Washington State Department of Transportation

Memorandum

June 21, 2010

TO: Sharon Rainsberry

FROM: Jim Laughlin
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SUBJECT: Airborne Noise Measurements (A-weighted and un-weighted) during Vibratory Pile Installation - Technical Memorandum.

Airborne Noise Levels

This memo summarizes the A-weighted airborne vibratory pile driving results measured at the Vashon Ferry Terminal and the un-weighted airborne vibratory pile driving results measured at the Wahkiakum Ferry Terminal on the Columbia River and the Keystone Ferry Terminal in an effort to collect site specific data on airborne noise levels. A-weighted airborne noise level data was collected during vibratory pile driving at the Vashon Ferry Terminal facility on Vashon Island during the month of November 2009. Un-weighted airborne data was collected at the Wahkiakum County Ferry Terminal on January 12-13, 2010 and at the Keystone Ferry Terminal on January 9, 2010.

Two 30-inch diameter steel piles were monitored as they were driven with an APE vibratory hammer at the Vashon ferry terminal, one 18-inch pile was monitored as it was driven with an APE vibratory driver at the Wahkiakum ferry terminal and one 30-inch pile was monitored as it was driven with an APE vibratory hammer at the Keystone ferry terminal. Airborne noise levels use the acoustic reference pressure of 20 microPa.

Vashon Ferry Terminal

For the Vashon Ferry Terminal the airborne noise levels are measured in terms of the 10-minute average continuous sound level (10-minute Leq):

(10 min) $$L_{eq} = 10\log\left(\frac{1}{T}\int_T p(t)^2\,dt\right)$$

Where p(t) is the acoustic overpressure, T = 10 minutes and 0 < t < T.

RMS values are calculated by integrating the sound pressure averaged over some time period, in this case 10-minutes in a similar way that the Leq values are calculated. Therefore, in this instance the 10-minute Leq is the same as the RMS sound pressure level over a 10-minute period. The 10-minute Leq and Lmax levels were measured with an A-weighting applied.

Continuous sounds occur for extended periods and are associated with the use of a vibratory hammer. The results of Table 1 shows A-weighted airborne noise levels (Leq/RMS) standardized to a distance of 50 feet to range between 77.0 and 80.1 dB(A) at the Vashon Ferry Terminal. The location where the measurements were collected is shown in Figure 1.

Table 1: Summary Table of A-Weighted Airborne Monitoring Results - Vashon.

Pile #	Distance To Pile (feet)	Measured Leq/RMS (dB(A))	Standardized Leq/RMS To 50 feet (dB(A))	Measured Lmax (dB(A))	Standardized Lmax To 50 feet (dB(A)
1	26	80.7	77.9	87.8	85.0
2	36	81.2	79.8	97.2	95.8
1	26	79.8	77.0	84.4	81.6
2	36	81.5	80.1	88.9	87.5
		Average:	**78.9**	**Average:**	**90.8**

Figure 1: Location of airborne noise measurement at the Vashon Ferry Terminal.

Figure 2 shows the 1/3rd octave frequency distribution for the A-weighted Leq/RMS metric for each pile driven with a vibratory hammer at Vashon.

- The distributions are all very similar with slight variability in the lower frequencies below 200 Hz. Lower frequencies typically are more variable than higher frequencies.
- The dominant frequency for all piles is around 1.25 kHz and there appears to be a slight increase at 0.125 kHz for three of the four piles.
- The increase in lower frequencies could be due to longer periods of heavy driving.

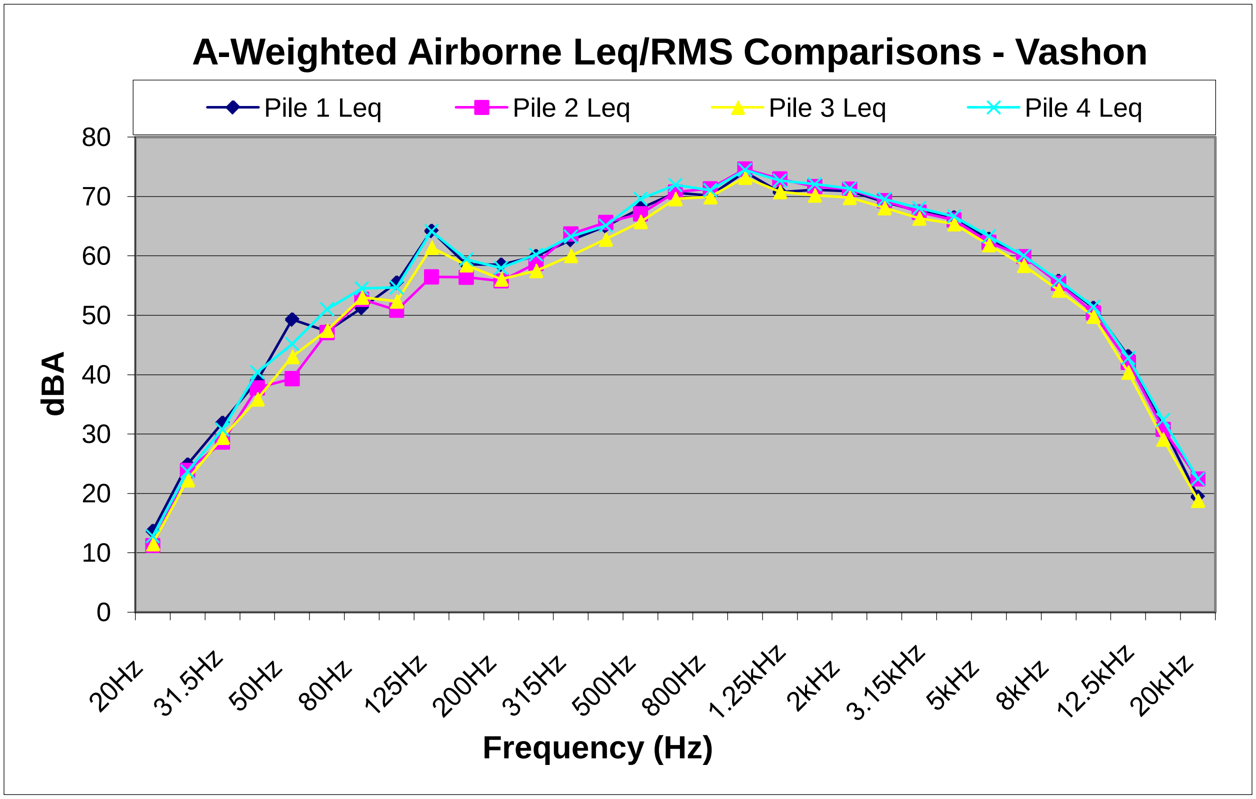

Figure 2: Comparison of Vashon A-weighted airborne frequency distribution for the Leq/RMS metric using a vibratory hammer.

Figure 3 shows the 1/3rd octave frequency distribution for the A-weighted Lmax metric for each pile driven with a vibratory hammer.

- The distribution of three of the four piles is similar at frequencies above 1.25 kHz except for Pile 2, which has higher noise levels at the higher frequencies.
- The lower frequencies are more variable, with a similar peak at 0.125 kHz for three of the four piles.
- The dominant frequency for all piles is between 1.25 kHz and 2 kHz.

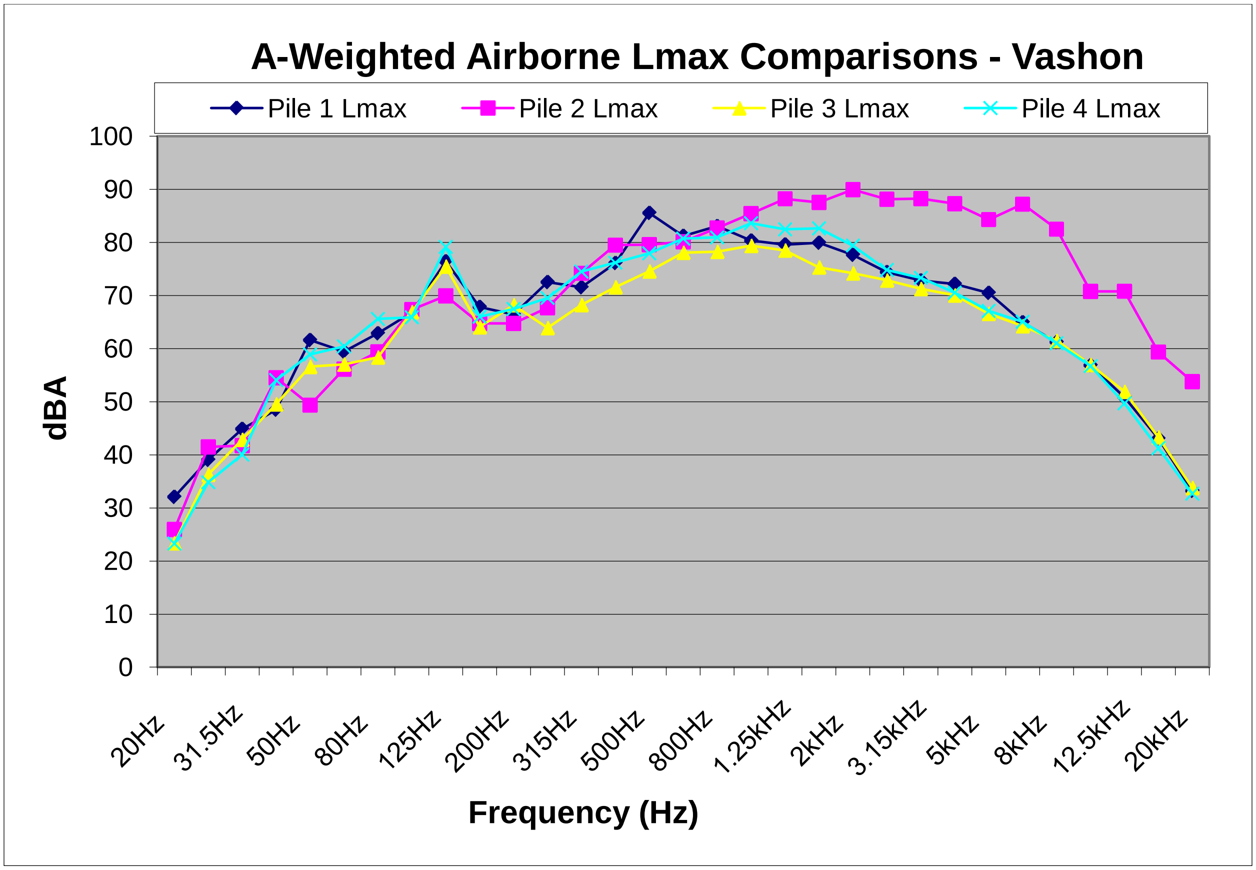

Figure 3: Comparison of Vashon A-weighted airborne frequency distributions for the Lmax metric using a vibratory hammer.

Wahkiakum County Ferry Terminal

For the Wahkiakum County Ferry Terminal the airborne noise levels are measured in terms of the 5-minute average continuous sound level (5-minute Leq) as the measurements were stable at 5 minutes:

$$\text{(5 min)} \quad L_{eq} = 10\log\left(\frac{1}{T}\int_T p(t)^2\,dt\right)$$

Where p(t) is the acoustic overpressure, T = 5 minutes and 0 < t < T.

RMS values are calculated by integrating the sound pressure averaged over some time period, in this case 5-minutes in a similar way that the Leq values are calculated. Therefore, in this instance the 5-minute Leq is the same as the RMS sound pressure level over a 5-minute period.

The 5-minute Leq and Lmax levels were measured without an A-weighting applied (un-weighted). Continuous sounds occur for extended periods and are associated with the use of a vibratory hammer. The results of Table 2 show the un-weighted airborne noise level (Leq/RMS) standardized to a distance of 50 feet to be 87.5 dB at the Wahkiakum County Ferry Terminal. The location where the measurements were collected is shown by the red circle in Figure 4.

Table 2: Summary Table of Un-weighted Airborne Monitoring Results - Wahkiakum.

Pile #	Distance To Pile (feet)	Measured Leq/RMS (dB)	Standardized Leq/RMS To 50 feet (dB)	Measured Lmax (dB)	Standardized Lmax To 50 feet (dB)
1	39	88.6	87.5	94.9	93.8

Figure 4: Location of airborne noise monitoring at the Wahkiakum County Ferry Terminal.

Figure 5 shows the 1/3rd octave frequency distribution for the un-weighted Leq/RMS metric for one pile driven with a vibratory hammer at the Wahkiakum County Ferry Terminal.

- There is some variability in the lower frequencies below 0.200 kHz.
- The dominant frequency is around 0.0315 kHz.

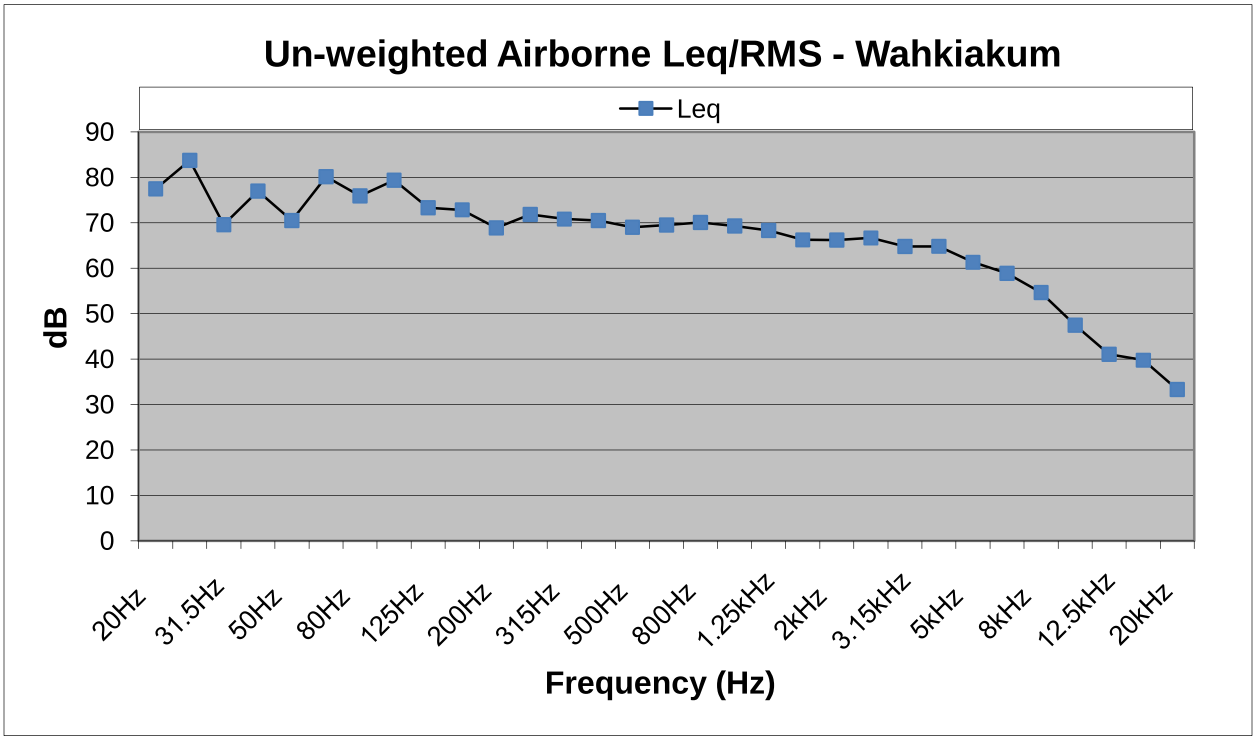

Figure 5: Comparison of Wahkiakum un-weighted airborne frequency distributions for the Leq/RMS metric using a vibratory hammer.

Figure 6 shows the 1/3rd octave frequency distribution for the un-weighted Lmax metric for one pile driven with a vibratory hammer.

- Frequencies below 0.500 kHz are more variable.
- The dominant frequency is 0.125 kHz.

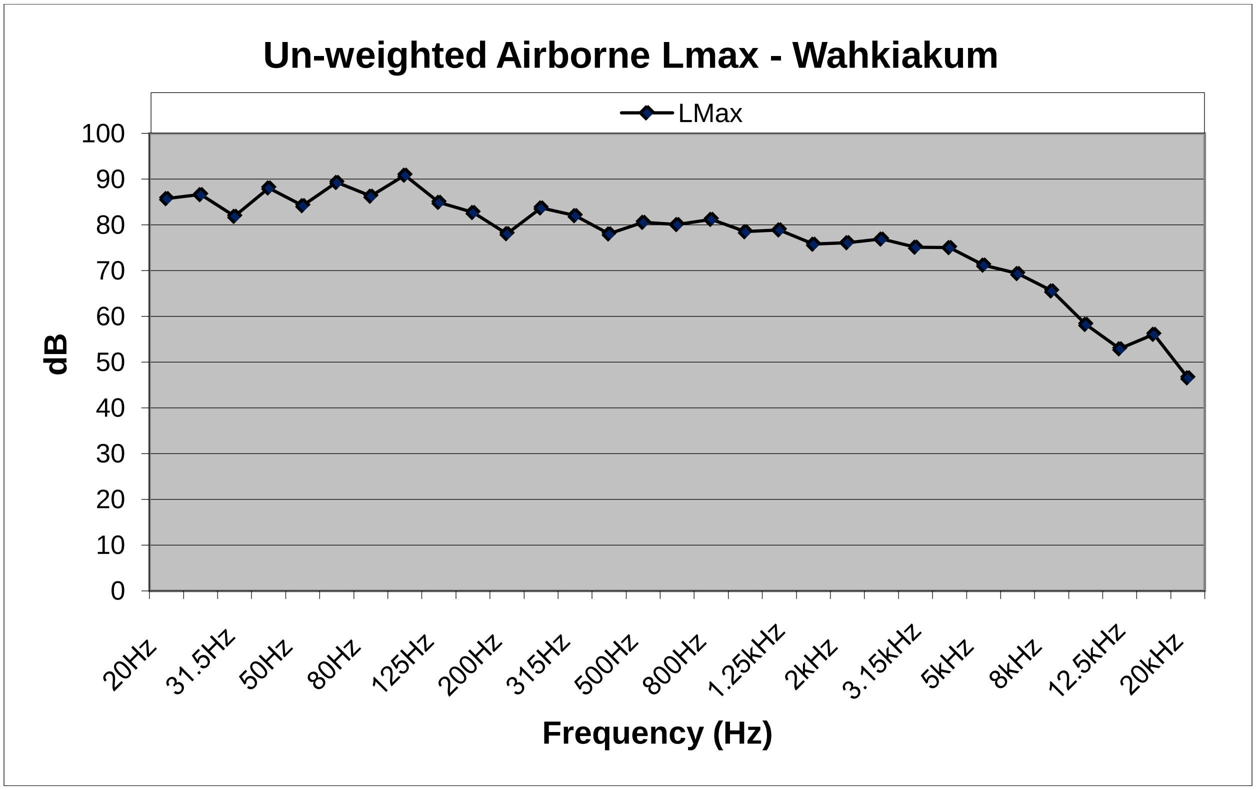

Figure 6: Comparison of Wahkiakum un-weighted airborne frequency distributions for the Lmax metric using a vibratory hammer.

Keystone Ferry Terminal

For the Keystone Ferry Terminal the airborne noise levels are measured in terms of the 5-minute average continuous sound level (5-minute Leq) as the measurements were stable after 5 minutes (see formula on page 4):

RMS values are calculated by integrating the sound pressure averaged over some time period, in this case 5-minutes in a similar way that the Leq values are calculated. Therefore, in this instance the 5-minute Leq is the same as the RMS sound pressure level over a 5-minute period.

The 5-minute Leq and Lmax levels were measured without an A-weighting applied (un-weighted). Continuous sounds occur for extended periods and are associated with the use of a vibratory hammer. The results of Table 3 show the un-weighted airborne noise level (Leq/RMS) standardized to a distance of 50 feet to range between 95.0 and 97.8 dB at the Keystone Ferry Terminal. The location where the measurements were collected is shown in Figure 7.

Table 3: Summary Table of Unweighted Airborne Monitoring Results - Keystone.

Pile #	Distance To Pile (feet)	Measured Leq/RMS (dB)	Standardized Leq/RMS To 50 feet (dB)	Measured Lmax (dB)	Standardized Lmax To 50 feet (dB)
1a	40	97.9	96.9	102.3	101.3
1b	40	96.0	95.0	101.3	100.3
1c	40	97.0	96.0	104.9	103.9
1d	40	98.8	97.8	106.3	105.3
		Average:	**96.5**	**Average:**	**103.1**

Figure 7: Location of airborne noise monitoring at the Keystone Ferry Terminal.

Figure 8 shows the 1/3rd octave frequency distribution for the un-weighted Leq/RMS metric for each of four replicate measurements on one pile driven with a vibratory hammer at Keystone.

- The distributions are all very similar with slight variability in the lower frequencies below 0.500 kHz.
- The dominant frequency for all piles is around 1.25 kHz and there appears to be a slight increase at 0.315 and 0.500 kHz for all four replicate measurements.

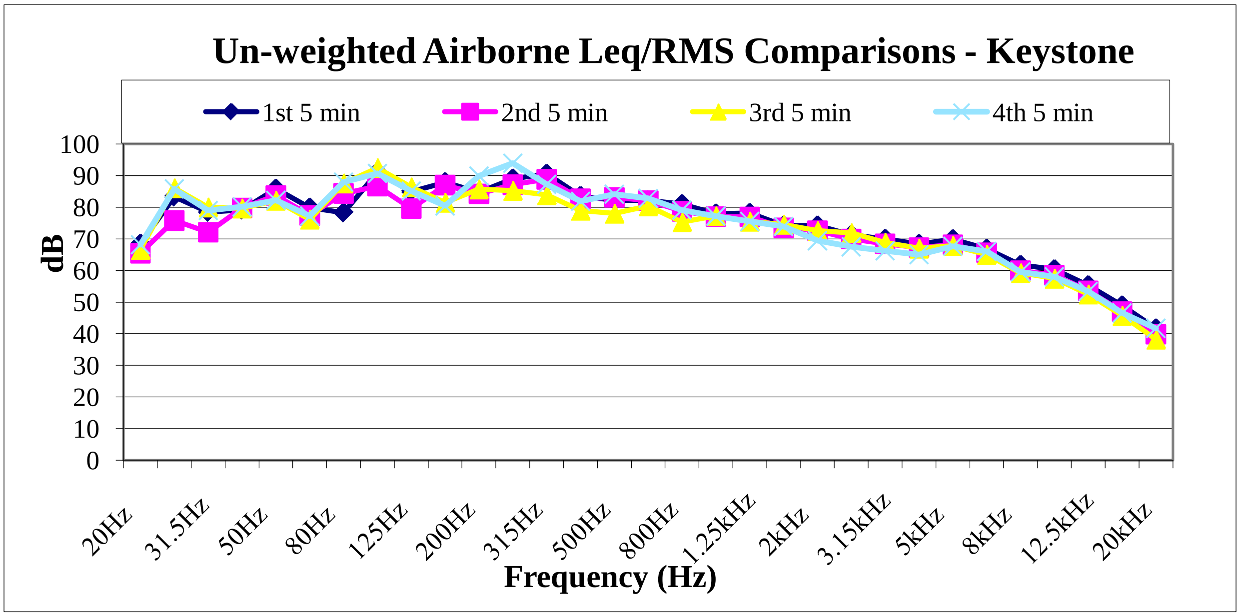

Figure 8: Location of airborne noise monitoring at the Keystone Ferry Terminal.

Figure 9 shows the 1/3rd octave frequency distribution for the un-weighted Lmax metric for four replicate measurements on one pile driven with a vibratory hammer.

- Frequencies below 0.500 kHz are more variable.
- The dominant frequency is between 0.200 and 0.315 kHz.

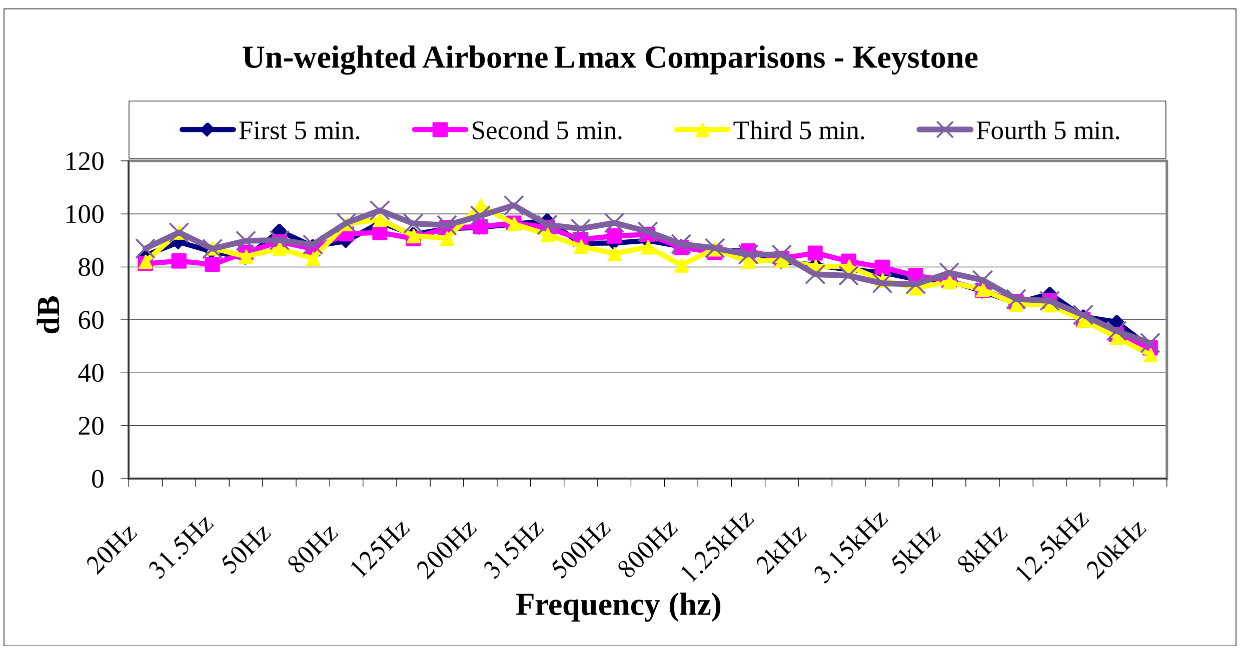

Figure 9: Location of airborne noise monitoring at the Keystone Ferry Terminal.

Conclusions

Airborne measurements were collected at the Vashon Ferry terminal, Wahkiakum County ferry terminal and the Keystone ferry terminal during vibratory pile driving. The Vashon measurements were A-weighted but the Wahkiakum County and Keystone measurements were un-weighted. The un-weighted airborne noise measurements may be the first airborne measurements of vibratory driving operations in Puget Sound. The A-weighted values ranged from 77.0 to 80.1 dB(A) RMS standardized at 50 feet with an overall average of 78.9 dB(A) RMS which is appropriate for continuous sound level measurements. The un-weighted values ranged from 87.5 to 97.8 dB RMS with an overall average of 96.5 dB RMS.

1/3rd octave band frequency measurements were collected and compared. The lower frequencies were more variable between measurements and the dominant frequency shifted to around 0.125 kHz for the un-weighted to 125 kHz for the A-weighted frequency measurements. This information could be useful when comparing these results to the hearing range of marine mammals to see what portion of the sound they actually hear.

Table 4: Summary Table of Airborne Monitoring Results.

Site	Pile #	Distance To Pile (feet)	Measured Leq/RMS (dB)	Standardized Leq/RMS To 50 feet (dB)	Measured Lmax (dB)	Standardized Lmax To 50 feet (dB)
	1	26	80.7[1]	77.9[1]	87.8[1]	85.0[1]
Vashon	2	36	81.2[1]	79.8[1]	97.2[1]	95.8[1]
	1	26	79.8[1]	77.0[1]	84.4[1]	81.6[1]
	2	36	81.5[1]	80.1[1]	88.9[1]	87.5[1]
Overall Average A-weighted Leq/RMS:				**78.9**[1]		**90.8**[1]
Wahkiakum	1	39	88.6	87.5	94.9	93.8
	1a	40	97.9	96.9	102.3	101.3
Keystone	1b	40	96.0	95.0	101.3	100.3
	1c	40	97.0	96.0	104.9	103.9
	1d	40	98.8	97.8	106.3	105.3
Overall Average un-weighted Leq/RMS:				**96.5**		**103.2**

[1] – A-weighted values

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

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Attachments
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