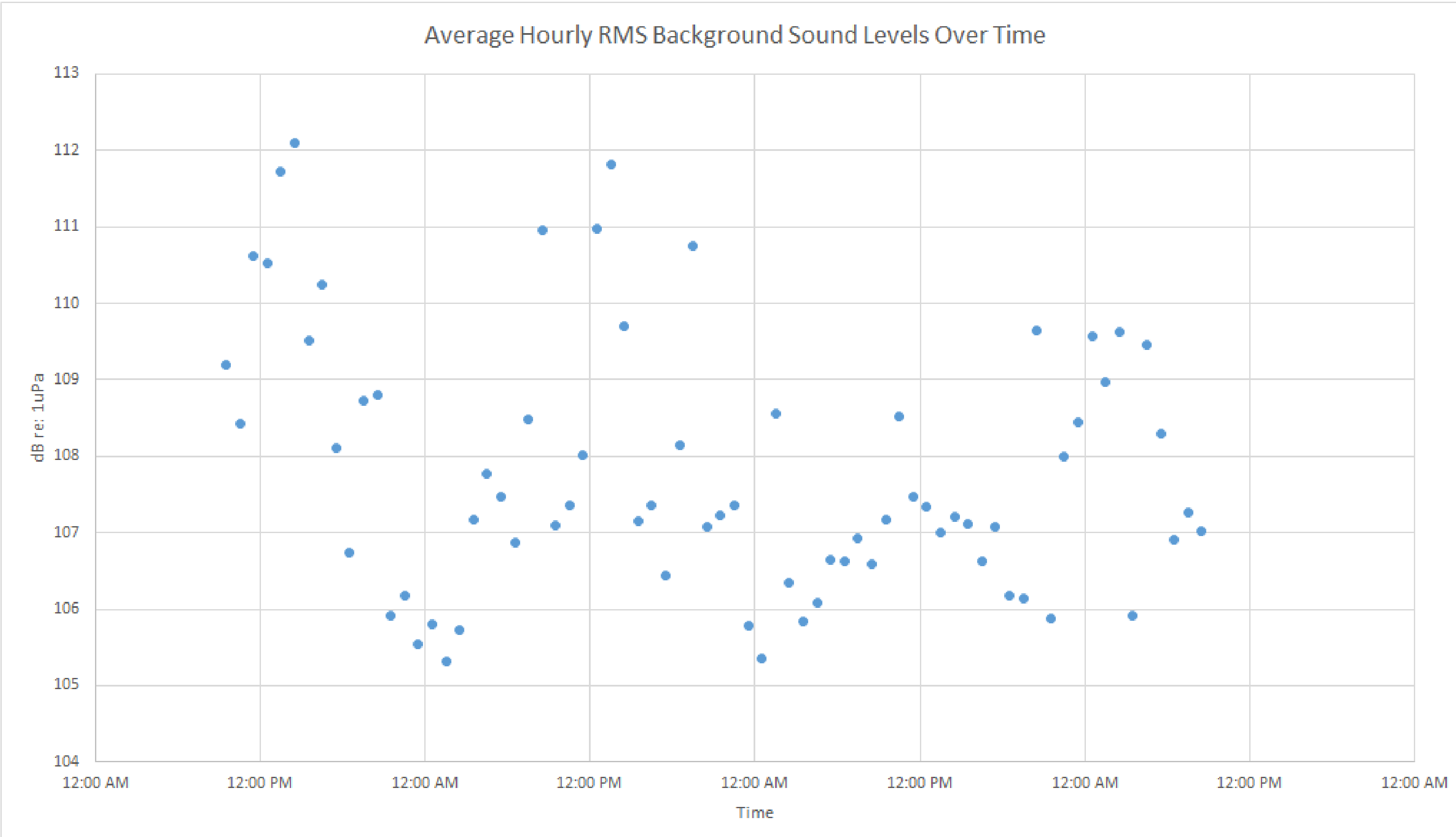
Figure 7 shows the overall 1/3-octave bands for the entire 72-hour recording analyzed for this report. The figure shows some low frequency peaks at about 63 Hz and below which are likely from wind and rain effects (Nystuen, 1996; Nystuen and Farmer, 1989).

Figure 7: 1/3rd octave analysis of the broadband 20 Hz to 20 kHz frequencies for the 72-hour period in Keechelus Lake.



The 30-second RMS data used in this analysis were averaged on an hourly basis and plotted over time (Figure 8). Figure 8 shows that there are daily peaks at 2 PM on the first day, 3 PM on the second day and 3 AM on the third day with the lowest sound levels recorded over this period at 3 AM on the first day, 1 AM on the second day and 11 PM on the third day. The peak sound levels at 3 AM on the third day were the result of a distant boat motoring around the lake at that time. Due to the low background sound levels in the lake this stood out as a high value. The sound levels measured during the early morning hours appear to be slightly less variable than the rest of the day which is probably due to sporadic construction activities in the area during the daytime hours.

Figure 8: Average hourly background sound levels measured for a 72-hour period in Keechelus Lake including frequencies between 20 Hz and 20 kHz.



Conclusions

The overall average background sound levels in Keechelus Lake over a three-day period were estimated to be 107 dB for both day and night combined and 107 dB for the daytime only for the frequency range 20 Hz to 20 kHz.

If you have any questions, please call me at (206) 440-4643.

Sincerely,

Jim Laughlin
Manager, Air Quality, Noise and Energy

References:

Nystuen, Jeffrey A. & David M. Farmer 1989. Precipitation in the Canadian Atlantic storms program: Measurements of the acoustic signature, Atmosphere-Ocean, 27:1, 237-257, DOI: 10.1080/07055900.1989.9649335

Nystuen, Jeffery A., 1996. Acoustical Rainfall Analysis: Rainfall Drop Size Distribution Using the Underwater Sound Field. Journal of Atmospheric and Oceanic Technology, Volume 13.

Wysocki, Lidia Eva, Sonja Amoser, and Friedrich Ladich, 2007. Diversity in Ambient Noise in European Freshwater Habitats: Noise Levels, Spectral Profiles, and Impact on Fishes. J. Acoust. Soc. Am., 121(5).