Washington State Department of Transportation

Memorandum

October 25, 2010

TO: Hans Prudom
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FROM: Jim Laughlin
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SUBJECT: Manette Bridge Vibratory Pile Driving Noise Measurements - Technical Memorandum.

Underwater Noise Levels

This memo summarizes the vibratory pile driving results measured at the Manette Bridge in an effort to determine site specific underwater noise levels and the boundary of the zone of influence for marine mammals. Data was collected during vibratory pile driving at the Manette Bridge during the month of August 2010.

Two 24-inch diameter steel piles were driven with a vibratory hammer, however, due to an equipment malfunction the second pile was not recorded at the near field position. 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.

The continuous sounds that frequently occur for extended periods associated with the use of a vibratory hammer may produce a harassment-level take of ESA listed marine mammals.
This harassment occurs when the sound exceeds the current 120 dB RMS NMFS threshold. Therefore, this memo adopts the 120 dB RMS threshold for the present analysis.

Measurement Locations

- Near field measurements were collected 10 meters from the pile in 12 feet of water on August 4th, 2010 (Figure 1). The hydrophone depth was 6 feet.
- One hydrophone deployed from the Autonomous Multichannel Acoustic Recorder (AMAR) approximately 10 feet from the bottom and 791 meters from the pile measured the far field sound levels over a 50.5 hour period. The hydrophone depth was 20 feet.

No noise mitigation was utilized as part of these vibratory measurements. Broadband (20 Hz to 10 kHz) Root Mean Square (RMS) noise levels and high pass filtered (1 kHz to 10 kHz) RMS noise levels are reported in terms of the 30-second average RMS continuous sound level computed from the Fourier transform of the pressure waveforms in 30-second time intervals.

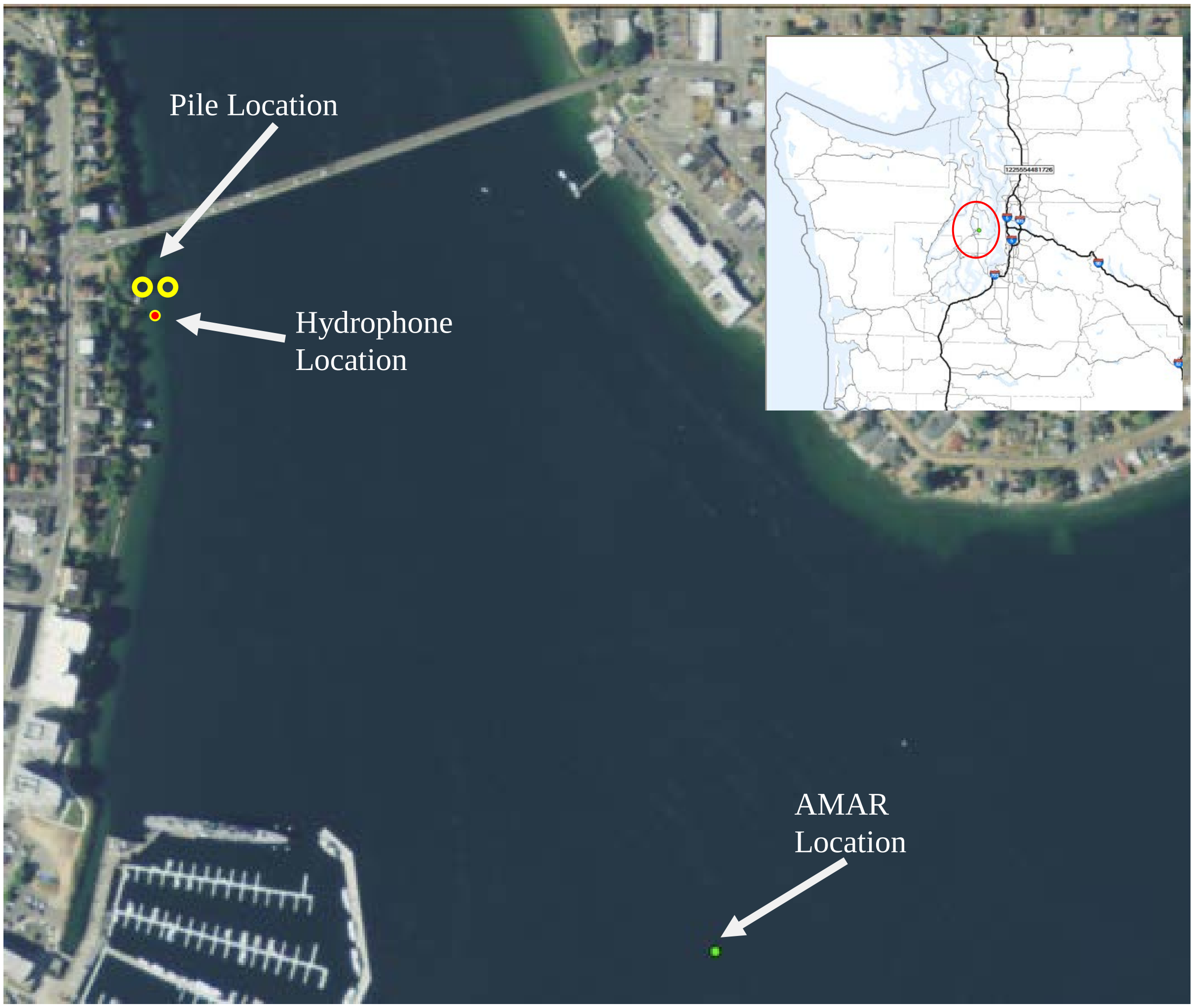

Figure 1: Approximate locations of near field and far field (AMAR) monitoring locations at the Manette Bridge. ○ = Approximate pile location

Near Field Measurements

Three 24-inch piles were driven with a vibratory hammer the day before and the morning before the arrival of the analysts to record underwater noise levels at the near field location. Therefore, the piles measured at the near field location are numbered Pile 4 and 5. There was also a sixth pile driven after the analysts left the site. There was an equipment malfunction during the recording of sound levels from pile 5 and so the data was lost at the near field location. Average broadband RMS values ranged from 141 to 173 dB RMS at the near field location with an overall average RMS value of 166 dB RMS (Table 1). The same data was analyzed using a high pass filter which removes all of the frequencies below 1 kHz.

The data was plotted in 1/3-octave bands (Figure 2). 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 for 1/3-octave bands because the effective filter bandwidth of mammalian hearing systems is roughly proportional to frequency and often about 1/3-octave. In other words a mammal'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.

The elimination of the frequencies below 1 kHz was done to approximate only those sound levels that most marine mammals can hear underwater as their lower threshold does not go beyond 1 kHz in most cases. Typical marine mammal hearing range extends well past our 10 kHz upper limit of the equipment although their sensitivity to noise at the higher frequencies diminishes with increasing frequencies. So we do not know how much these additional higher frequencies might add to the overall sound levels but it is thought that it is not a substantial amount (Dahl, pers. Comm., 2010).

Table 1: Summary Table of Broadband and High Pass Filtered Underwater Monitoring Results at the Near Field Location.

Pile	Date	Hydrophone Depth (feet)	Distance To Pile (meters)	Average RMS Value (dB)	High Pass Filtered Average RMS Value (dB)
4	8/4/10	6	10	166	158
5	8/4/10	6	10	N/A	N/A

N/A – Data not collected for this pile due to equipment malfunction.

Average RMS values calculated for this high pass filtered data ranged from 130 to 166 dB RMS at the near field location with an overall average RMS value of 158 dB RMS (Table 1). There is an eight decibel difference between the broadband and the high pass filtered data. Average RMS values are appropriate for continuous sounds generated during vibratory driving. The dominant frequency at the near field location is at 25 Hz with a secondary peak at 500 Hz. This agrees with similar results that Burgess and Blackwell (2003) have reported.

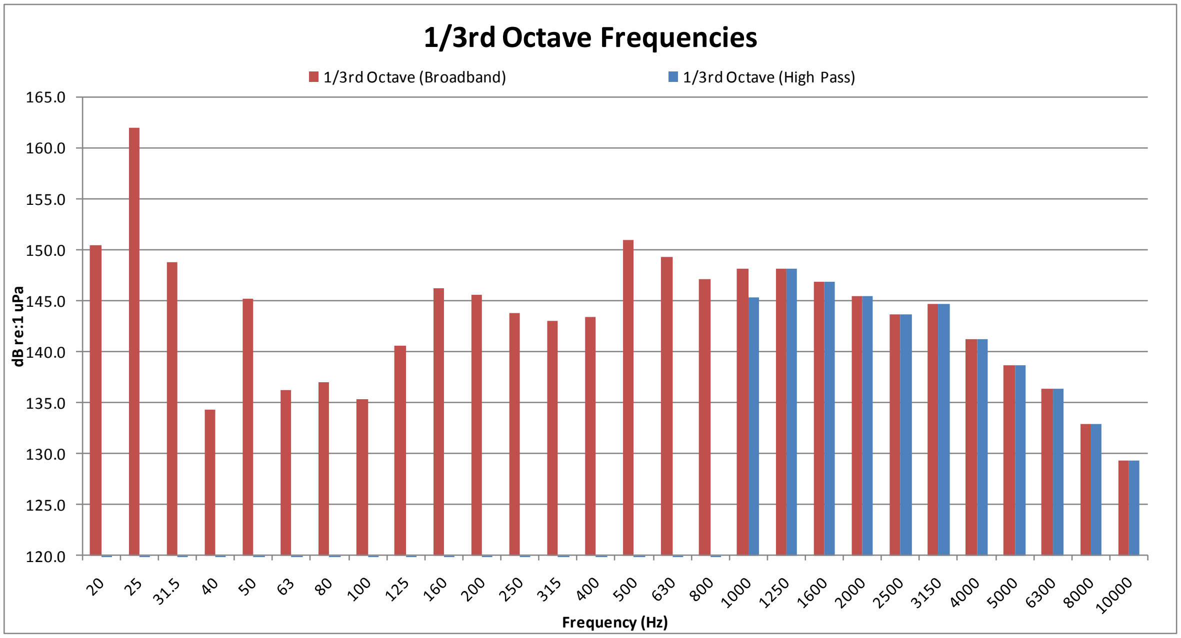

Figure 2: 1/3rd octave analysis of the broadband versus the high pass filtered data.

AMAR Far Field Measurements

In addition to the near field noise measurements, analysts measured far field sound levels at distances of 791 meters (AMAR deployment location, Figure 1) using an Autonomous Multi-Channel Acoustic Recorder (AMAR mini) from Jasco Research Ltd. in Canada. WSDOT is using the AMAR to determine the accuracy of the estimated range of impacts to marine mammals according to the NMFS underwater threshold of 120 dB RMS. WSDOT is concerned that the practical spreading model used by NMFS is overly conservative and hopes to use site specific information collected with the AMAR to develop a more appropriate model (e.g. spherical or cylindrical). It is hoped that for some WSDOT projects the AMAR will allow a fine tuning of the threshold boundary during the very early stages of future projects.

The AMAR was also able to collect background data at the 971 meter location when vibratory pile driving was not being performed.

Average broadband RMS values at the far field location ranged from 140 to 160 dB RMS with an overall average RMS value of 154 dB RMS (Table 2). The same data was analyzed using a high pass filter which removes all of the frequencies below 1 kHz (Figure 2).

Table 2: Summary Table of Underwater Monitoring Results at the Far Field Location.

Pile	Date	Hydrophone Depth[1] (feet)	Distance To Pile (meters)	Average RMS Value (dB)	Transmission Loss[2] (dB)	High Pass Filtered Average RMS Value (dB)	High Pass Transmission Loss[2] (dB)
1	8/3/10	20	791	152	14	147	11
2	8/3/10	20	791	158	8	150	8
3	8/3/10	20	791	160	6	157	1
4	8/4/10	20	791	140	26	125	33
5	8/4/10	20	791	152	14	148	10
6	8/4/10	20	791	149	17	135	23
			Overall Average:	**154**	**14**	**148**	**14**

[1] – Depth represents depth as measured from the surface. In all locations the hydrophone was deployed approximately 13 feet above the bottom.

[2] – Transmission loss based on single near field average RMS value measured for Pile 4. Transmission loss is a complicated function of local bathymetry, sound-speed profile, range, source frequency, absorption, and scattering (Medwin and Clay, 1998). However, if it is possible to measure both the source and received sound pressure levels, the equation below may be used to calculate the transmission loss (Carr et al., 2006).

$TL_{dB} = SL_{dB} - RL_{dB}$; where SL_{dB} is the measured source level and RL_{dB} is the measured received level

The dominant frequencies at the far field location are between 100 and 400 Hz with a secondary peak at 3150 Hz (Figure 3).

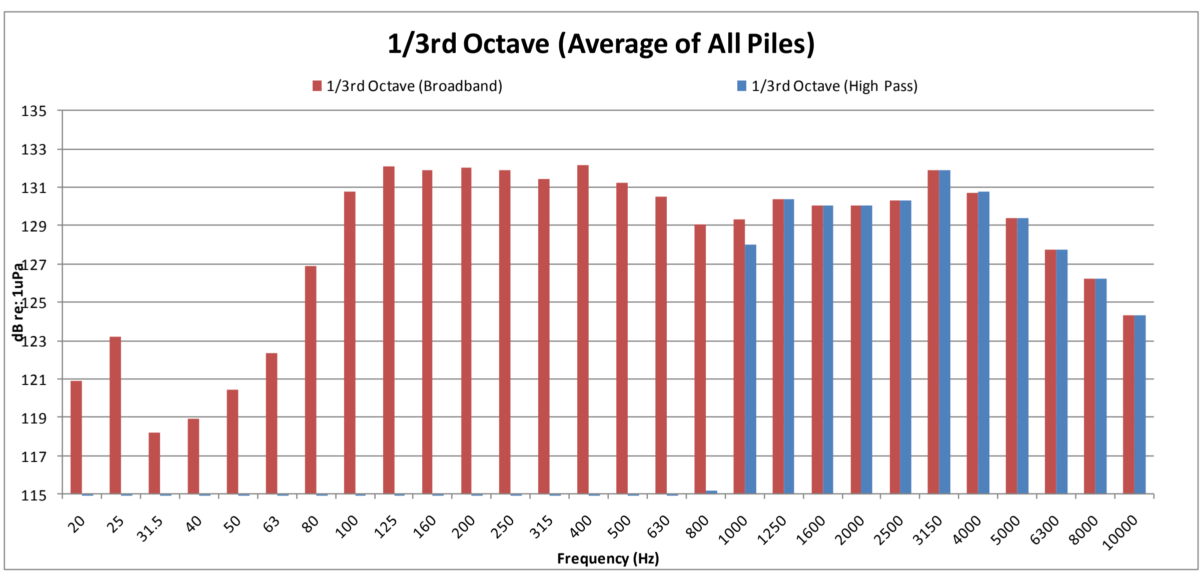

Figure 3: 1/3rd octave analysis of the broadband versus the high pass filtered data averaged for all 6 piles.

Based on the results of Table 3 WSDOT proposes that the Practical spreading model most closely fits the vibratory data for the Manette Bridge project, WSDOT proposes the use of the conservative practical spreading model for the Manette Bridge project. With the exception of the Cylindrical model the models under predict the measured values. This is likely due to the relatively gently sloping bottom near the Manette Bridge. The slope in the study area near the Manette Bridge is only 0.4 degrees slope.

Table 3: Comparison of different spreading models using actual measured data.

Spreading Model	Distance From Pile (meters)	Pile #	Transmission Loss[1]	Meters To Measured dB RMS	Miles To Measured dB RMS	Measured Distance at 131 dB RMS (miles)
Practical	10	1	14	86	.05	0.5
		2	8	34	.02	0.5
		3	6	25	.02	0.5
		4	**26**	**541**	**.34**	**0.5**
		5	14	86	.05	0.5
		6	17	136	.08	0.5
				Average	**0.09**	
Spherical	10	1	14	50	.03	0.5
		2	8	25	.02	0.5
		3	6	20	.01	0.5
		4	**26**	**200**	**.12**	**0.5**
		5	14	50	.03	0.5
		6	17	71	.04	0.5
				Average	**0.04**	
Cylindrical	10	1	14	251	.16	0.5
		2	8	63	.04	0.5
		3	6	40	.02	0.5
		4	**26**	**3981**	**2.47**	**0.5**
		5	14	251	0.16	0.5
		6	17	501	0.31	0.5
				Average	**0.53**	

[1] - $TL_{dB} = SL_{dB} - RL_{dB}$; where SL_{dB} is the measured source level and RL_{dB} is the measured received level. Pile 4 is bolded to show that it is the only dataset that has two points measured simultaneously and which correlates reasonably well with the three models. The other pile data is compared to the near field measurement at Pile 4 and indicates the need for two simultaneous measurements.

Comparison of Near Field and Far Field Underwater Measurements

Figure 4 shows the relative differences between the near field 1/3rd Octave frequency values and with and without the high pass filter applied. Figure 4 compares the broadband measurements of the 1/3rd Octave frequency distribution for the near and far field locations for Pile 4 only. At the far field location the center frequency bands follow roughly the same pattern as the near field measurements but at lower amplitude by about 10 dB overall. The dominant frequencies range between approximately 125 Hz and 250 Hz. It also appears that some of the lower frequencies below 100 Hz and higher frequencies above 500 Hz may be attenuating faster. It is generally understood that higher frequencies will attenuate faster than lower frequencies. However, the lower frequencies will not propagate in water depths that are less than one quarter of their wavelength (Urick, 1983). The water depth at the pile was 12 feet and the water depth at the far field location was 30 feet.

$$\text{Wavelength} = \frac{1500 \text{ m/s}}{40 \text{ Hz}} = 37.5 \text{ meters}$$

$$\text{Water Depth} = \frac{\text{Wavelength}}{4} = \frac{37.5 \text{ meters}}{4} = 9.4 \text{ meters or } 30.8 \text{ feet}$$

Therefore, the frequencies less than about 40 Hz will not propagate in water depths that are less than 30 feet deep. Figure 4 indicates that those frequencies are not propagating to the far field site. Some frequencies between 40 Hz and 100 Hz are not propagating through the water near the pile but will transmit through the sediment and into the deeper water though will attenuate faster through the sediment.

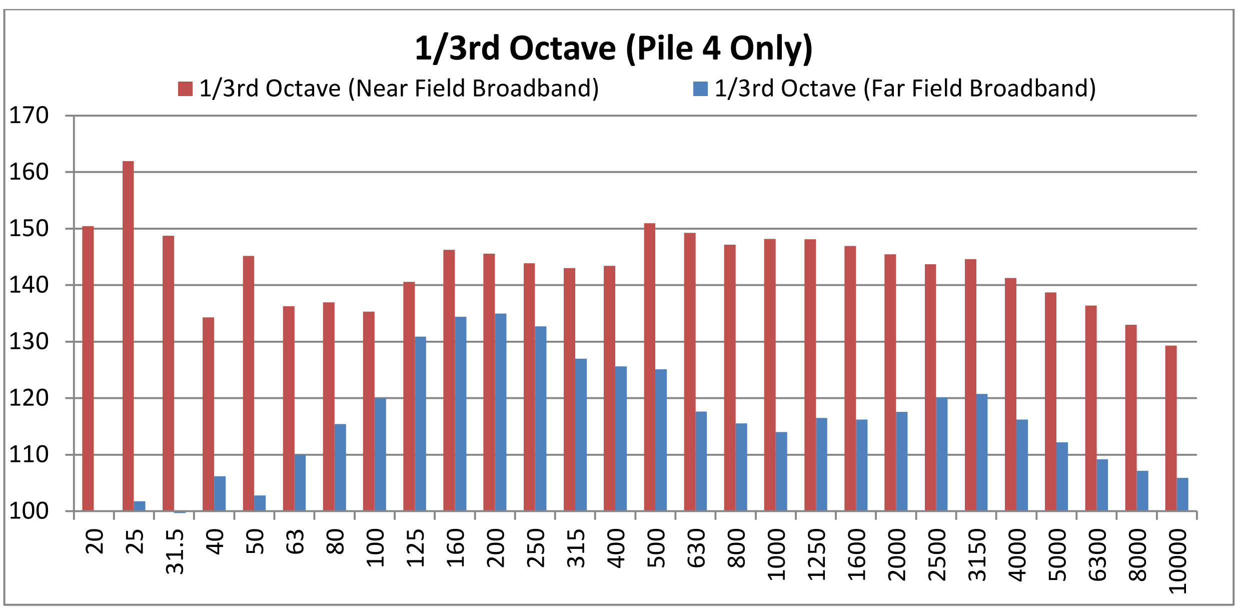

Figure 4: 1/3rd octave analysis of the broadband near field versus far field data for Pile 4 only.

AMAR Background Measurements

Background measurements between 2 Hz and 10 kHz were collected on August 2nd through August 4th, 2010 when there was no vibratory pile driving occurring over a period of 50.5 hours (Figure 5) between 9:37 AM on August 2nd through 11:37 AM on August 4th, 2010. As can be seen in Figure 5 there was an early morning rise in the background sound levels between about 2 AM and 4 AM. It was a very low frequency hum in the recording for these hours. Without more information it is assumed that this was due to the tidal current in the area.

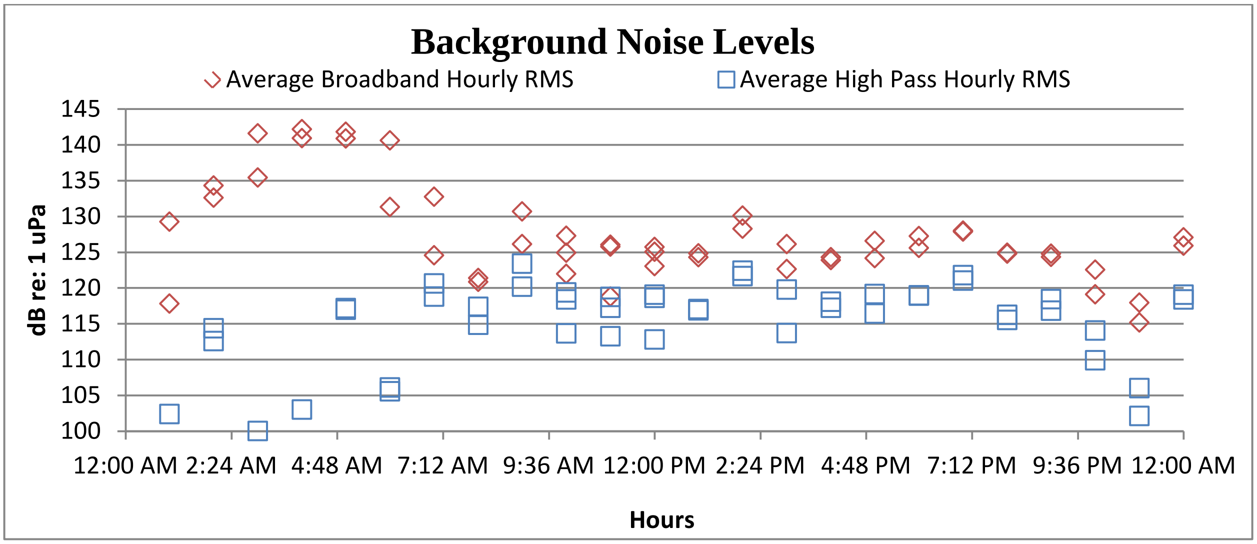

Figure 5: Hourly average RMS values with and without the high pass filter applied.

Figure 6 shows the comparison of the 3:00 AM low frequency recordings compared to more normal recordings at 3:00 PM. There was a high tide of 10.6 feet at 10:17 PM in the evening of August 2nd and a low tide of 1.3 feet at 5:25 AM on August 3rd. Almost the same scenario occurred in the evening of August 3rd and morning of August 4th except shifted almost one hour later. It is unclear whether this low frequency 'hum' was coming from turbulence around the hydrophone or from some other source.

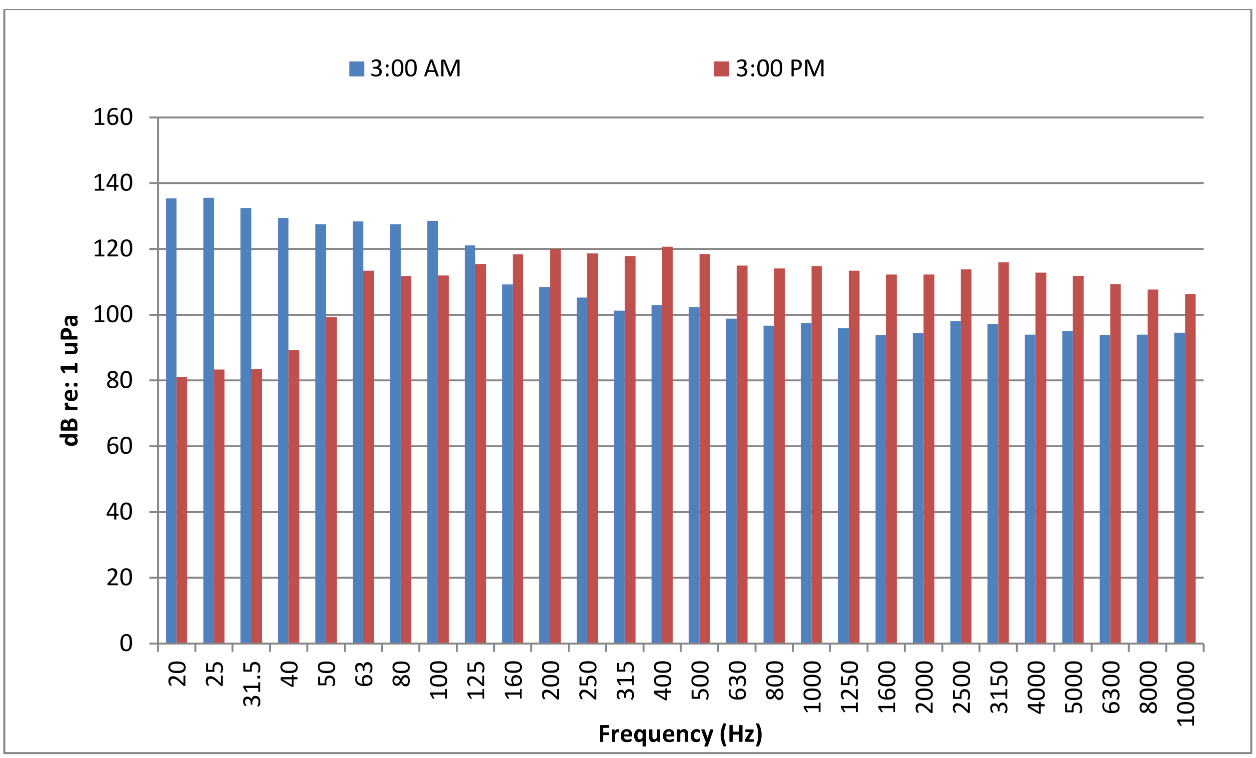

Figure 6: 1/3rd octave analysis of the broadband levels comparing 3:00 AM vs. 3:00 PM.

Background noise levels during the daytime are dominated by the presence of ferry traffic and frequent outboard motorboats. 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. Background levels were measured at 791 meters from the piles using the AMAR system which has a more sensitive hydrophone.

Following the 2009 NMFS guidance on collecting and reporting underwater background noise levels each 30-second RMS value both with and without the high pass filter applied was plotted using a Cumulative Distribution Function (CDF) to determine the percent of time each sound level occurred during the 50.5 hour recording. The 50th percentile from the CDF plot reflects the average background sound level near the Manette Bridge.

Background sound levels collected between 9:37 AM on August 2 through 11:37 PM on August 4, 2010 in between vibratory pile driving activities indicate that the overall average broadband background RMS level (50th percentile) is 127 dB RMS (Figure 6). Per NMFS guidance on underwater background noise levels, the same data was passed through a high pass filter and plotted on the CDF chart (Figure 7). The 50th percentile for the high pass filtered data is 112 dB RMS. The difference between the broadband and high pass filtered background noise level is 15 dB. Therefore, using the broadband background noise level the vibratory driving noise levels will not attenuate to background levels before they reach the 120 dB RMS threshold.

Comparing Figures 6 and 7 it can be seen that Figure 7 has more of a typical sigmoid or ‘S’ shaped curve whereas the sigmoid curve in Figure 6 is less distinct. This indicates that the broadband data including the lower frequencies has a lot more variability in the data as is typically seen in lower frequency data. This may also be indicative that the 50.5 hours of data analyzed was representative of two full nights and one full day with two half days and not the minimum of three days as recommended by Stockham et al., 2010. To get a more accurate picture of what the broadband background noise levels are for the Manette Bridge area it would require additional full days of data to lower the overall variability.

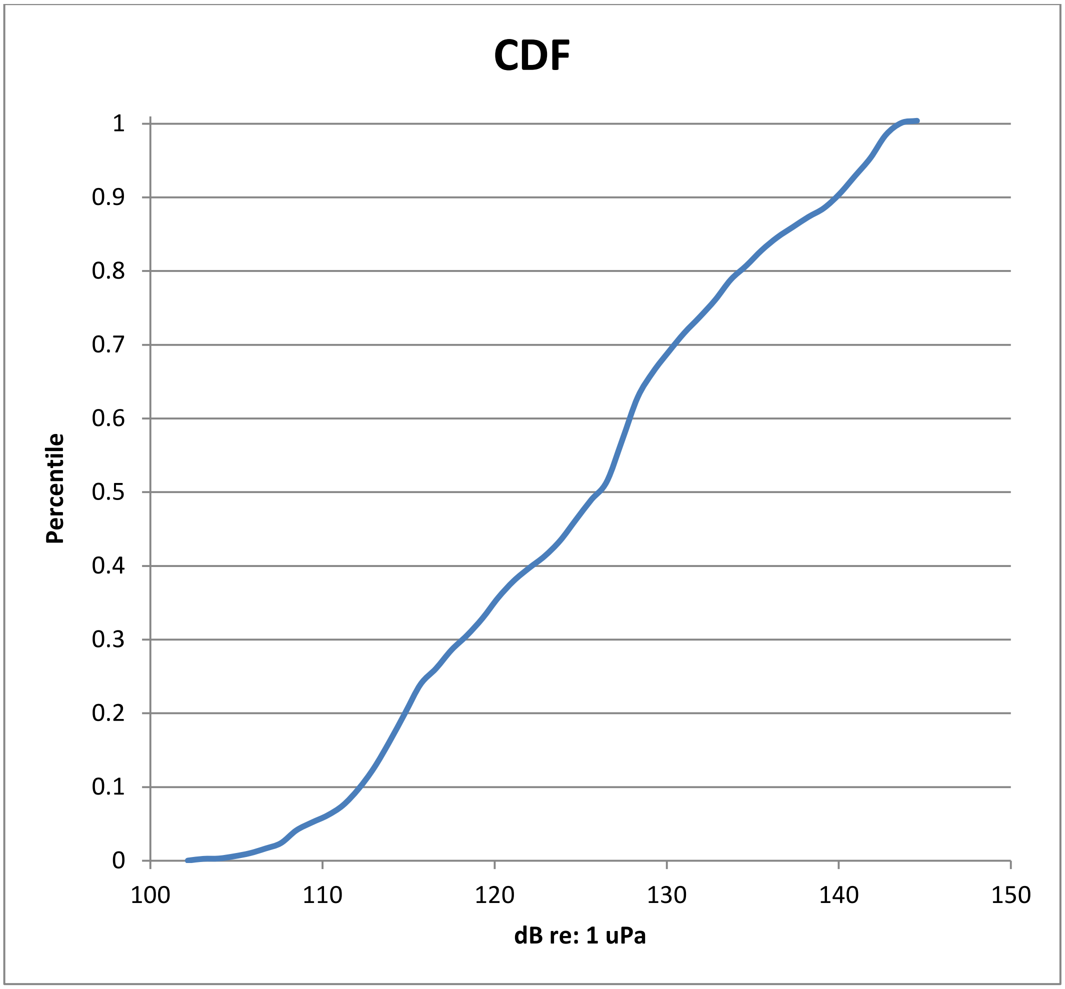

Figure 7: Cumulative Distribution Function (CDF) plot for the broadband hourly RMS background noise level data.

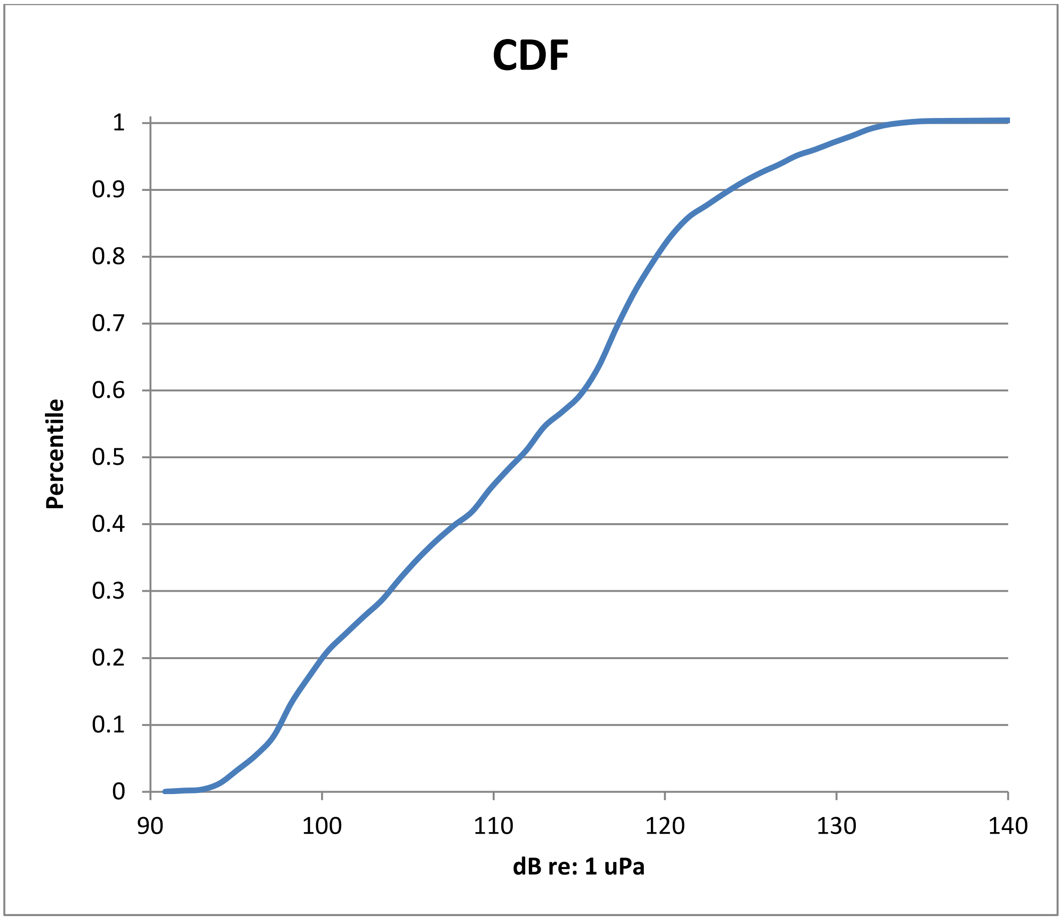

Figure 8: Cumulative Distribution Function (CDF) plot for the high pass filtered hourly RMS background noise level data.

Conclusions

Near field measurements were taken in addition to background measurements at the Manette Bridge during vibratory pile driving. The vibratory sound levels recorded are typical for 24-inch steel piles. The average broadband RMS sound levels at 10 meters from the pile is 166 dB RMS and at 791 meters from the pile is 154 dB RMS. When the high pass filter was applied to the data the RMS sound level at 10 meters from the pile is 158 dB RMS and 148 dB RMS at 791 meters from the pile.

Average RMS levels measured during vibratory pile driving indicate that the Practical Spreading model is the most appropriate model for this area. Background noise levels were determined to be 112 dB RMS and the vibratory noise levels will not attenuate to background before reaching the 120 dB RMS threshold. Therefore, the previously established biological monitoring limits should not be modified as a result of these measurements.

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

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Attachments
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