

*SR 20*

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*Port Townsend Test Pile Project*  
**UNDERWATER NOISE MONITORING**  
**DRAFT FINAL REPORT**

*Prepared by:*  
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## INTRODUCTION

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The Washington State Department of Transportation - Ferries Division (WSF) Port Townsend Vibratory Test Pile project field work was completed on October 5, 2010. This draft final report presents the analysis and results of the test pile project.

## PROJECT AREA

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The project was located on SR 20 northeast of the Port Townsend Ferry terminal in the City of Port Townsend (Figure 1).



Figure 1. Vicinity map of Port Townsend Test Pile Project.

## REPORTING

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Per the Port Townsend Test Pile Monitoring Plan (WSF 2010a), this report includes the following information (not necessarily in this order):

1. Size and type of piles.
2. The vibratory hammer size used to drive the piles.
3. A description of the monitoring equipment.
4. The distance between hydrophones and pile(s).
5. The depth of the hydrophones.
6. The distance from the pile to the wetted perimeter.
7. The depth of water in which the pile was driven.
8. The depth into the substrate that the pile was driven.
9. The physical characteristics of the bottom substrate into which the piles were driven.

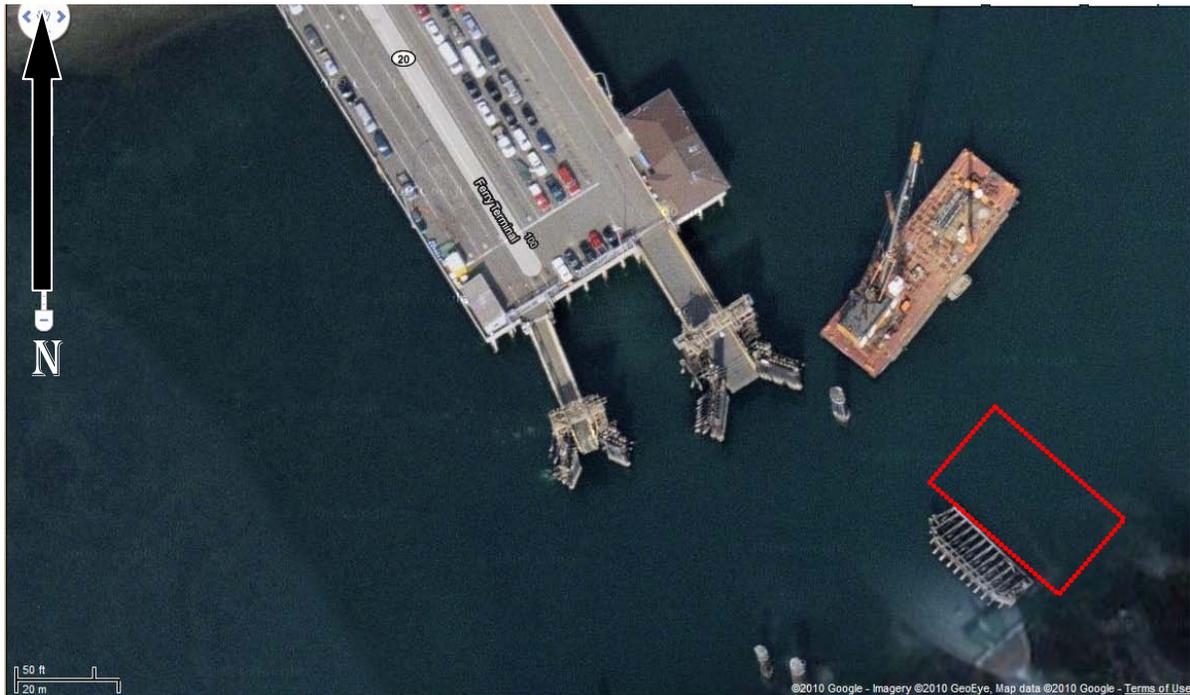
10. The ranges and means for peak, average RMS, and SEL's for each pile.
11. The results of the hydroacoustic monitoring, including the frequency spectrum, peak and RMS SPL's, and single-strike and cumulative SEL.
12. A description of any observable fish or bird behavior in the immediate area will and, if possible, correlation to underwater sound levels occurring at that time.

## TEST PILE LOCATION AND DRIVING SUMMARY

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The Port Townsend Test Pile Project drove two piles, one 30-inch and one 36-inch in diameter, near the existing dolphin (Figure 2). The piles were located immediately northeast of the terminal's floating dolphin (Figure 3). The distance from the piles to the wetted perimeter was approximately 204 meters/670 feet.

The piles were driven with an APE Super Kong 600 vibratory hammer (Figure 4). When fully driven, the 30-inch pile was in 8.8 meters/29 feet of water; and the 36-inch pile was in 9.5 meters/31 feet of water. Both piles were driven in sequence, approximately 10 feet apart. Water depth differences are the result of tidal changes. Piles were driven 12.2 meters/40 feet into the substrate. The geotechnical report for the site indicates that the substrate consists of 1.5 meters/5 feet of loose sand over very dense glacially consolidated soils (WSF 2010b). Figures 5-7 show test pile activities.



**Figure 2. Location of the Port Townsend Test Ferry Terminal where pile driving activity took place (red rectangle).**



Figure 3. APE Super Kong 600 vibratory hammer.



Figure 4. Test piles.



Figure 5. Crane pickup up hammer and 30" pile.



**Figure 6. Driving 30" pile.**



**Figure 7. Driving complete on 36" pile.**

## Monitoring Equipment

One 10-meter hydrophone and associated monitoring equipment was used (specifications listed in Table 1).

**Table 1. Equipment for underwater sound monitoring (All have current National Institute of Standards and Technology (NIST) traceable calibration.<sup>1</sup>)**

Item	Specifications	Quantity	Usage
Hydrophone with 200 feet of cable	Receiving Sensitivity- 211dB ±3dB re 1V/μPa	1	Capture underwater sound pressures and convert to voltages that can be recorded/ analyzed by other equipment.
Signal Conditioning Amplifier (4-channel)	Amplifier Gain- 0.1 mV/pC to 10 V/pC Transducer Sensitivity Range- 10 <sup>-12</sup> to 10 <sup>3</sup> C/MU	1	Adjust signals from hydrophone to levels compatible with recording equipment.
Calibrator (pistonphone-type)	Accuracy- IEC 942 (1988) Class 1	1	Calibration check of hydrophone in the field.
Portable Dynamic Signal Analyzer (4-channel)	Sampling Rate- 24K Hz or greater	1	Analyzes and transfers digital data to laptop hard drive.
Microphone (free field type)	Range- 30 – 120 dBA Sensitivity- -29 dB ± 3 dB (0 dB = 1 V/Pa)	1	Monitoring airborne sounds from pile driving activities (if not raining).
Laptop computer	Compatible with digital analyzer	1	Record digital data on hard drive and signal analysis.
Real Time and Post-analysis software	-	1	Monitor real-time signal and post-analysis of sound signals.
Weighted nylon line marked in 5-foot increments to attach hydrophone.	-	1	Takes the strain off of the hydrophone cables preventing damage.
Various surface floats.	-	-	To keep the hydrophone at the appropriate depth in relation to the surface.

*Monitoring equipment (Table 1) will be set to a minimum frequency range of DC to 10 KHz and a sampling rate of 24,000 Hz. To facilitate further analysis, the underwater signal data will be recorded as a text (.txt) or wave (.wav) file.*

<sup>1</sup> If acoustic monitoring is conducted by a contractor specialized in hydroacoustic monitoring and not conducted directly by WSDOT, the contractor will submit a detailed equipment list for underwater sound pressure level monitoring for approval by a WSDOT acoustic specialist.

Three Autonomous Multichannel Acoustic Recorder (AMAR) developed by Jasco Research, Ltd. in B.C. Canada were also used during the test pile. Each AMAR consists of one GeoSpectrum M15 hydrophone with a filter/amplifier board, 0.1 to 20 kHz bandwidth, and a sensitivity of -160 dB re 1  $\mu$ Pa. The AMAR has 1 channel of 16-bit, 1 MS/s, solid state storage with 128 GB base, .wav formatted recordings. Technicians anchored the AMAR on the bottom of the sea floor and retrieve it using an acoustical release system.

The 10-meter hydrophone was located at 10 meters from the piles. Two of the three AMARs were in fixed locations for the duration of the test pile, at 3200 and 6400 meters. A small boat was used to deploy the hydrophone, and a tug to deploy the AMARs (Figures 9-10). The third AMAR was moved between 100, 200, 400, 800 and 1600 meters (Figure 11). Hydrophone distances from piles and depths are listed in Table 2, and represented in Figure 12.

**Table 2. Hydrophone depths**

Hydrophone Distance from Piles (meters)	Depth (meters)	Depth (feet)
10	8.2	27
100	8.2	27
200	12.8	42
400	18.3	60
800	18.3	60
1600	29.3	96
3200	10.0	33
6400	54.9	180



**Figure 9. Deploying hydrophone.**



**Figure 10. Deploying AMAR.**



Figure 11. Approximate location of the AMAR deployment sites along a transect moving away from the pile for the Port Townsend Test Pile Project.

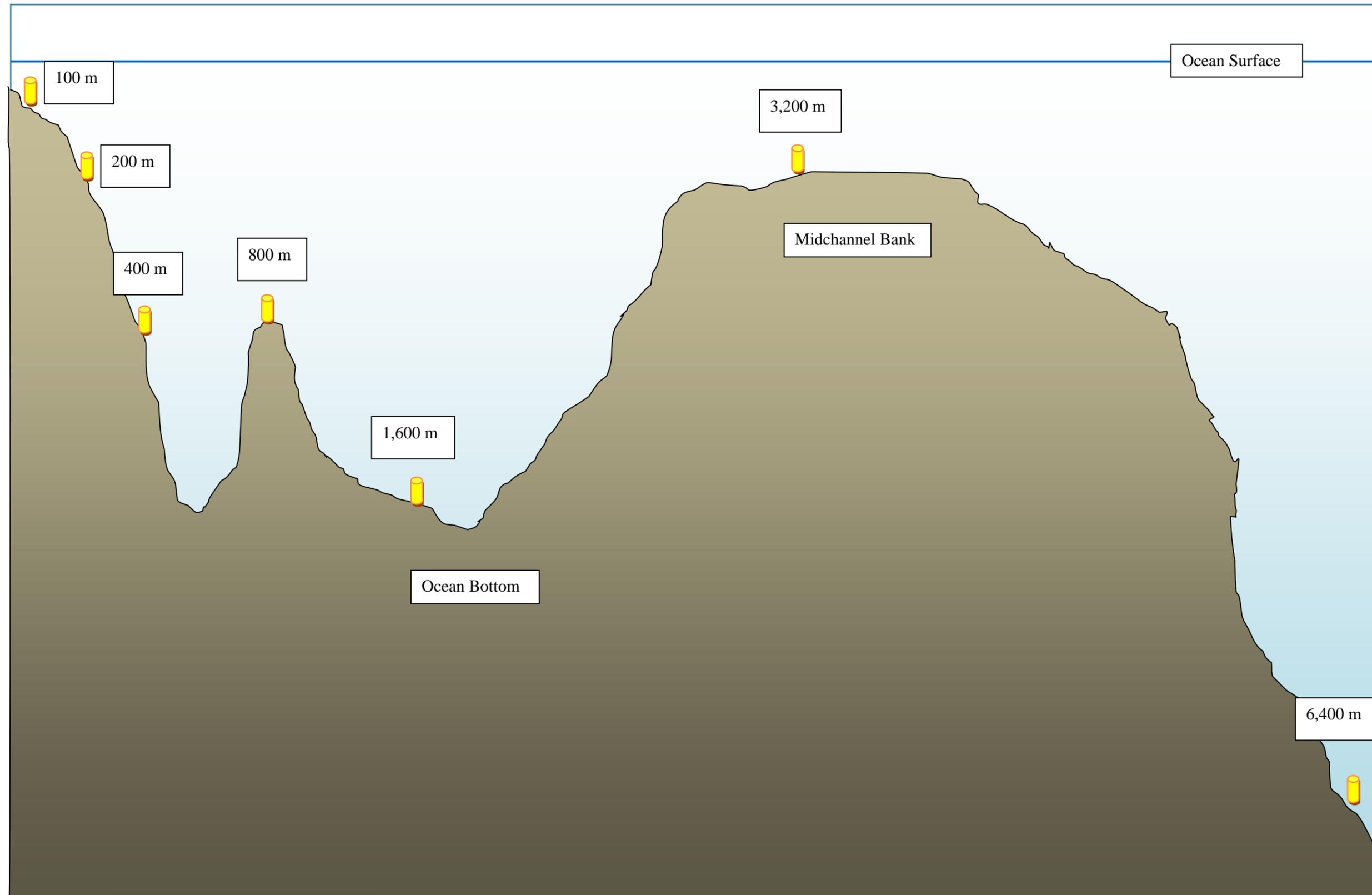


Figure 12. Profile of the AMAR deployment sites (yellow cylinder) along a transect moving away from the pile on the Port Townsend Test Pile Project (vertical scale exaggerated).

## RANGES/MEANS for PEAK, AVERAGE RMS and SEL's for each PILE

The peak values ranged from 189 dB peak at ten meters from the source to about 149 dB at 3200 meters for the 30-inch pile and approximately 144 dB peak at 3200 meters for the 36-inch pile (UW 2010a)(Figures 13-14).

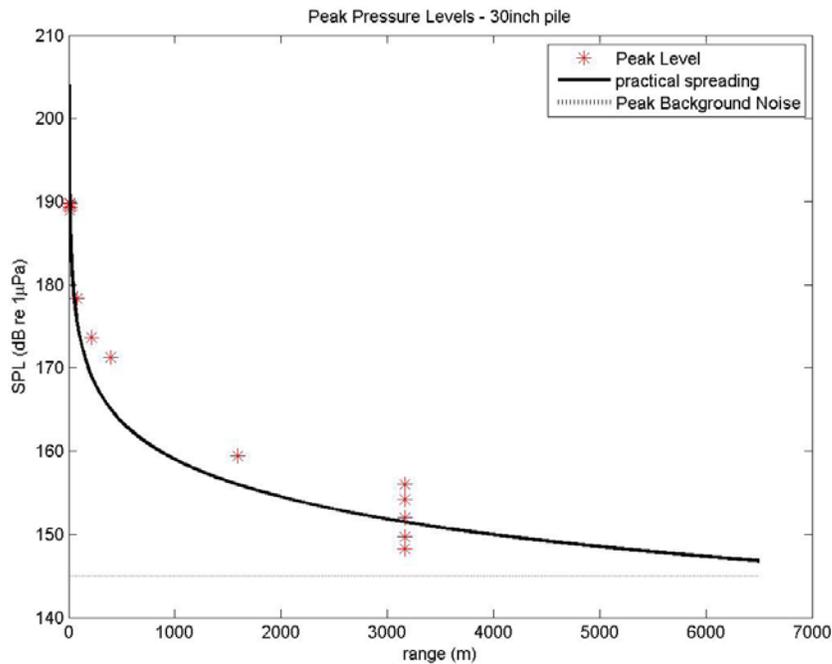


Fig. 13. The measured peak levels for each test on the 30-inch pile.

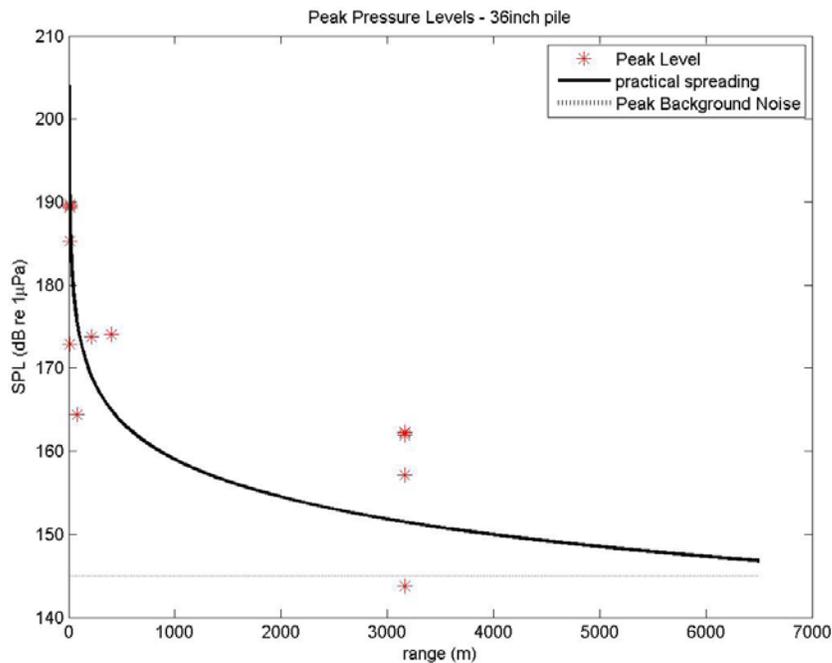
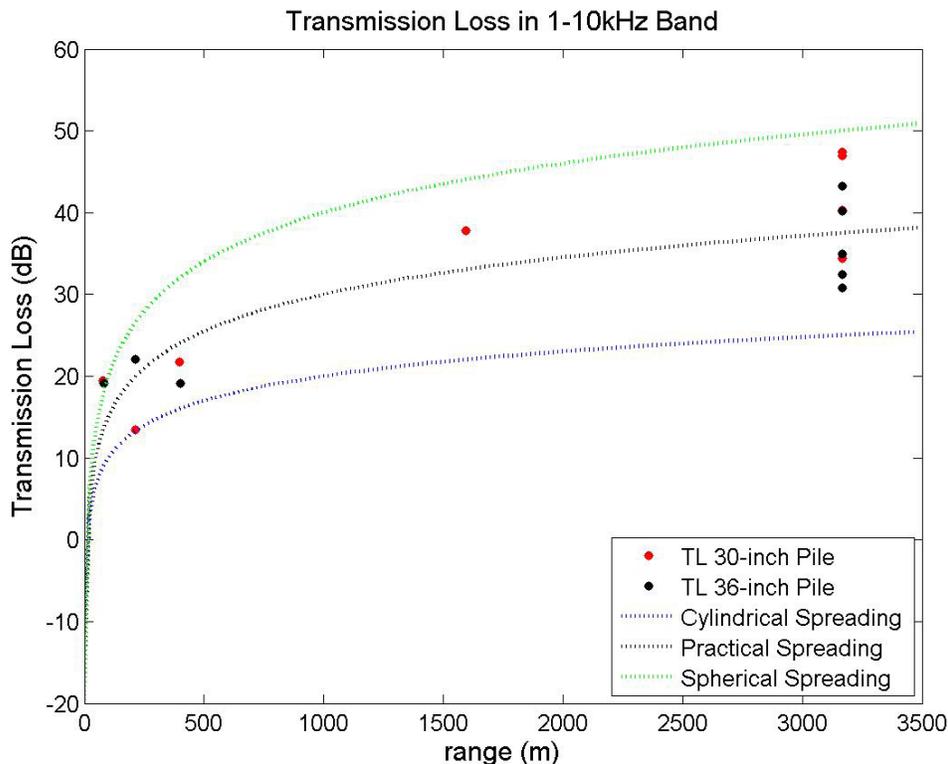


Fig. 14. The measured peak levels for each test on the 36-inch pile.

## HYDROACOUSTIC MONITORING RESULTS

There were six pile driving tests associated with the 30-inch pile and five pile driving tests associated with the 36-inch pile. Each test has a set of data points that are at different ranges, with some overlap. In each set there was a hydrophone taking data at 10 meters from the pile and two AMARs located nominally at 3200 meters and 6400 meters that were taking data during all testing. There was a third AMAR that was moved between tests to take measurements at intermediate distances, nominally at 100, 200, 400, 800 and 1600 meters. Due to some malfunctioning of this third AMAR, the intermediate measurement is not available for every test. Also, due to a very low signal to noise ratio at 6400 meters, no measurements from that AMAR site are used in this summary.

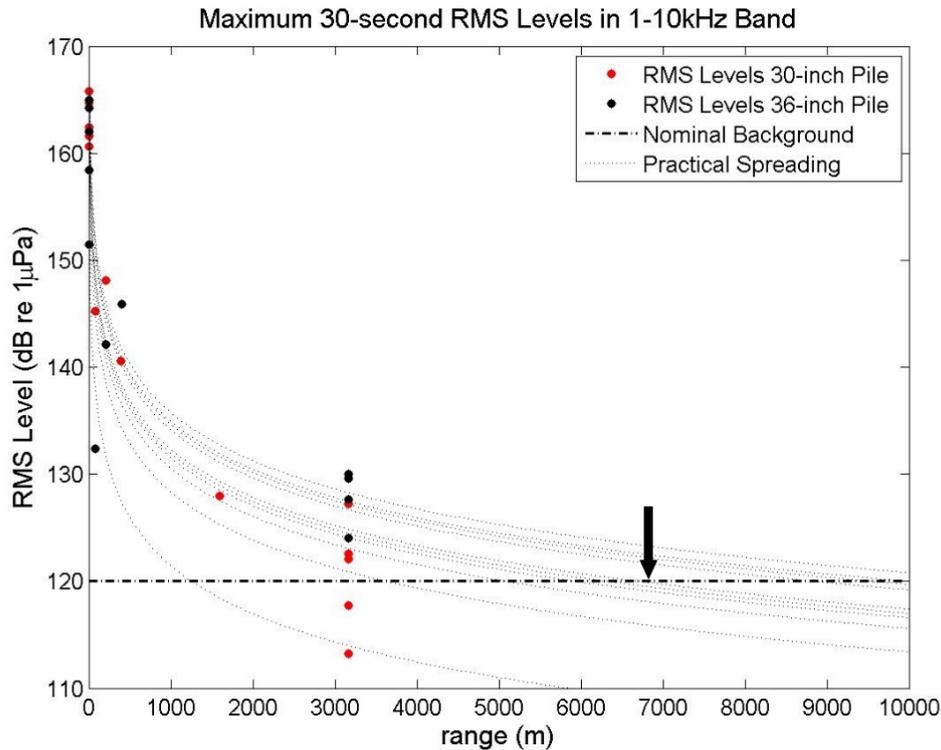
A 30-second averaging window was used to find the maximum 30-second RMS pressure level during the vibratory pile driving. Due to the widely varying source level over the duration of the pile driving events, this was determined to be a better way to quantify the sound levels and the transmission loss than a peak measurement. The data used in this analysis was filtered through a high pass filter which results in only the frequencies between 1 and 10 kHz used for this analysis. The transmission loss is given as  $20\text{Log}_{10}$  of the ratio of the maximum 30-second RMS value at the 10 meter hydrophone to the maximum 20-second RMS value at the more distant hydrophones. The measured transmission loss is compared to the three geometrical spreading models in Figure 15 (UW 2010b).



**Fig. 15. The measured transmission loss to each AMAR hydrophone for each test on the 30-inch and 36-inch piles.**

Acoustic signals are nominally expected to undergo spherical spreading in shallow water at ranges on the order of a few depth scales; this is reflected in the data points at the nearest ranges in Fig. 15. As the range increases, this loss is expected to be more closely approximated by cylindrical spreading. Cylindrical and spherical spreading should represent the lower and upper bounds (respectively), on the transmission loss. The transmission loss at Port Townsend is approximated reasonably well by the practical spreading model for both the 30-inch and 36-inch piles.

Figure 16 shows the maximum RMS levels as a function of range for multiple tests on the 30-inch and 36-inch piles in the band from 1 to 10 kilohertz with lines representing practical spreading from each source level. It can be seen that the RMS levels at 10 meters change from driving event to driving event. This figure suggests that if the spreading continues to be accurately modeled by the practical spreading model the RMS values will reach the nominal background threshold of 120 dB RMS between 3 and 10 kilometers with a central tendency value at approximately 6800 meters for both the 30-inch and 36-inch piles (UW 2010a).



**Fig. 16. The maximum 1-10kHz band 30-second RMS levels for multiple tests on the 30-inch and 36-inch piles. The dashed lines represent practical spreading based on the level at 10 meters for each test. The arrow is the centroidal range where the level of vibratory pile driving is expected to reach the nominal background.**

## HIGH FREQUENCY CONTENT

The following Figures 17-20 address the high frequency content of the data (UW 2010c).

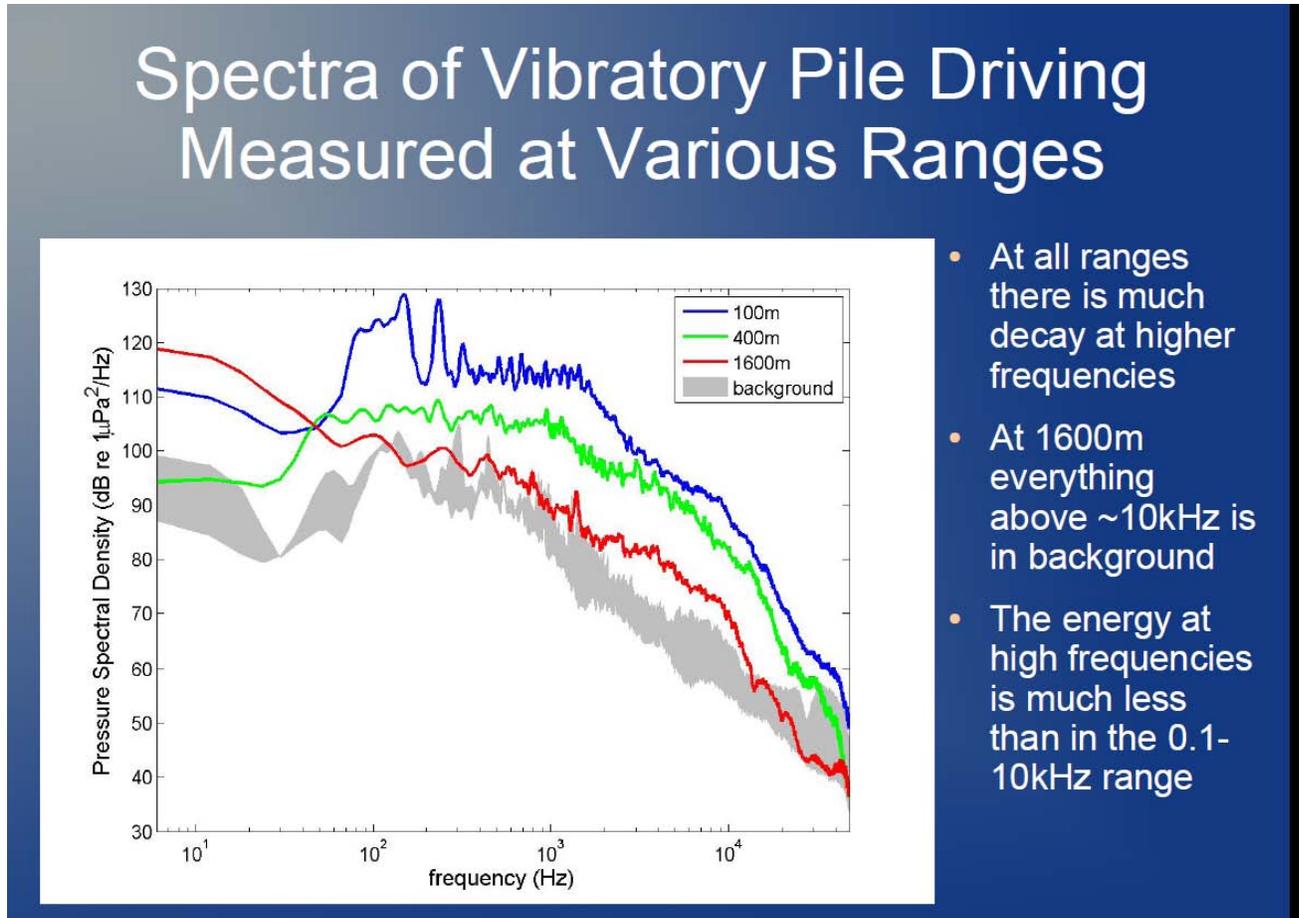
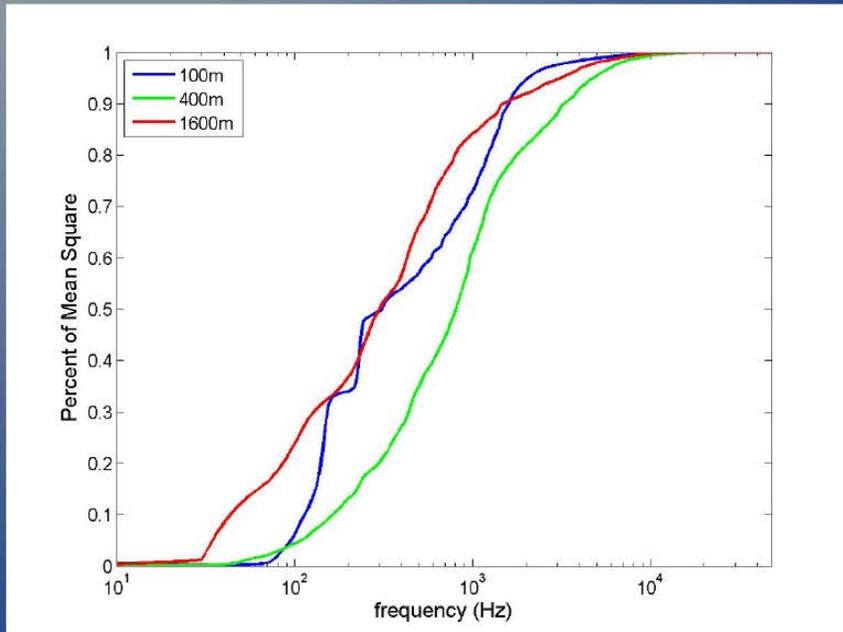


Figure 17. Spectra of Vibratory Pile Driving Measured at Various Ranges

# Cumulative Energy



- As the previous spectra suggested, very little augmentation to the mean square of the signal occurs by including frequency components higher than ~10kHz

Figure 18. Cumulative Energy

# RMS Levels of Filtered Data – 100 m

- Signal is sent through 2 filters, 1-10kHz and 1-40kHz
- 10-second RMS with 5 second overlap calculated for each filtered signal
- Max RMS 1-10kHz = 149.7 dB
- Max RMS 1-40kHz = 149.8 dB

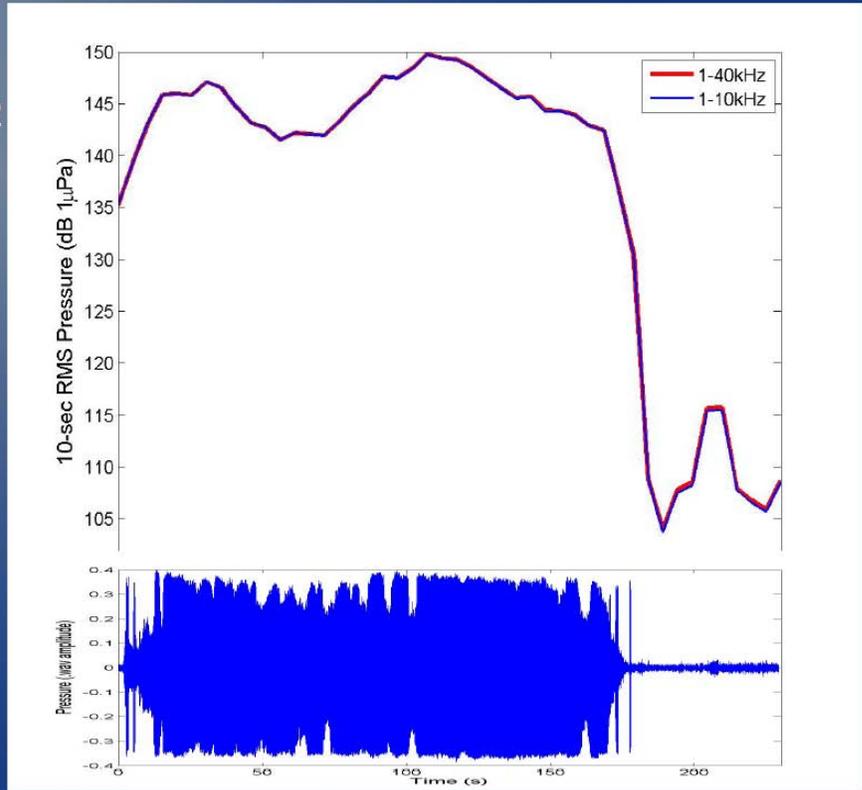


Figure 19. RMS Levels of Filtered Data – 100 m

# RMS Levels of Filtered Data – 400 m

- Signal is sent through 2 filters, 1-10kHz and 1-40kHz
- 10-second RMS with 5 second overlap calculated for each filtered signal
- Max RMS 1-10kHz = 141.6 dB
- Max RMS 1-40kHz = 141.7 dB

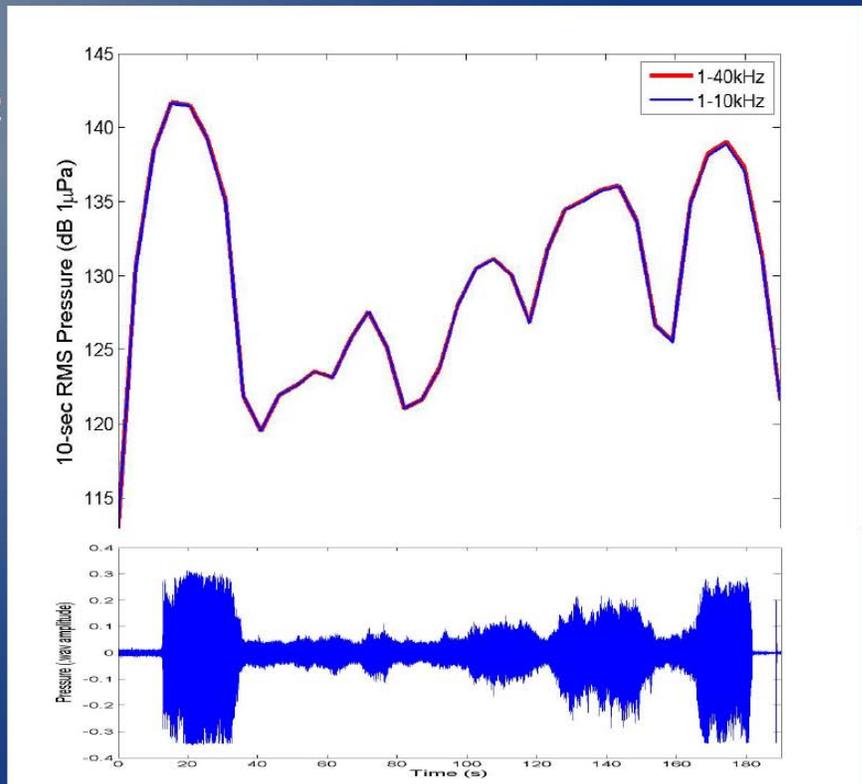


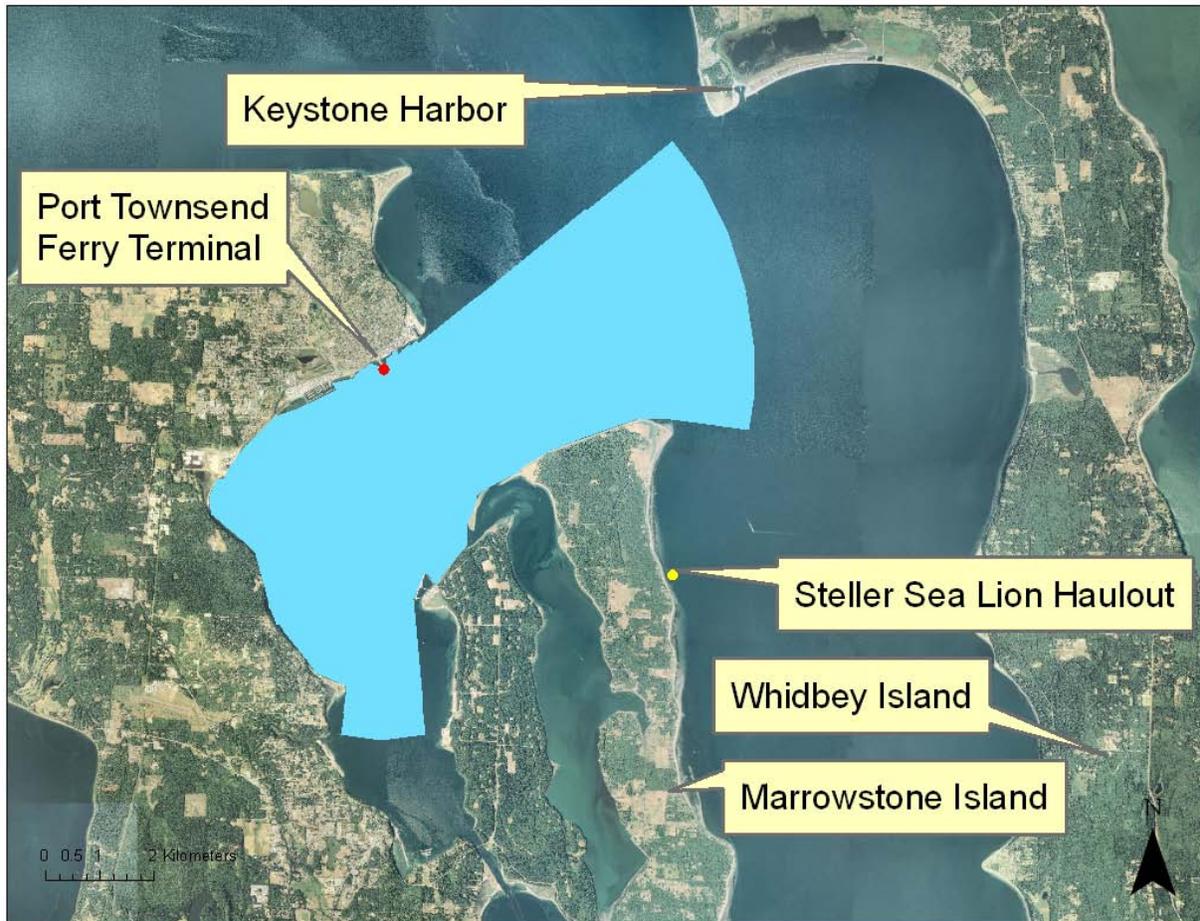
Figure 20. RMS Levels of Filtered Data – 400 m

## SUMMARY AND RESULTS

Results from the October 2010 Port Townsend vibratory pile driving tests were presented. Transmission loss for the 30-inch and 36-inch piles can best be approximated by the practical spreading model.

The underwater noise levels due to the vibratory hammering at Port Townsend are expected to reach the nominal background level (120 dB) between 3 and 10 kilometers, with a centroidal value of approximately 6.8 kilometers (Figure 21). Analysis of data including frequencies between 10 kHz and 40 kHz high frequency data does not alter this conclusion. Furthermore, the addition of the high frequency data does not add any additional energy to the overall sound levels.

Future research will be aimed at understanding how a more refined model may improve upon the practical spreading model as well as providing more rigorously determined error estimates on the range to background level.



**Figure 21. Approximate extent of in-water noise for Port Townsend Test Pile Project vibratory pile driving with 6800 meter attenuation to 120 dB RMS.**

## **FISH OR BIRD BEHAVIOR OBSERVATIONS**

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No biologists were assigned to the immediate area where pile driving occurred. One member of the construction staff observed two ducks (unknown species) leave the immediate area when the 30-inch pile was struck with a hand-held hammer prior to the start of pile driving , to mark the start of pile driving on the hydrophone and AMARs. No other fish or bird behaviors observations were reported.

Marine mammal observations will be submitted as a separate report.

## REFERENCES

UW 2010a. Underwater Sound Measurements During Vibratory Pile Driving at Port Townsend, WA. Peter Dahl, Per G. Reinhall, Mark L. Stockham. University of Washington Applied Physics Lab/Department of Mechanical Engineering. Seattle, WA. October 25, 2010.

UW 2010b. Underwater Sound Measurements During Vibratory Pile Driving at Port Townsend, WA (*Preliminary*). Peter Dahl, Per G. Reinhall, Mark L. Stockham. University of Washington Applied Physics Lab/Department of Mechanical Engineering. Seattle, WA. November 4, 2010.

UW 2010c. High Frequency Content of Vibratory Pile Driving at Port Townsend, WA. Peter Dahl, Per G. Reinhall, Mark L. Stockham. University of Washington Applied Physics Lab/Department of Mechanical Engineering. Seattle, WA. November 9, 2010.

WSF 2010a. Port Townsend Test Pile Project Underwater Noise Monitoring Plan. Washington State Department of Transportation. Office of Air Quality and Noise. Seattle, WA. June 17, 2010.

WSF 2010b. Port Townsend Dolphin Slip 1 Dolphin Replacement Geotechnical Recommendations – Resistance Figures for 36-inch dia. Piles. J.M. Allen/A.J. Fiske. E&EP Geotechnical Division, 47365. Olympia, WA. March 4, 2010.