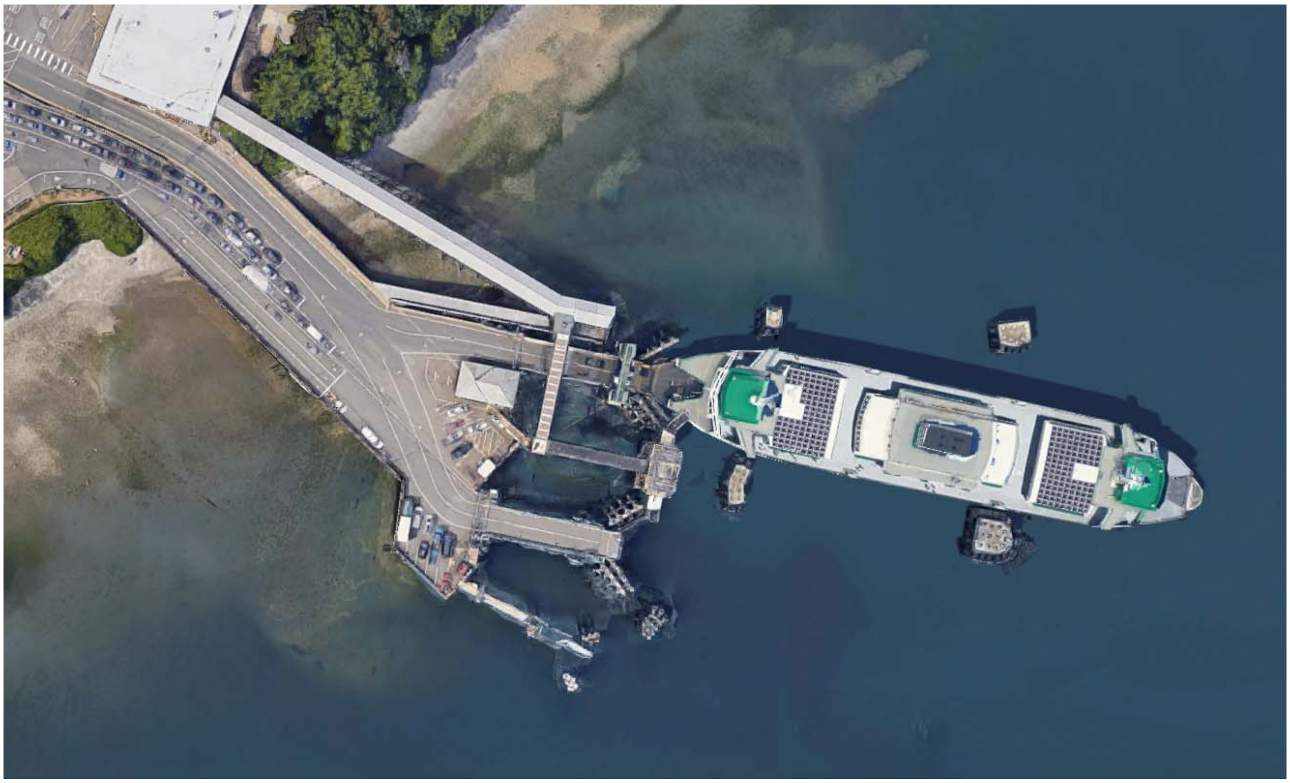
Bainbridge / Fauntleroy: Vibratory Driving Monitoring of H-Piles



Prepared by:
Jim Laughlin
Washington State Department of Transportation
Office of Air Quality and Noise
15700 Dayton Avenue North, P.O. Box 330310
Seattle, WA 98133-9710

February 26, 2019

TABLE OF CONTENTS

Table of Contents .... ***i***

List of Tables i

List of Figures i

Acronyms and Abbreviations .... ***iii***

Executive Summary ***1***

Introduction ***2***

Project Location 2

Project Description 4

Monitoring Locations 4

Characteristics of Underwater Sound ***7***

Methodology ***8***

Typical Equipment Deployment 8

Hydroacoustic Data Analysis 9

Results ***10***

Underwater Sound Levels 10

Daily Cumulative SEL 14

Underwater Sound Level Meter (USLM) 15

Summary ***18***

References ***19***

List of Tables

Table 1: Summary of 12-inch H-Pile Vibratory Underwater Sound Levels. *1*
Table 2: Summary of Underwater Sound Levels for the Bainbridge and Fauntleroy H-Piles *10*
Table 3: Summary of daily cumulative SEL's *14*
Table 4: Summary Table of Underwater Monitoring of Broadband and Marine Mammal Functional Hearing Groups During Installation of one 12-inch Steel H-pile at Bainbridge Ferry Terminal with the Underwater Sound Level Meter (USLM). *17*

List of Figures

Figure 1: Bainbridge Ferry Terminal Location *3*
Figure 2: Fauntleroy Ferry Terminal Location *4*
Figure 3: The location of the Bainbridge monitored pile *5*
Figure 4: The location of the Fauntleroy monitored pile *6*
Figure 5: Near Field Acoustical Monitoring Equipment *8*
Figure 6: Power Spectral Density Plot for the Pile 1H-Pile Driven at Bainbridge Terminal *11*
Figure 7: Spectrogram for the H-Pile Driven at Bainbridge Terminal *12*
Figure 8: Power Spectral Density Plot for the H-Pile Driven at Fauntleroy Terminal *13*

Figure 9: Spectrogram for the H-Pile Driven at Fauntleroy Terminal *14*
Figure 10: Locations of the ULSM noise measurement locations near the Bainbridge Ferry Terminal. *16*

ACRONYMS AND ABBREVIATIONS

dB	decibel
Hz	hertz
μPa	micro-Pascal
NIST	National Institute of Standards and Technology
Pa	Pascal
RMS	root mean squared
s.d.	standard deviation
SEL	Sound Exposure Level
cSEL	Cumulative Sound Exposure Level
SL	sound level, regardless of descriptor
SPL	sound pressure level
SR	State Route
USFWS	U.S. Fish and Wildlife Service
WSF	Washington State Ferries
WSDOT	Washington State Department of Transportation

EXECUTIVE SUMMARY

This technical report describes the results of underwater sound level monitoring conducted during the vibratory driving of 12-inch steel H- piles at both the Bainbridge and Fauntleroy ferry terminals on October 16 and 24, 2018 respectively. The goal of these measurements were to collect vibratory measurements of steel H-piles. All measurements were collected at 10 meters from the pile at midwater depth.

The values measured at Fauntleroy were generally lower than those measured at Bainbridge Terminal (Table 1).

Table 1: Summary of 12-inch H-Pile Vibratory Underwater Sound Levels.

Pile #	Terminal	Lower Frequency Band (Hz)	RMS L_{50} (dB)	SEL L_{50} (dB)	Peak L_{50} (dB)	Cumulative SEL (dB)
1	Bainbridge	Broadband	152	162	172	186
		7	144	154	166	178
		50	130	140	156	164
		60	130	140	156	165
		150	115	125	148	149
		275	112	122	145	146
2		Broadband	153	163	175	190
		7	148	158	171	185
		50	134	144	160	169
		60	132	142	159	166
		150	120	130	153	156
		275	117	127	150	154
1	Fauntleroy	Broadband	137	147	161	160
		7	130	140	157	153
		50	125	135	156	151
		60	125	135	156	150
		150	115	125	148	141
		275	111	121	143	137

INTRODUCTION

This technical report presents the results of underwater noise monitoring conducted during the vibratory driving of 12-inch steel H-Piles at the existing Bainbridge and Fauntleroy ferry terminals on October 16, 2018 and October 24, 2018 respectively. This study was to gather data on vibratory driving of steel H-Piles.

Project Location

The Bainbridge ferry terminal is located in the city of Bainbridge west of Seattle (Figure 1) and is the western terminus of SR 305. Fauntleroy ferry terminal is located in the city of Fauntleroy south of Seattle and is the eastern terminus of SR 160 (Figure 2).

Figure 1: Bainbridge Ferry Terminal Location

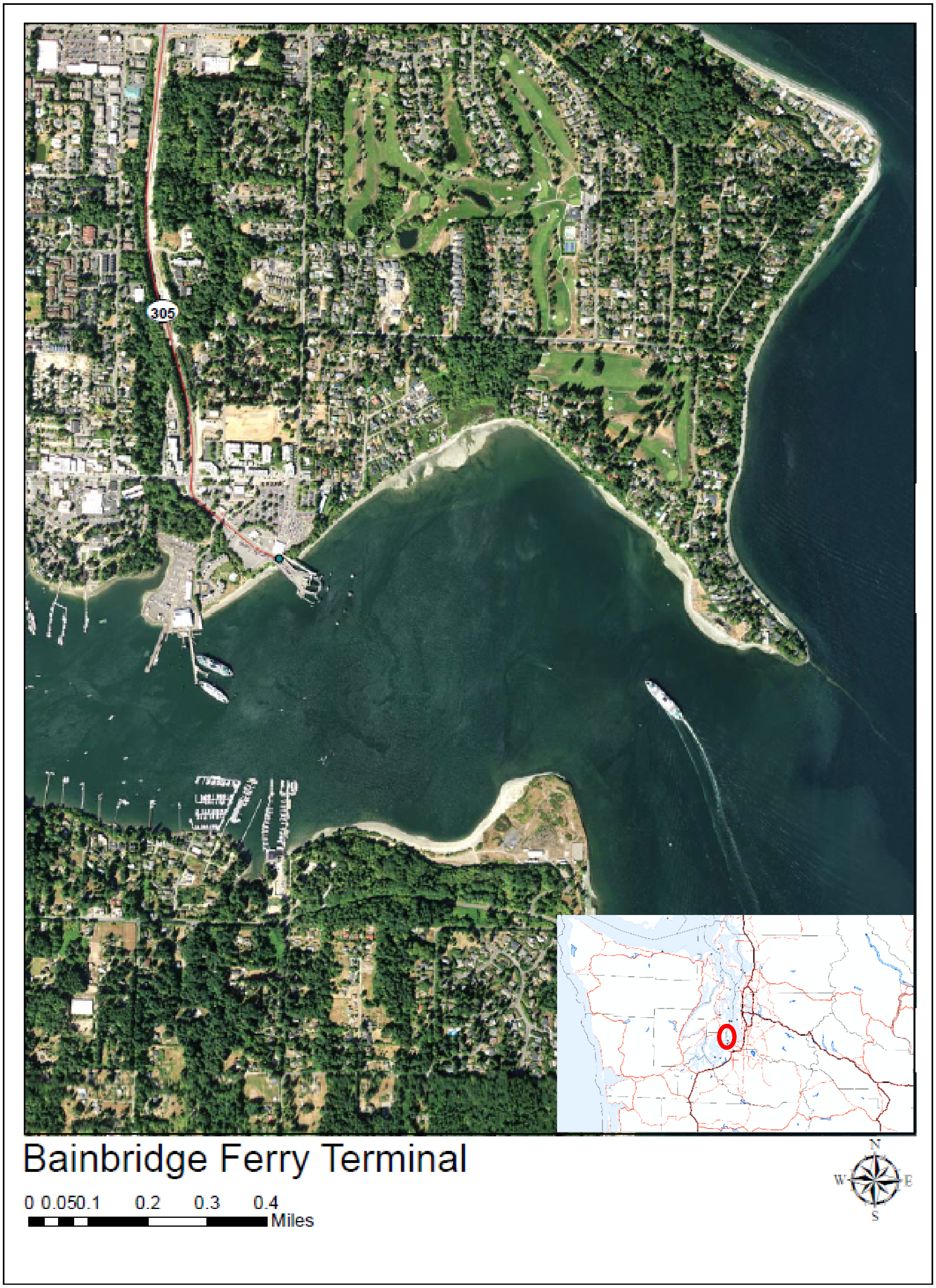
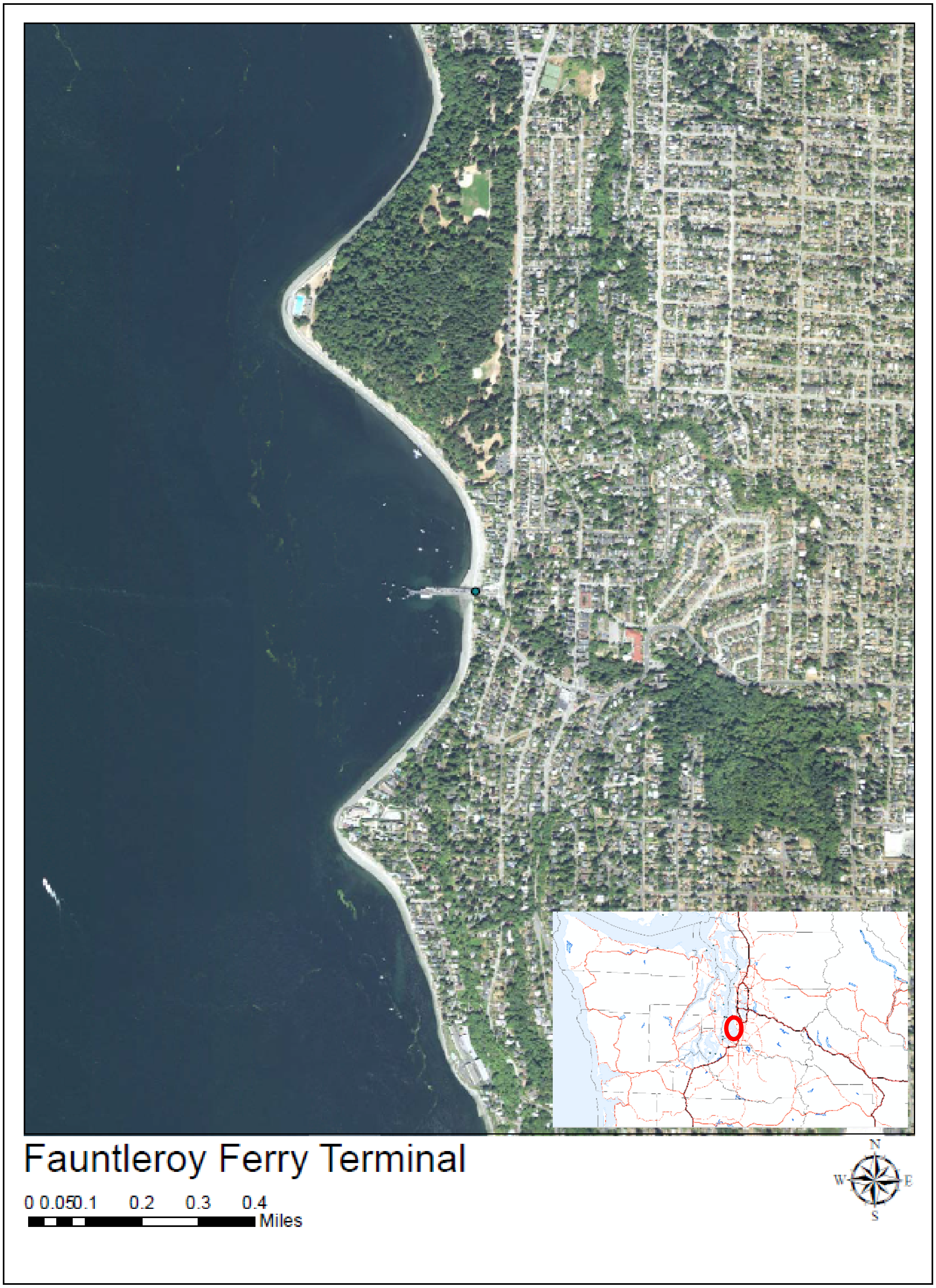


Figure 2: Fauntleroy Ferry Terminal Location



Project Description

H-Piles were driven with a vibratory hammer to provide additional seismic support to existing timber piles and structures at the Bainbridge and Fauntleroy ferry terminals. Two H-Piles at the Bainbridge ferry terminal (10/16/2018)and one H-Pile at the Fauntleroy ferry terminal (10/24/2018) were monitored for underwater noise during the vibratory pile driving activity to acquire additional data on vibratory driving of piles.

Monitoring Locations

All underwater noise monitoring was conducted on three 12-inch steel H-piles combined at two ferry terminals (Figures 3 and 4).

Figure 3: The location of the Bainbridge monitored pile

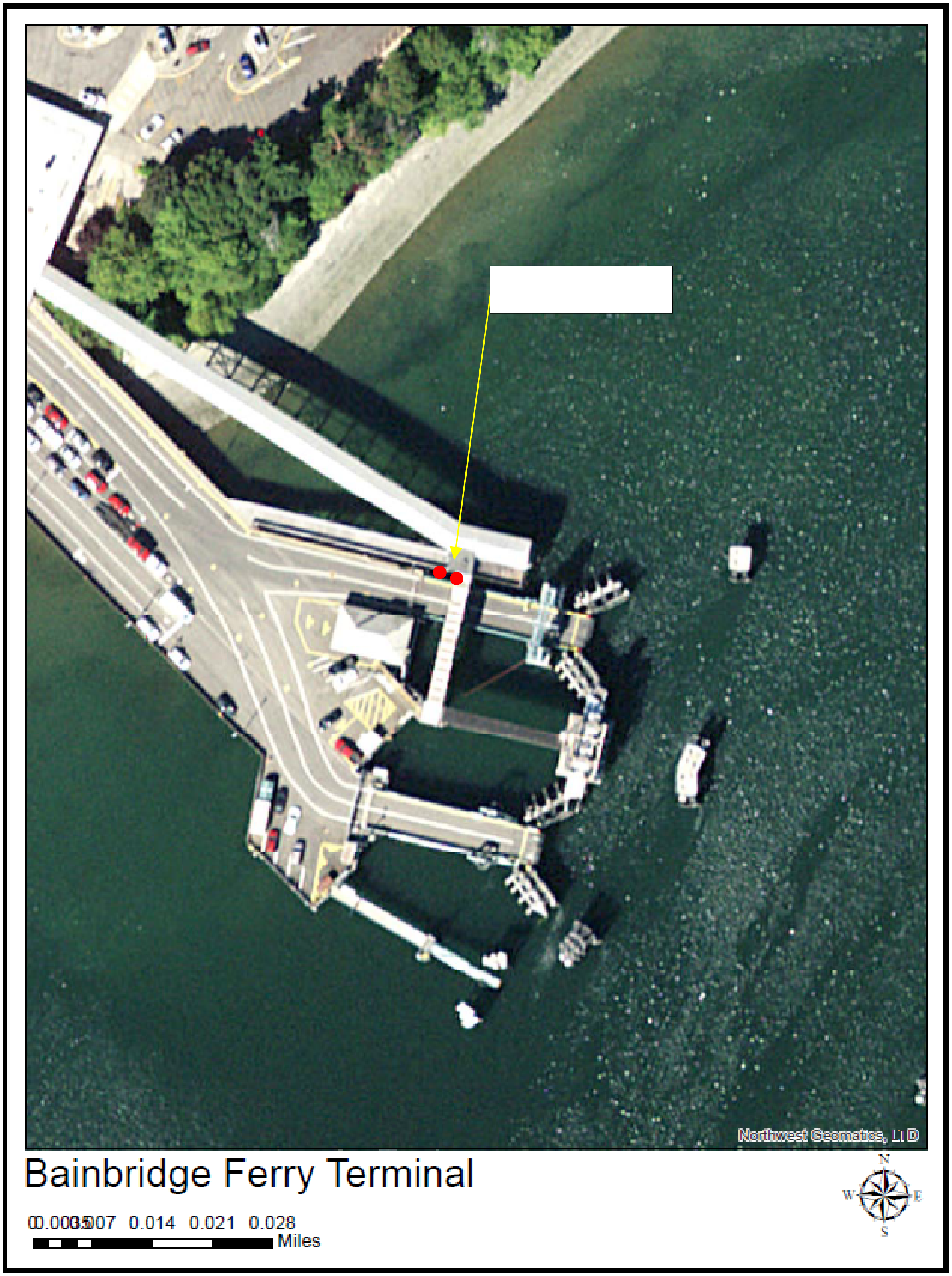
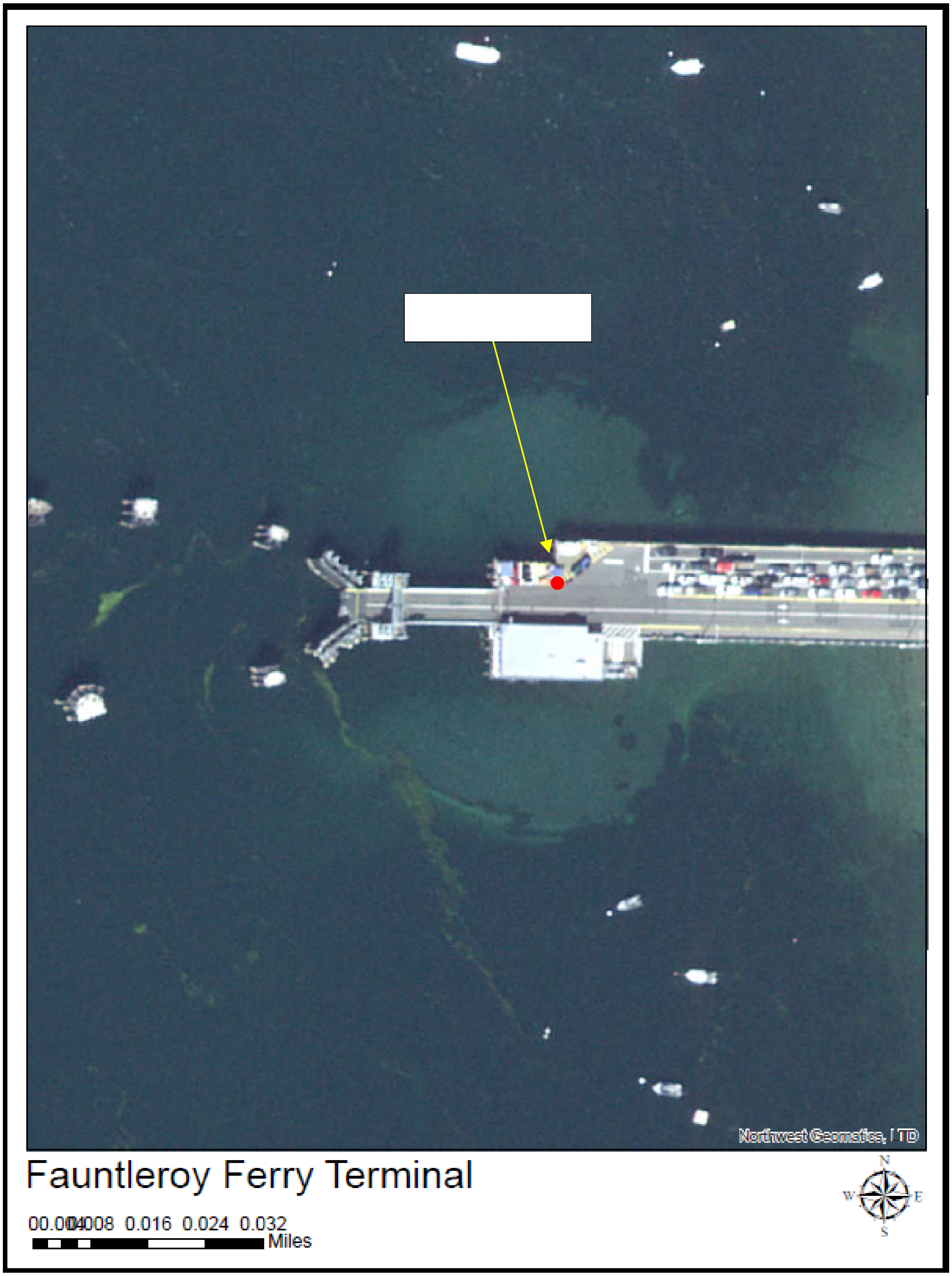


Figure 4: The location of the Fauntleroy monitored pile



CHARACTERISTICS OF UNDERWATER SOUND

Several descriptors are used to describe underwater noise impacts. Two common descriptors are the instantaneous peak sound pressure level (SPL) and the Root Mean Square (RMS) pressure level during the impulse. The majority of literature uses SPL to evaluate barotrauma injury to fish, whereas Cumulative Sound Exposure Level (cSEL) and RMS is used by the National Marine Fisheries Service (NMFS) in criteria for judging effects to marine mammals from underwater continuous and impulse-type sounds.

The peak SPL is the instantaneous maximum or minimum overpressure observed during each pulse and can be presented in Pascale (Pa) or decibels (dB) referenced to a pressure of 1 micro Pascal (μPa). Since water and air are two distinctly different media, a different sound level reference pressure is used for each. In water, the most commonly used reference pressure is 1 μPa whereas the reference pressure for air is 20 μPa. The equation to calculate the sound pressure level is:

Sound Pressure Level (SPL) = 20 log (p/p_{ref}), where p_{ref} is the reference pressure (i.e., 1 μPa for water) (eq. 1)

The RMS level is the square root of the energy divided by the impulse duration. This level, presented in dB re: 1 μPa, is the mean square pressure level of the pulse. Except where otherwise noted, sound levels reported in this report are expressed in dB re: 1 μPa.

Sound Exposure Level (SEL) is a measure of the total energy that an individual is exposed to over a given time period. For vibratory pile driving sound levels underwater the SEL is calculated for each individual 10-second interval using the RMS and the pulse duration over which the RMS is calculated (10-seconds). Then the SEL for each 10-second interval is accumulated for each pile drive and for all piles driven during a 24-hour period to determine the Cumulative SEL (cSEL). The injury thresholds for marine mammals, fish and marbeled murrelets are a cSEL threshold.

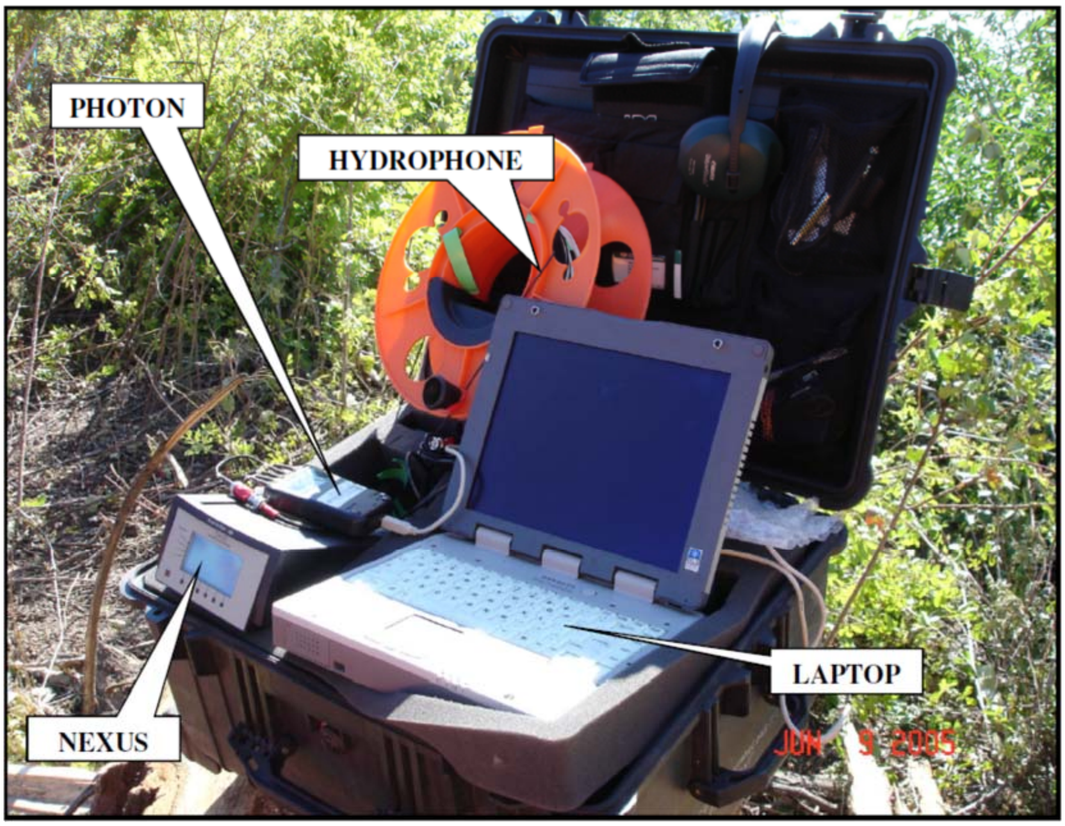
METHODOLOGY

Typical Equipment Deployment

Underwater sound levels were measured near the piles using a Reson TC 4013 hydrophone deployed on a weighted nylon cord from the monitoring location. The hydrophone was deployed from the side of the terminal transfer span near the piles being vibed and positioned at a distance of 10 meters and at mid-water depth (7.5 feet at Bainbridge and 7 feet at Fauntleroy terminal). The hydrophone was fixed in position with anchors and a surface float. The measurement system also includes a Bruel and Kjaer Nexus type 2692 4-channel signal conditioner, which kept the high underwater sound levels within the dynamic range of the signal analyzer. The output of the Nexus signal conditioner is received by a Bruel and Kjaer Photon 4-channel signal spectrum analyzer that is attached to a Dell ATG laptop computer.

The monitoring equipment is outlined below and shown in Figure 5.

Figure 5*: Near Field Acoustical Monitoring Equipment*



The equipment captures underwater sound levels from the pile driving operations in the format of an RTPro signal file for processing later. The system and software calibration is checked annually against the NIST traceable standard.

Hydroacoustic Data Analysis

The signal received by the Photon signal analyzer is stored as a proprietary digital signal file format. Data for the entire duration of each pile drive is captured and recorded in this manner. The peak sound pressure levels in units of Pascals are displayed on the screen during monitoring.

Signal analysis software provided with the Photon was set at a sampling rate of one sample every 20.8 μs (18,750 Hz). This sampling rate provides sufficient resolution to catch the peaks and other relevant data. The anti-aliasing filter included in the Photon also allows the capture of the true peak.

Due to the variability of the recording, an L_{50} peak and RMS value is computed to give an indication of the median value for each pile. The L_{50} or 50^{th} percentile is a statistical measure of the median value over the measurement period where 50 percent of the measured values are above the L_{50} and 50 percent are below.

Post analysis of the raw recordings were analyzed using Matlab software. The RMS was calculated for each 10-second interval with a 50% overlap. The SEL was calculated for each 10-second interval using the following equation, where τ is the time interval over which the RMS value is calculated (5 seconds):

$$SEL = RMS + 10\ LOG\ (\tau) \qquad \text{(eq. 3)}$$

From these results the cumulative SEL (cSEL) was calculated by accumulating each of these values for each pile and each day.

In addition, the raw data was weighted using the NOAA weighting functions (NMFS, 2018) for the different marine mamal functional hearing groups (Southall, 2007). The above calculations for RMS, SEL and cSEL were then repeated for each weighted dataset.

A Power Spectral Density plot was created using Matlab to show the differences in frequency composition between the different pile locations.

RESULTS

Underwater Sound Levels

WSDOT monitored a total of 3, 12-inch steel H-Piles for underwater noise, two H-piles at the Bainbridge ferry terminal and one at the Fauntleroy ferry terminal. Data from all piles monitored are presented in Tables 2 and 3 below.

The vibratory driving of the H-pile at Fauntleroy terminal was quieter than the H-piles at Bainbridge. On average, the Fauntleroy RMS values were approximately 15 dB to 16 dB quieter than the H-piles at Bainbridge. The vibratory drive at Bainbridge was also approximately 24 minutes longer than at Fauntleroy which in addition to the lower overall sound levels at least in part resulted in higher cSEL values at Bainbridge terminal (Table2).

Table 2: Summary of Underwater Sound Levels for the Bainbridge and Fauntleroy H-Piles

Pile #	Terminal	Lower Frequency Band (Hz)	RMS L_{50} (dB)	SEL L_{50} (dB)	Peak L_{50} (dB)	Cumulative SEL (dB)
1 10 /16/18	Bainbridge	Broadband	152	162	172	186
		7	144	154	166	178
		50	130	140	156	164
		60	130	140	156	165
		150	115	125	148	149
		275	112	122	145	146
2 10 /16/18		Broadband	153	163	175	190
		7	148	158	171	185
		50	134	144	160	169
		60	132	142	159	166
		150	120	130	153	156
		275	117	127	150	154
1 10 /24/18	Fauntleroy	Broadband	137	147	161	160
		7	130	140	157	153
		50	125	135	156	151
		60	125	135	156	150
		150	115	125	148	141
		275	111	121	143	137

Figure 6 is a Power Spectral Density plot representing the H-piles vibratory driven at Bainbridge terminal. The plot shows that most of the energy for driving the H-piles are in the range between approximately 20 Hz and 800 Hz. Both H-piles monitored at Bainbridge followed the same general trend.

Figure 6*: Power Spectral Density Plot for the Pile 1H-Pile Driven at Bainbridge Terminal*

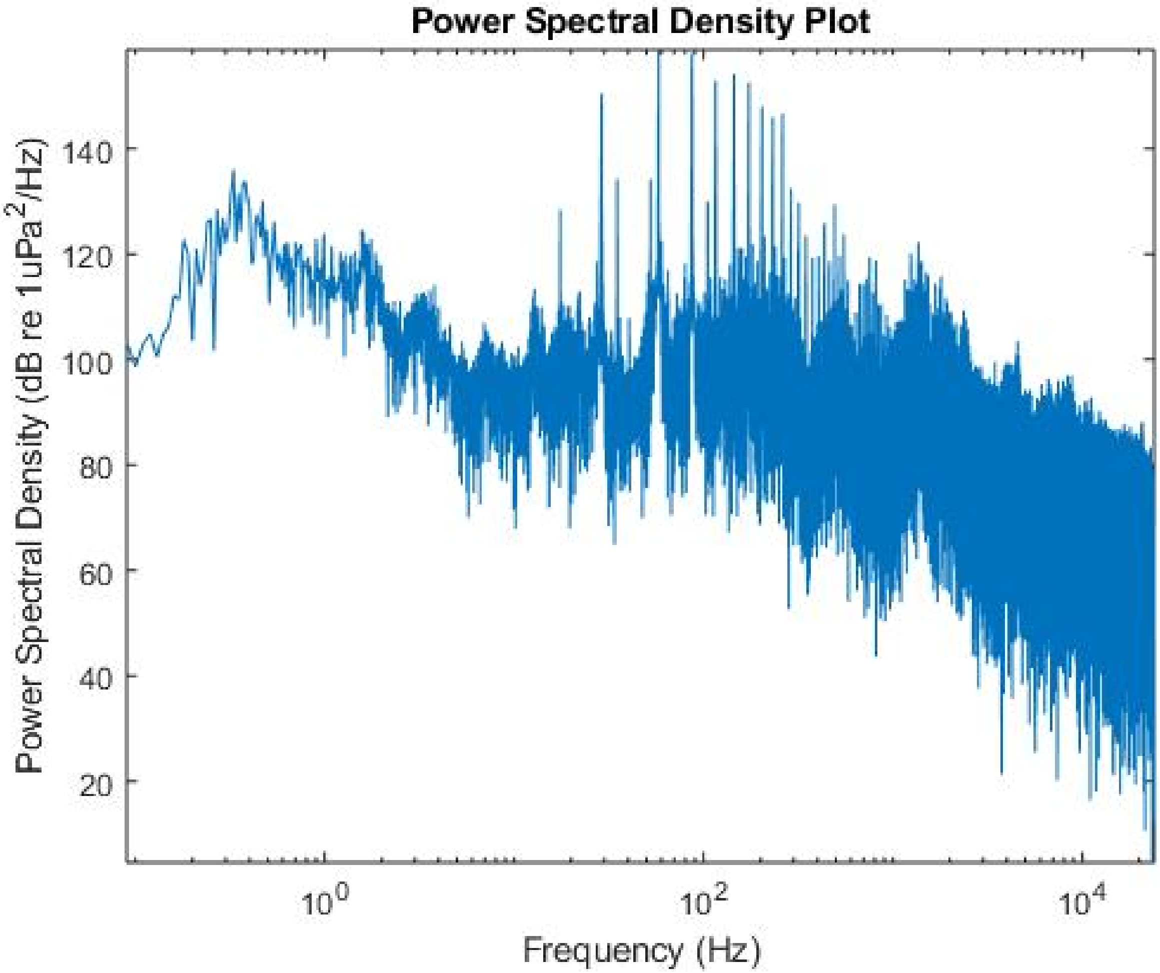


Figure 7 is a Spectrogram representing Pile 1 H-pile vibratory driven at Bainbridge terminal. The plot shows that most of the energy for driving the H-piles are below 800 Hz with another energy band at around 1500 Hz. Both H-piles monitored at Bainbridge followed the same general trend.

Figure 7*: Spectrogram for the H-Pile Driven at Bainbridge Terminal*

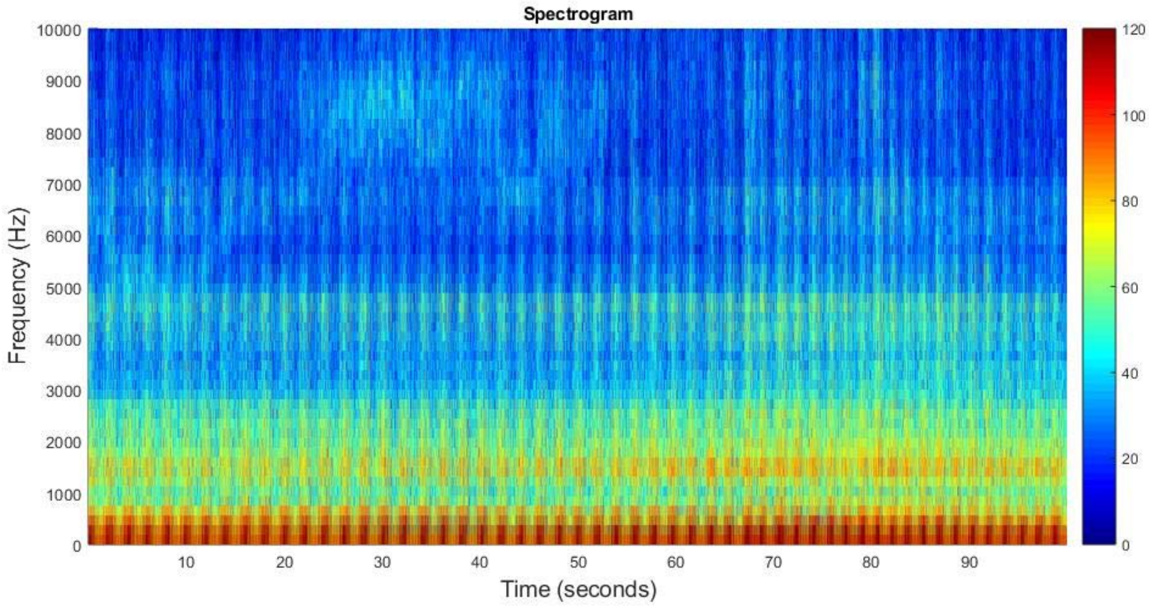


Figure 8 is a Power Spectral Density plot representing the H-pile vibratory driven at Fauntleroy terminal (10/26/2016). The plot shows that most of the energy for driving the H-piles are in the range between approximately 20 Hz and 800 Hz which is the same as the Bainbridge H-piles, however, the overall sound levels for individual frequencies are about 30 dB lower than those for Bainbridge terminal. This is likely due to differences in the substrate composition between the two terminal facilities. The H-piles at the Bainbridge terminal encountered subsurface rocks during the pile driving which can increase the overall energy levels generated by the pile.

Figure 8*: Power Spectral Density Plot for the H-Pile Driven at Fauntleroy Terminal*

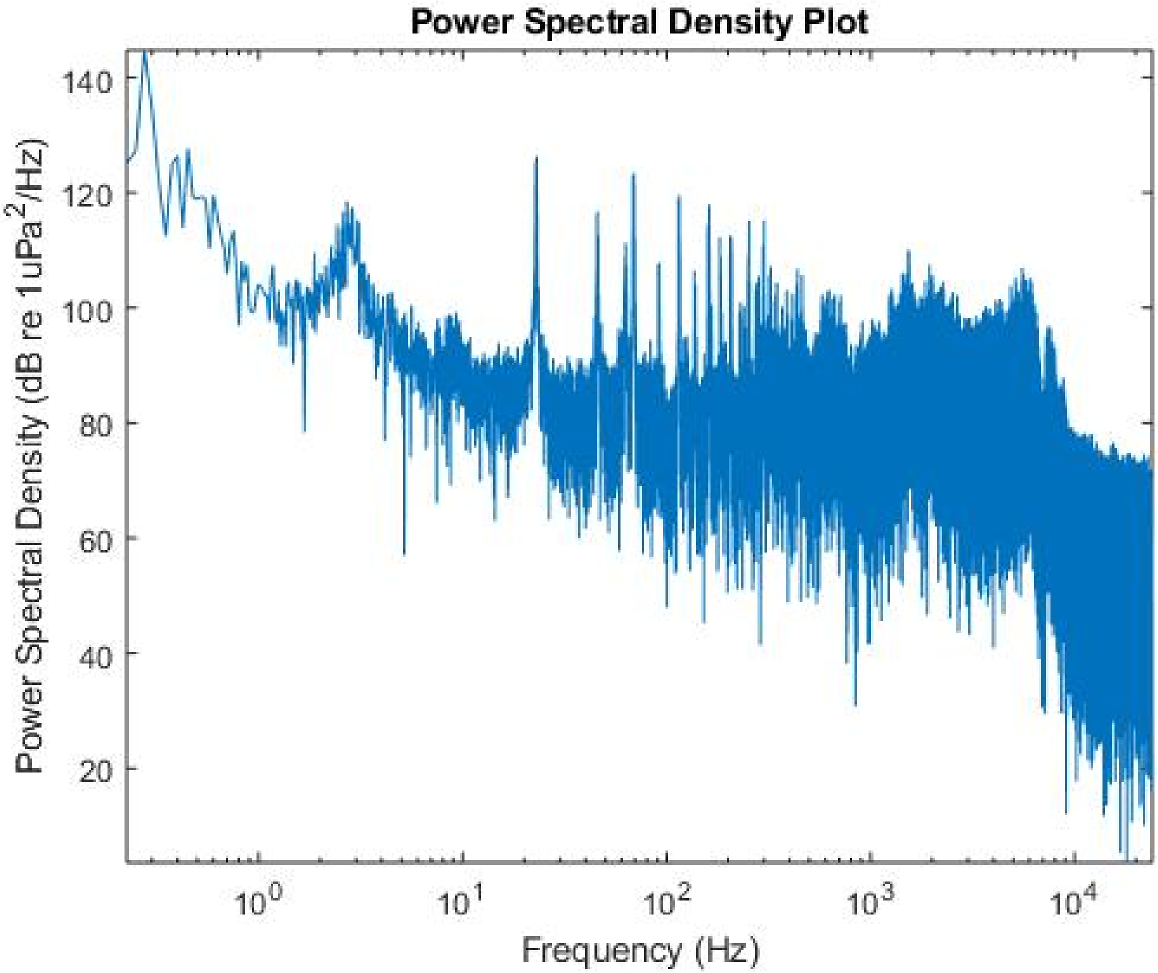
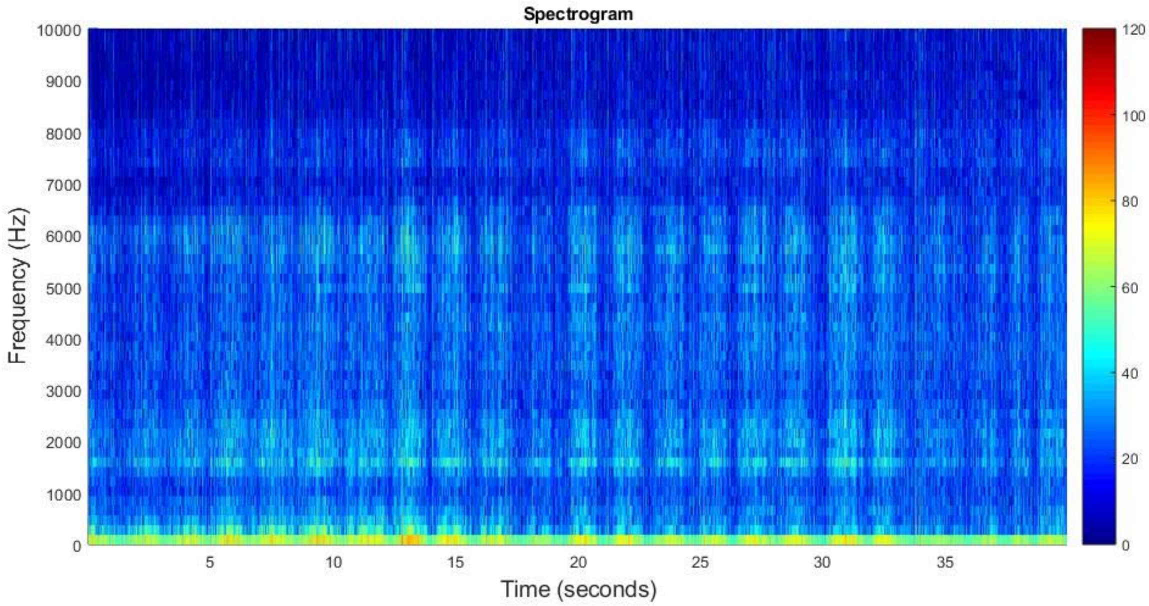


Figure 9 is a Spectrogram representing the H-pile vibratory driven at Fauntleroy terminal. The plot shows that most of the energy for driving the H-pile is less than about 30 Hz and a lesser band of energy at approximately 1500 Hz. The overall energy levels from this H-pile were lower than at Bainbridge.

Figure 9*: Spectrogram for the H-Pile Driven at Fauntleroy Terminal*



Daily Cumulative SEL

The daily cSEL's were calculated using an actual individual SEL value calculated for every 10 seconds of each pile for each day and accumulated over that period (Table 3).

Table 3: Summary of daily cumulative SEL's

Day	Lower Frequency Band (Hz)	Daily Cumulative SEL (dB)
10/16/2018	Broadband	191
	7	185
	50	168
	60	171
	150	157
	275	154
10/24/2018	Broadband	160
	7	153
	50	151
	60	150
	150	141
	275	137

Underwater Sound Level Meter (USLM)

Measurements were collected in real time during vibratory driving near the Bainbridge Ferry terminal to detect the outer boundary of the Zone of Influence (ZOI) during the installation of one 12-inch steel H-pile. Data was collected using the Underwater Sound Level Meter (USLM) deployed from a boat with the motor off at distances of 4.65, 4.68 4.91 and 5.00 miles from the source on October 16, 2018 (Figure 10). Measurements were collected in approximately 2 minute increments. The measurement at 5.00 miles was discarded due to interference from a nearby ferry vessel.

The measurements were collected using the updated 2018 USLM and software where the Marine Mammal Hearing weighting functions for the RMS calculations were updated to the newest NMFS guidance.

Measurements

For the Bainbridge Ferry Terminal the Seattle background daytime RMS sound levels were used (WSDOT, 2015) since we have not collected background underwater sound levels for Bainbridge Terminal at this time and Seattle is the nearest terminal with measurements.

Table 4 summarizes the results of the measurements and indicates that all of the measured values are above background sound levels. However, when the recordings are played back they are audible at the 4.65 mile and 4.68 mile range but are not audible at the 4.91 mile range. Therefore the ZOI boundary should be at 4.91 miles from the Bainbridge Terminal.

Figure 10: Locations of the ULSM noise measurement locations near the Bainbridge Ferry Terminal.

Table 4: Summary Table of Underwater Monitoring of Broadband and Marine Mammal Functional Hearing Groups During Installation of one 12-inch Steel H-pile at Bainbridge Ferry Terminal with the Underwater Sound Level Meter (USLM).

Functional Hearing Group		Distance to Pile (miles)	Average RMS (dB)	Background Sound Level (dB)	Detectable? (Y/N)
	Broadband	4.65	148	120	Y
		4.68	148		Y
		4.91	145		N
	Low Frequency	4.65	131	117	Y
		4.68	128		Y
		4.91	120		N
	Mid Frequency	4.65	123	108	Y
		4.68	112		Y
		4.91	100		N
	High Frequency	4.65	120	106	Y
		4.68	110		Y
		4.91	98		N
	Otariids	4.65	130	113	Y
		4.68	121		Y
		4.91	111		N
	Phocids	4.65	130	113	Y
		4.68	121		Y
		4.91	111		N

SUMMARY

Three, 12-inch steel H-piles were monitored at a 10 meter range during the vibratory pile driving activity at Bainbridge and Fauntleroy ferry terminals. The first of the two 12-inch steel H-piles at Bainbridge Terminal was also monitored at a range of approximately 5 miles from the pile. The underwater sound levels analyzed are as follows:

Near Source Levels -

- Peak broadband underwater 50^{th} percentile (L_{50}) sound levels at 10 meters varied in a range between 161 dB and 175 dB for the three piles with the pile at Fauntleroy being at the low end of the range.
- The broadband L_{50} RMS levels ranged between 137 dB_{RMS} and 153 dB_{RMS} for the H-piles.
- Broadband cumulative Sound Exposure Levels (cSEL) for the H-piles ranged between 160 dB_{cSEL} and 190 dB_{cSEL} and 153 dB_{cSEL} and 191 dB_{cSEL} for the daily cSEL.
- The H-pile driven at Fauntleroy pile was quieter than the H-piles driven at Bainbridge which is likely due to substrate differences between the two sites.

ZOI Levels -

- The ZOI boundary at which the broadband sound levels were not audible during playback is 4.91 miles.
- USLM RMS measured values were below the background sound levels for broadband and all functional hearing groups except for the mid-frequency cetaceans, high-frequency cetaceans, otariids and phocids at the 4.91 mile range. This could be due to some other low frequency noise source such as vessel noise influencing the recording slightly.

REFERENCES

NMFS- National Marine Fisheries Service. 2018. 2018 Revision to: *Technical Guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammal Hearing (Version 2.0): Underwater Thresholds for Onset Permanent and Temporary Threshold Shifts*. U.S. Department of Commerce, NOAA. NOAA Technical Memorandum NMFS-OPR-59. 167 pp.

Southall, B.L., A.E. Bowles, W.T. Ellison, J.J. Finneran, R.L. Gentry, C.R. Greene, D. Kastak, D.R. Ketten, J.H. Miller, P.E. Nachtigall, W.J. Richardson, J.A. Thomas, and P.L. Tyack. 2007. Marine Mammal Noise Exposure Criteria: Initial Scientific Recommendations. Aquatic Mammals 33(4): 411-521.

WSDOT, 2015. Compendium of Background Sound Levels for Ferry Terminals in Puget Sound.