ELLIOTT BAY SEAWALL PROJECT SEASON 3 (2016) ACOUSTIC MONITORING REPORT (NWS-2011-778-WRD and NWR-2013-10650)

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1.0 EXECUTIVE SUMMARY

This Technical Report presents the results of airborne and underwater sound level measurements conducted in January and February 2016 during the installation of the first five unobstructed steel sheet piles driven with a vibratory hammer and five obstructed sheet piles driven with a diesel impact hammer. This monitoring was conducted during Season 3 (2015/2016 in-water work window) of the Elliott Bay Seawall Project (“Project”).

Vibratory sheet pile installation produced average underwater 10-second root mean square (RMS) sound levels ranging between 153 and 164 decibels (dB) re: 1 micropascal (μPa) and average peak values between 169 and 182 dB re: 1 μPa. Measured underwater sound levels generated by full powered vibratory pile driving are summarized in Table 1.1 below.

Table 1.1 Measured Underwater Sound Levels from Vibratory Pile Driving, dB re: 1 μPa

Pile ID	Frequency Range	Peak				RMS				SEL			
		Min	Max	SD	Avg	Min	Max	SD	Avg	Min	Max	SD	Avg
January 14, 2016													
VIB-1	7 Hz-20 kHz	169	182	2	**176**	150	161	2	**157**	147	163	2	**157**
	75 Hz-20 kHz	169	182	3	**176**	150	161	2	**156**	147	163	2	**156**
	150 Hz-20 kHz	169	182	3	**176**	150	161	2	**156**	146	163	2	**156**
	200 Hz-20 kHz	169	182	3	**176**	150	161	2	**156**	146	163	2	**156**
January 15, 2016													
VIB-1	7 Hz-20 kHz	173	190	4	**181**	148	166	4	**160**	148	172	2	**161**
	75 Hz-20 kHz	174	190	4	**181**	147	166	4	**159**	147	172	3	**160**
	150 Hz-20 kHz	174	190	4	**181**	147	166	4	**159**	146	172	3	**160**
	200 Hz-20 kHz	174	190	4	**181**	147	166	4	**159**	143	172	3	**160**
VIB-2	7 Hz-20 kHz	175	186	2	**182**	153	168	2	**164**	150	168	2	**164**
	75 Hz-20 kHz	175	185	2	**181**	151	166	3	**162**	146	167	2	**162**
	150 Hz-20 kHz	175	185	2	**181**	150	166	3	**162**	146	167	2	**162**
	200 Hz-20 kHz	175	185	2	**181**	150	166	3	**162**	146	167	2	**162**
VIB-3	7 Hz-20 kHz	165	183	4	**175**	147	167	4	**158**	149	167	4	**159**
	75 Hz-20 kHz	165	183	4	**174**	143	163	4	**156**	145	164	4	**157**
	150 Hz-20 kHz	166	183	4	**174**	143	163	4	**156**	145	164	4	**157**
	200 Hz-20 kHz	166	183	4	**174**	143	163	4	**156**	145	164	4	**157**
VIB-4	7 Hz-20 kHz	166	188	2	**175**	141	167	2	**161**	147	167	2	**161**
	75 Hz-20 kHz	167	187	3	**174**	145	162	3	**155**	146	163	3	**156**
	150 Hz-20 kHz	166	185	3	**174**	145	162	3	**155**	146	163	3	**156**
	200 Hz-20 kHz	166	184	3	**174**	145	162	3	**155**	146	163	3	**156**
VIB-5	7 Hz-20 kHz	166	174	2	**171**	144	164	4	**157**	148	164	3	**158**
	75 Hz-20 kHz	165	174	2	**169**	143	157	3	**153**	145	159	2	**153**
	150 Hz-20 kHz	165	174	2	**169**	143	157	3	**153**	145	159	2	**153**
	200 Hz-20 kHz	165	173	2	**169**	143	157	3	**153**	145	159	2	**153**

Note: Underwater sound levels were measured 32 to 38 feet (10 to 12 meters) from the piles.
Source: The Greenbusch Group, Inc.

Underwater sound levels produced by vibratory pile driving during Season 3 were below the sound levels predicted in the memorandum authored by The Greenbusch Group titled "EBSP Season 2 Hydroacoustic Monitoring Approach" dated October 6, 2014, as well as the anticipated sound levels listed in the Project's Biological Opinion.

Average 10-second RMS airborne sound levels produced by vibratory sheet pile installation ranged between 101 and 106 dB re: 20 μPa at 50 feet (15 meters). Measured airborne sound levels are summarized in Table 1.2.

Table 1.2 Measured Airborne Sound Levels from Vibratory Pile Driving, dB re: 20 μPa

Pile ID	Minimum	Maximum	Average
January 14, 2016			
VIB-1	93	105	101
January 15, 2016			
VIB-1	99	106	104
VIB-2	97	108	105
VIB-3	97	107	104
VIB-4	97	109	103
VIB-5	99	108	106

Note: Airborne sound levels measured 50 feet (15 meters) from the piles.
Source: The Greenbusch Group, Inc.

Average underwater 90% RMS (RMS_{90}) sound levels generated by impact pile driving ranged between 177 and 179 dB re: 1 μPa and produced average peak values between 190 and 193 dB re: 1 μPa. Measured underwater sound levels generated by the diesel impact hammer are summarized in Table 1.3.

Table 1.3 Measured Underwater Sound Levels from Impact Pile Driving, dB re: 1 μPa

Pile ID	Frequency Range	Peak				RMS$_{90}$				SEL				cSEL
		Min	Max	SD	Avg	Min	Max	SD	Avg	Min	Max	SD	Avg	
IMP-1	7 Hz-20 kHz	189	199	2	**193**	175	183	1	**179**	161	168	1	**165**	**188**
	75 Hz-20 kHz	189	199	2	**193**	175	183	1	**179**	161	168	1	**165**	**188**
	150 Hz-20 kHz	189	199	2	**193**	175	183	1	**179**	161	168	1	**165**	**188**
	200 Hz-20 kHz	189	199	2	**193**	175	183	1	**179**	161	168	1	**165**	**188**
IMP-2	7 Hz-20 kHz	187	194	2	**190**	175	181	1	**177**	161	167	1	**164**	**180**
	75 Hz-20 kHz	187	194	2	**190**	175	181	1	**177**	161	167	1	**164**	**180**
	150 Hz-20 kHz	187	194	2	**190**	175	181	1	**177**	161	167	1	**164**	**180**
	200 Hz-20 kHz	187	195	2	**190**	175	181	1	**177**	161	167	1	**164**	**180**
IMP-3	7 Hz-20 kHz	186	192	2	**190**	175	180	2	**177**	162	166	1	**164**	**173**
	75 Hz-20 kHz	186	192	2	**190**	175	180	2	**177**	162	166	1	**164**	**173**
	150 Hz-20 kHz	186	192	2	**190**	175	180	2	**177**	162	166	1	**164**	**173**
	200 Hz-20 kHz	187	192	2	**190**	175	180	2	**177**	162	166	1	**164**	**173**
IMP-4	7 Hz-20 kHz	182	193	2	**190**	169	178	1	**177**	156	164	1	**163**	**180**
	75 Hz-20 kHz	182	193	2	**190**	170	178	1	**177**	156	164	1	**163**	**180**
	150 Hz-20 kHz	181	193	2	**190**	170	178	1	**177**	156	164	1	**163**	**180**
	200 Hz-20 kHz	181	193	2	**190**	170	178	1	**177**	156	164	1	**163**	**180**
IMP-5	7 Hz-20 kHz	187	194	2	**191**	176	182	2	**178**	162	167	1	**165**	**180**
	75 Hz-20 kHz	187	194	2	**191**	176	182	2	**178**	162	167	1	**165**	**180**
	150 Hz-20 kHz	187	194	1	**191**	176	182	2	**178**	162	167	1	**165**	**180**
	200 Hz-20 kHz	187	194	2	**191**	182	176	2	**178**	162	167	1	**165**	**180**

Note: Underwater sound levels are normalized to 33 feet (10 meters) using the practical spreading model.
Source: The Greenbusch Group, Inc.

Measured underwater sound levels generated by impact pile driving during Season 3 were below the anticipated sound levels provided in the Project's Biological Opinion.

The average airborne sound levels produced by impact pile driving ranged between 106 and 108 dB re: 20 μPa and are summarized in Table 1.4.

Table 1.4 Measured Airborne Sound Levels from Impact Pile Driving, dB re: 20 μPa

Pile ID	Minimum	Maximum	Average
IMP-1	106	111	108
IMP-2	105	112	108
IMP-3	105	108	106
IMP-4	105	108	107
IMP-5	105	109	106

Note: Airborne sound levels measured 50 feet (15 meters) from the piles.
Source: The Greenbusch Group, Inc.

Based on the highest recorded broadband RMS value from vibratory sheet pile installation, the distance required for underwater sound levels to reach the marine mammal detection (Level B) threshold of 120 dB re: 1 μPa was calculated to be up to 5.4 miles (8.7 kilometers). The calculated distance required for the highest measured RMS_{90} sound level generated by impact driving of steel sheet piles to reach the 160 dB re: 1 μPa marine mammal detection (Level B) threshold is 610 feet (186 meters).

Two different background sound level measurements were performed to assess underwater sound levels in Elliott Bay in the absence of in-water construction activities. One set of measurements determined background sound levels near the pile driving activities (near shore) and the other set (far field) was conducted to verify the results of previous measurements made during Season 2 and by the Washington State Department of Transportation (WSDOT) in 2011. Average background sound levels are summarized in Table 1.5.

Table 1.5 Average Underwater Background Sound Levels, dB re: 1 μPa

Functional Hearing Group	Frequency Range	WSDOT Background Sound Level	Far Field Background Sound Level	Near Shore Background Sound Level
Low-Frequency Cetaceans	7 Hz – 20 kHz	130	126	127
Mid-Frequency Cetaceans	150 Hz – 20 kHz	124	119	125
High-Frequency Cetaceans	200 Hz – 20 kHz	124	118	125
Pinnipeds	75 Hz – 20 kHz	127	120	126

Note: The median was used to report the average background sound levels
Source: The Greenbusch Group, WSDOT report titled "Compendium of Background Sound Levels for Ferry Terminals in Puget Sound" issued April, 2014

Utilizing the highest measured average underwater RMS sound level produced during vibratory steel sheet pile installation in each marine mammal functional hearing group and the average background sound levels ranging between 124 dB and 130 dB collected by WSDOT in 2011, the distances required to reach background sound levels (Level B) are up to 2.1 miles (3.4 kilometers).

The calculated distance required for the highest measured average RMS_{90} sound level of 179 dB produced by impact driving of steel sheet piles to reach background sound levels is up to 29 miles (46.7 kilometers) using the background sound data collected by WSDOT. However, these distances are reduced due to the proximity of adjacent land masses. The WSDOT background sound levels were used rather than the near shore data collected by Greenbusch in 2016 because the WSDOT data more accurately describes the environment where marine mammals are likely to be present.

2.0 INTRODUCTION

This Technical Report presents the results of airborne and underwater sound levels measured during vibratory and impact pile driving of steel sheet piles associated with Season 3 (2015/2016 in-water work window) of the Elliott Bay Seawall Project ("Project").

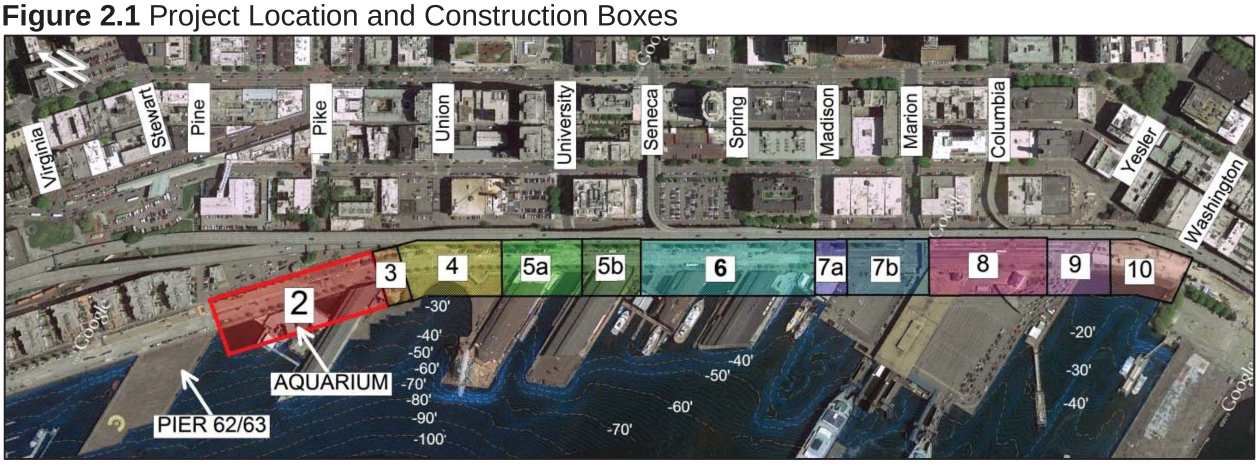
Consultation with the National Oceanic and Atmospheric Administration (NOAA) and the U.S. Fish and Wildlife Service (USFWS) under the Marine Mammal Protection Act (MMPA) and the Endangered Species Act (ESA) requires sound level monitoring for the first five unobstructed piles of each pile type and installation method. This Acoustic Monitoring Technical Report fulfills the requirements of the Project's Biological Opinion issued by NOAA and USFWS, and the MMPA Letter of Authorization (LOA), issued by NOAA.

The Project construction area is located on Alaskan Way between Washington Street and Virginia Street in Seattle, Washington. Airborne and underwater sound level measurements were conducted between January 14 and February 8, 2016 during the installation of unobstructed and obstructed steel sheet piles between the Seattle Aquarium and Pier 62/63 in Seattle, Washington. This area is located in Box 2 between Union Street and Pine Street (see Figure 2.1).

Marine mammal monitoring for pile installation began on January 14, 2016 and coincided with the beginning of acoustic monitoring. During Season 3, sound levels were measured from the first five unobstructed sheet piles driven with a vibratory hammer. Sound levels were also measured during the impact installation of five piles. However, they were neither the first five, nor were they unobstructed. This was due to a delay in monitoring that resulted from coordination with NOAA regarding the agency's desire for monitoring data during concurrent operation of multiple pile drivers.

Underwater sound levels were also measured near a buoy in Elliott Bay during the impact pile driving to determine whether sound levels generated by pile driving exceeded the disturbance and injury thresholds for pinnipeds. Pile installation with an impact hammer only occurred when the vibratory hammer was unable to drive the pile to the required depth, as required by the Project's LOA and Biological Opinion. No concrete or other types of piles were installed during Season 3.

Figure 2.1 Project Location and Construction Boxes



Source: The Greenbusch Group, Inc. Google Earth Pro, Mortenson/Manson

3.0 NOMENCLATURE

The auditory response to sound is a complex process that occurs over a wide range of frequencies and intensities. Decibel levels, or “dB,” are a form of shorthand that compresses this broad range of levels with a convenient, logarithmic scale.

Decibels are defined as the squared ratio of the sound pressure level (SPL) with a reference sound pressure. The reference pressure for airborne sound is 20 micropascals (μPa) and for underwater sound the reference pressure is 1 μPa. The use of 20 μPa in air is convenient because 1 dB re: 20 μPa correlates to the human threshold for hearing. It is important to note that because of these different reference pressures, airborne and underwater sound levels cannot be directly compared.

The following descriptors are referenced in this Report:

- **Background Sound Level**

  The background sound level is the sound pressure level that describes the sound environment at a specified location during a specified time period and is also referred to as “ambient sound levels”. The measured sound levels include contributions from all sound sources, both local and distance, excluding specific sound sources of interest or under investigation.

- **Peak**

  The peak sound pressure level is the instantaneous absolute maximum pressure observed during a measured event. Peak pressure can be presented as a pressure or dB referenced to a standard pressure (20 μPa for airborne and 1 μPa for underwater). Peak sound pressure is commonly used during hydroacoustic monitoring to assess the potential injuries to fish.

- **Root Mean Square (RMS)**

  The RMS level is the square root of the average squared-pressure over a given time period. For vibratory pile driving RMS levels are calculated over 10 second periods. In hydroacoustics, the RMS level has been used by the National Marine Fisheries Service (NMFS) in criteria for assessing impacts to marine mammals.

- **90% Root Mean Square (RMS_{90})**

  The RMS_{90} level is used for the analysis of impact pile driving and is the RMS level containing 90 percent of the energy in a pile strike. The RMS_{90} energy is established between the 5% and 95% of the pile energy and is calculated for each pile strike.

- **Sound Exposure Level (SEL)**

  The SEL is the squared sound pressure integrated or summed over time referenced to a standard pressure squared (20 μPa for airborne and 1 μPa for underwater) normalized to one second and converted to decibels.

- **Cumulative Sound Exposure Level (cSEL)**

  The cSEL is the SEL accumulated over time. In this report cSEL is calculated by adding the SEL corresponding to the absolute maximum peak pile strike to ten times the log of the number of pile strikes.

4.0 REGULATORY CRITERIA

Anticipated underwater sound levels from the Project's Biological Opinion are presented in Table 4.1 below.

Table 4.1 Predicted Unmitigated Underwater Sound Levels (ESA and MMPA Consultation)

Pile Type and Approximate Size	Method	Relative Water Depth of Piles	Average Sound Pressure Measured in dB re: 1 μPa	
			Peak	RMS
16.5 inch diameter precast concrete octagonal pile	Impact	~15 meters	188	176
Steel sheet pile pair, 48 inches long per pair	Vibratory (Installation and Removal)	~15 meters	182	165
Steel sheet pile pair, 48 inches long per pair	Impact (Installation Proofing)	~15 meters	205	190

Source: EBSP Updated Marine Mammal Monitoring and Mitigation Plan (April 2013), EBSP Biological Opinion (September 2013)

Because some of the piles driven in Season 1 exceeded the underwater sound levels indicated above, measured sound levels from Season 1 vibratory pile driving were used to estimate more realistic sound levels for subsequent EBSP pile installation. These predicted sound levels are included in a memorandum authored by The Greenbusch Group dated October 6, 2014 and were attached to the Season 2 Letter of Authorization (LOA) issued by NOAA. Table 4.2 provides these predicted underwater sound levels for vibratory pile installation based on data collected during Season 1.

Table 4.2 Predicted Unmitigated Underwater Sound Levels (Based on Season 1 Sound Levels)

Predicted Season 2 Sound Levels	Average / Maximum Sound Levels at 10 meters, dB re: 1 μPa		
	Peak	RMS	SEL[1]
Vibratory Sheet Pile Installation	188 / 196	163 / 169	163 / 169

1. 1-second SEL

Source: Greenbusch Memorandum titled "EBSP Season 2 Hydroacoustic Monitoring Approach" dated October 6, 2014

Sound levels provided in Table 4.1 and Table 4.2 are established 33 feet (10 meters) from the pile. RMS sound levels for piles driven with an impact hammer are RMS_{90} sound levels.

The Project's LOA and Biological Opinion require reporting of underwater sound levels generated by the first five unobstructed piles of each pile type and driving method shown in Table 4.1 above. These reported sound levels must include the frequency spectrum, ranges, means and standard deviation for the peak and RMS sound pressure levels for each marine mammal functional hearing group, as well as the estimated distance required for the RMS values to reach the marine mammal thresholds and background sound levels. During impact pile driving, the pile strike resulting in the absolute highest peak sound pressure level must be used to calculate the cSEL of the pile drive.

As requested by NOAA during a conference call on September 22, 2014, sound levels measured during ramp-up activities are reported separately from sound levels measured during pile driving under full power. In addition, NOAA requested sound level data to include the range of SEL values.

Consultation with NOAA and USFWS under the MMPA and ESA also requires collection of underwater background sound levels. As a result of the September 22, 2014 coordination with NOAA, USFWS and SDOT, the parties agreed that background sound level data would be collected between 500 and 1,000 meters from the construction area to verify that sound levels reported by WSDOT in 2011 had not changed and that additional data would be collected approximately 10 meters from the monitored piles during Season 2. Although background sound level measurement locations for Season 3 are not specified in the Project's Biological Opinion or LOA, during Season 3 background sound levels were collected in Elliott Bay to verify the underwater sound levels collected by WSDOT had not changed and another set of data was collected near the pile driving locations.

During Season 3, NOAA suspended the requirement to collect underwater sound data from the first five unobstructed piles of each pile type and installation method to allow for underwater sound levels to be measured near a buoy in Elliott Bay where sea lions congregate. These measurements were used to determine whether underwater sound levels generated by pile driving were above the disturbance (Level A) and injury (Level A) thresholds for pinnipeds.

5.0 PILE AND PILE DRIVING EQUIPMENT INFORMATION

During Season 3, all steel sheet pile installation was initiated with a vibratory hammer. In some instances, the vibratory hammer was unable to drive the piles to the required depth and it was necessary to drive the remainder of the pile with an impact hammer. The steel sheet pile wall consists of two different types of sheet pile. AZ38 and AZ26 are 57 feet long and 50 feet long respectively. Two sheets of each type are welded together prior to being driven. Pile pairs alternate in length such that every other pair is driven to a deeper depth. Generally, the substrate the sheet piles were driven into was hard, rocky and covered with silt and marine debris.

Sheet piles were installed using an APE 250VM Vibratory Driver/Extractor operating at a frequency of 1,750 VPM and generated a driving force of 196 tons. The suspended weight with a clamp and 75-foot long hose weighs 17,500 pounds. A cut sheet of the APE 250VM Vibratory Driver/Extractor can be found in the Appendix of this Report. Table 5.1 presents a summary of the sheet piles driven with the vibratory hammer while sound level monitoring was occurring.

Table 5.1 Summary of Sheet Piles Driven with a Vibratory Hammer, Feet

Pile ID	Date Driven	Sound Attenuation	Distance to Water's Edge	Water Depth	Depth Driven into Substrate	Drive Time (minutes)[1]
VIB-1	1/14/16	None	3	9	NA	4.2
	1/15/16		3	10	32	5.8
VIB-2	1/15/16		3	10	37	17
VIB-3			3	9	32	9
VIB-4			3	8	37	68
VIB-5			3	2	32	8

1. Total drive time included in analysis, which only includes periods when the vibratory hammer was operating.

Source: The Greenbusch Group, Inc. Mortenson/Manson Pile Logs

In cases when the vibratory hammer was unable to drive the piles to the required depth, the pile was driven with an APE Model D50-42 Single Acting Diesel Impact Hammer with a maximum rated energy of 124,031 foot-pounds. The ram weight was 11,025 pounds and could achieve a stroke height of 135 inches when operating at the maximum rated energy. The hammer operated at between 34 and 53 strikes per minute. Table 5.2 provides a summary of the sheet piles that required driving with the impact hammer while sound level monitoring was occurring.

Table 5.2 Summary of Sheet Piles Driven with an Impact Hammer, Feet

Pile ID	Date Driven	Sound Attenuation	Distance to Water's Edge	Water Depth	Depth Driven into Substrate	Number of Strikes[1]
IMP-1	2/8/16	None	3	5	37	147
IMP-2			3	5	32	20
IMP-3			3	5	37	5
IMP-4			3	5	32	40
IMP-5			3	5	37	18

1. Number of strikes included in analysis.

Source: The Greenbusch Group, Inc. Mortenson/Manson Pile Driving Logs

6.0 MEASUREMENT METHODOLOGY

6.1 Equipment

Equipment used to collect airborne sound data during vibratory and impact pile driving are identified in Table 6.1.

Table 6.1 Airborne Sound Measurement Equipment

Make and Model	Quantity	Description	Serial Number
Brüel & Kjaer Type 2270	1	Sound Level Analyzer	2679351
Brüel & Kjaer ZC0032	1	Preamplifier	9437
Brüel & Kjaer 4189	1	Microphone	2550228
Brüel & Kjaer 4231	1	Acoustic Calibrator	2545696
Panasonic CF-31	1	Laptop Computer	CF-31ATAAXPM
National Instruments NI USB-4431	1	4 Channel DAQ	14F31A5
Larson Davis 2560	1	Microphone	2045
Larson Davis 2200C	1	Preamplifier	0915
Larson Davis 900B	1	Preamplifier	3024
Larson Davis CAL200	1	Acoustic Calibrator	9512

Source: The Greenbusch Group, Inc.

Field calibrations for airborne monitoring equipment were performed each day prior to monitoring and verified at the end of each day. Calibration tones were also recorded before each day of monitoring. Microphones were calibrated using either the Brüel & Kjaer 4231 or Larson Davis CAL200 acoustic calibrators.

Table 6.2 identifies the equipment used to monitor underwater sound levels during pile driving and both sets of background sound level measurements.

Table 6.2 Underwater Sound Measurement Equipment

Make and Model	Quantity	Description	Serial Number
Brüel & Kjaer Type 2250	1	Sound Level Analyzer	3006756
Brüel & Kjaer Type 2270	1	Sound Level Analyzer	2679351
Reson TC-4013	3	Hydrophone	1613020
			0712213
			0900019
Brüel & Kjaer Type 2647-A	2	Charge Converter (1 mV/pC)	2638260
			2638259
Brüel & Kjaer Type 2647-B	1	Charge Converter (10 mV/pC)	3019408
PCB 422E02	1	Charge Converter (10 mV/pC)	36638
G.R.A.S. Type 42AC	1	Pistonphone	201835
Panasonic CF-31	1	Laptop Computer	CF-31ATAAXPM
National Instruments NI USB-4431	1	4 Channel DAQ	14F31A5
Brüel & Kjaer 1704-A-002	1	Signal Conditioner	101161
PCB Model 482A16	1	Signal Conditioner	2987

Source: The Greenbusch Group, Inc.

All measurement equipment for underwater monitoring was factory calibrated within 1 year of the measurement date. Field calibrations were performed each day prior to monitoring and verified at the end of each day. Calibration tones were also recorded from each hydrophone before every day of monitoring. Hydrophones were calibrated using the G.R.A.S. pistonphone.

On January 14 and January 15, 2016, airborne sound levels were measured with the Brüel & Kjaer Type 2270 sound level analyzer. During these dates, two Reson TC-4013 hydrophones were attached to the Brüel & Kjaer Type 2647-A charge converters and the PCB Model 482A16 signal conditioner. The signal conditioner was attached to the National Instruments NI USB-4431 4-channel data acquisition system, which transferred the data into a laptop. The laptop recorded the time waveforms from each pile driving event for subsequent signal analysis. This equipment setup allowed for real-time approximations of peak and RMS sound levels while the measurements were being performed. Photos illustrating the airborne and underwater measurement equipment used on January 14 and January 15, 2016 are provided in Figure 6.1 and Figure 6.2.

Figure 6.1 Airborne Measurement Equipment

Source: The Greenbusch Group, Inc.

Figure 6.2 Hydroacoustic Equipment

Source: The Greenbusch Group, Inc.

On February 8, 2016, airborne sound levels were measured with the Larson Davis 2560 microphone with Larson Davis 900B preamplifier, which were attached to the Larson Davis 2200C preamplifier. The Larson Davis 2200C was attached to the National Instruments NI USB-4431 4 channel data acquisition system, which transferred the data into a laptop.

In addition to the airborne sound level measurements on February 8, 2016, underwater sound levels were measured simultaneously at two different monitoring locations, one near the pile and the other near a buoy in Elliott Bay. Underwater sound monitoring near the pile utilized one Reson TC-4013 hydrophone attached to a Brüel & Kjaer Type 2647-A charge converter and the PCB Model 482A16 signal conditioner. The signal conditioner was attached to the National Instruments NI USB-4431 4-channel data acquisition system, which transferred the data into a laptop. The laptop recorded the time waveforms from each pile driving event for subsequent signal analysis. This equipment setup allowed for real-time approximations of peak and RMS sound levels while the measurements were being performed.

Underwater background sound level measurements and measurement of impact pile driving in Elliott Bay were conducted with one Reson TC-4013 hydrophone attached to the PCB 422E02 charge converter. The charge converter was attached to the Brüel & Kjaer Type 2270 sound level analyzer, which recorded an audio file for post processing. This equipment setup allowed for real-time approximations of peak and cSEL sound levels while the measurements were being conducted.

Photos of the airborne and underwater measurement equipment used on February 8, 2016 are shown in Figure 6.3 and Figure 6.4.

Figure 6.3 Airborne Measurement Equipment

Source: The Greenbusch Group, Inc.

Figure 6.4 Hydroacoustic Equipment

Source: The Greenbusch Group, Inc.

6.2 Measurement Locations

Airborne sound level measurements were made approximately 50 feet (15 meters) from each pile being driven. The distance between the microphone and pile was determined using a laser distance measurement device. The microphone was located 5 to 7 feet (1.5 to 2 meters) above the pier and a direct line of site was maintained between the microphone and each pile driven.

Hydroacoustic monitoring conducted during vibratory pile driving was performed using two hydrophones located between 32 and 38 feet (10 to 12 meters) from the piles being driven. Underwater data collected during impact pile driving was conducted using one hydrophone located approximately between 45 and 60 feet (14 to 18 meters) from the piles and another hydrophone located approximately 10,000 feet (3,048 meters) southwest of the piles. The distance between the hydrophones and piles were verified for all monitored piles using a laser distance measurement device. Hydrophone locations were selected based on site access, water depth and to achieve an unobstructed path between the hydrophones and piles.

During hydroacoustic monitoring of piles driven with the vibratory hammer, one hydrophone was positioned 3.3 feet (1 meter) below the surface and the second hydrophone was positioned 3.3 feet (1 meter) above the sea floor. Water depth was measured at all hydrophone deployment positions as well as each time the hydrophones were relocated. The depth of the upper hydrophone was maintained by suspending the hydrophone 3.3 feet (1 meter) below a buoy. The lower hydrophone was fixed 3.3 feet (1 meter) above the sea floor by attaching the hydrophone to a weighted line.

In addition to water depth measurements, tidal information was obtained from NOAA Station #9447130 and was used to track tidal changes during construction and to calculate the resulting distance between the two hydrophones. Table 6.3 presents the depth of the hydrophones, water depth at the measurement location, distance between the hydrophones and distance between the hydrophones and the pile.

Table 6.3 Hydrophone Location Summary, Feet

Pile ID	Hydrophone	Depth at Measurement Location[1]	Hydrophone Depth	Distance between Hydrophones	Distance to Pile[2]
Vibratory Installation					
VIB-1 (1/14/16)	Upper	11	3	5	34
	Lower		8		
VIB-1 (1/15/16)	Upper	12	3	6	32
	Lower		9		
VIB-2	Upper	12	3	6	33
	Lower		9		
VIB-3	Upper	11	3	5	35
	Lower		8		
VIB-4	Upper	10	3	3	37
	Lower		6		
VIB-5[3]	Upper	4	1	2	38
	Lower		3		
Impact Installation					
IMP-1	Near Field	8	3	N/A	50
	Far Field	210	30		
IMP-2	Near Field	8	3	N/A	45
	Far Field	210	30		
IMP-3	Near Field	8	3	N/A	50
	Far Field	210	30		
IMP-4	Near Field	8	3	N/A	55
	Far Field	210	30		
IMP-5	Near Field	8	3	N/A	60
	Far Field	210	30		

1. Depth at start of pile drive
2. Distances from hydrophone to piles driven with the impact hammer are only reported for near field measurements. Far field measurements were approximately 10,000 feet (3,048 meters) southwest of impact pile driving.
3. Upper and lower hydrophones switched positions as water depth was reduced due to tides

Source: The Greenbusch Group, Inc. NOAA Station #9447130

Figures illustrating the airborne and underwater measurement locations are presented in Sections 8.0 and 9.0 of this Report.

7.0 BACKGROUND SOUND LEVEL MEASUREMENT METHODOLOGY

Background underwater sound levels were measured at two locations in the absence of in-water construction activities to determine the distance required for the RMS sound levels produced by pile driving to attenuation to background sound levels and to satisfy the background sound measurement requirements of the ESA and MMPA consultation.

The first set of background sound level measurements was made approximately 10,000 feet (3,048 meters) to the southwest of Box 2 (see Figure 7.1). These measurements verified that background sound levels in Elliott Bay have not significantly changed from those measured by WSDOT in 2011.

A description of the equipment used to collect background sound data southwest of Box 2 in Elliott Bay is provided in Section 6.1. The hydrophone was deployed approximately 30 feet (9 meters) below the surface.

The second set of background sound level measurements were made near shore, approximately 280 feet (85 meters) west of Box 2 (see Figure 7.10). This location was selected based on site access, ability to secure the equipment and water depth to ensure the hydrophone would remain submerged over the entire measurement duration.

Underwater background sound data collected near Box 2 used a Reson TC-4013 hydrophone attached to the Brüel & Kjaer 2647-B 10 mV/pC charge converter. This charge converter was attached to the Brüel & Kjaer 1704-A-002 signal conditioner, which amplified the signal. Data from the signal conditioner went into the Brüel & Kjaer Type 2250 sound level analyzer. The hydrophone was deployed at mid-water depth.

10-second RMS background sound data collected from 30 minutes after sunrise to 30 minutes before sunset was used to calculate the cumulative density function (CDF) of each marine mammal functional hearing group in accordance with the NOAA Guidance Document: “Data Collection Methods to Characterize Underwater Background Sound Relevant to Marine Mammals in Coastal Nearshore Waters and Rivers of Washington and Oregon” dated January 31, 2012. The marine mammal functional hearing groups are presented in Table 7.1.

Table 7.1 Marine Mammal Functional Hearing Groups

Functional Hearing Group	Low Frequency	High Frequency
Low-Frequency Cetaceans	7 Hz	20 kHz
Mid-Frequency Cetaceans	150 Hz	20 kHz
High-Frequency Cetaceans	200 Hz	20 kHz
Pinnipeds	75 Hz	20 kHz

Source: NOAA Guidance Document: “Data Collection Methods to Characterize Underwater Background Sound Relevant to Marine Mammals in Coastal Nearshore Waters and Rivers of Washington and Oregon” dated January 31, 2012

The overall broadband background sound levels for each hearing group described in Table 7.1 is reported as the 50^{th} percentile of the CDFs.

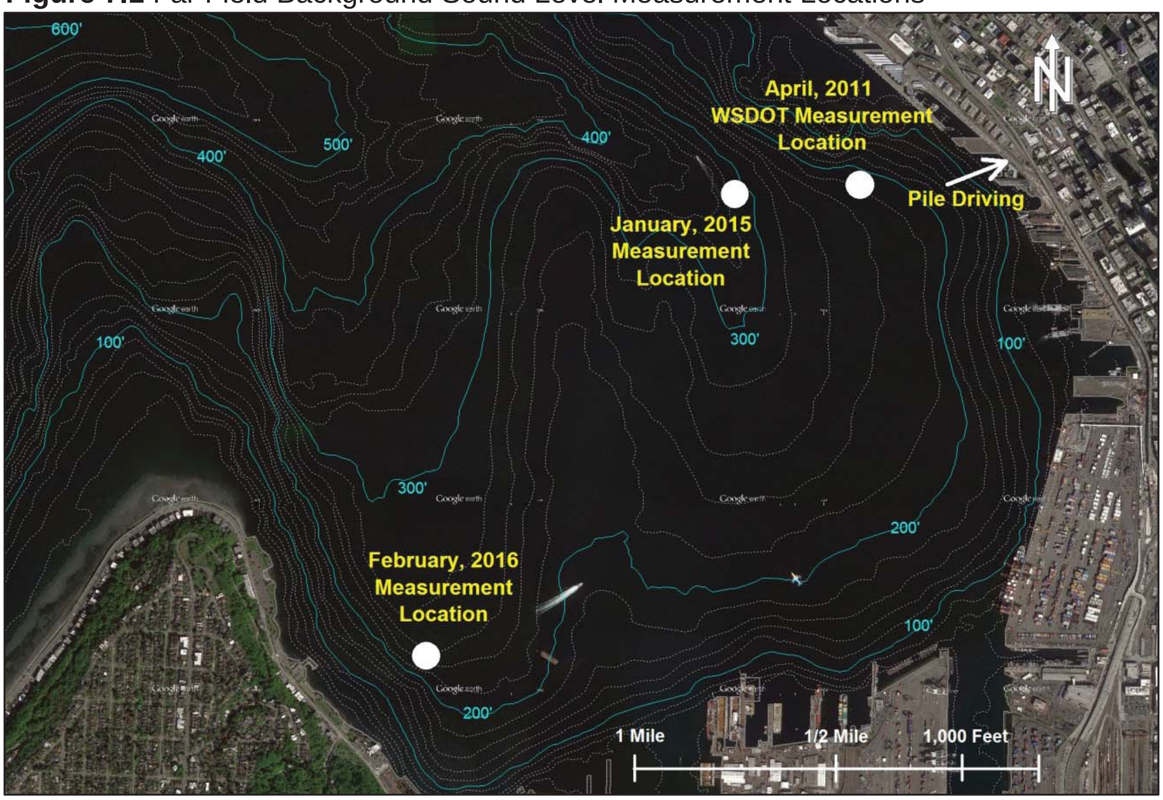
7.1 Far Field Background Sound Levels

Short-term background sound level measurements were made during daytime hours approximately 10,000 feet (3,048 meters) to the southwest of Box 2 for 20 minutes on February 8 and 2 hours on February 9, 2016. Measurements were made from a drifting boat. These measurements were used to verify that background sound levels collected during Season 2 and by WSDOT in 2011 had not changed significantly.

WSDOT collected background sound levels in Elliott Bay over three consecutive 24-hour periods between April 19 and April 22, 2011. These measurements are presented in a report titled "Compendium of Background Sound Levels for Ferry Terminals in Puget Sound" issued in April 2014. Background sound levels measured in January 2015 during Season 2 demonstrated that underwater sound levels remained consistent with those collected by WSDOT. Short-term measurements made during Season 3 were used to further verify that sound levels remained consistent. By demonstrating that the short-term measurements conducted in February 2016 do not vary significantly from the daytime levels reported by WSDOT and those reported during Season 2, the long term data collected by WSDOT can be used to calculate the distance required for noise from pile driving to reach background sound levels.

Figure 7.1 below presents the location of the February 2016 measurements during Season 3, the Season 2 measurements and the approximate WSDOT 2011 measurement location.

Figure 7.1 Far Field Background Sound Level Measurement Locations



Source: The Greenbusch Group, Inc. Washington State Department of Transportation report "Compendium of Background Sound Levels for Ferry Terminals in Puget Sound" issued April, 2014

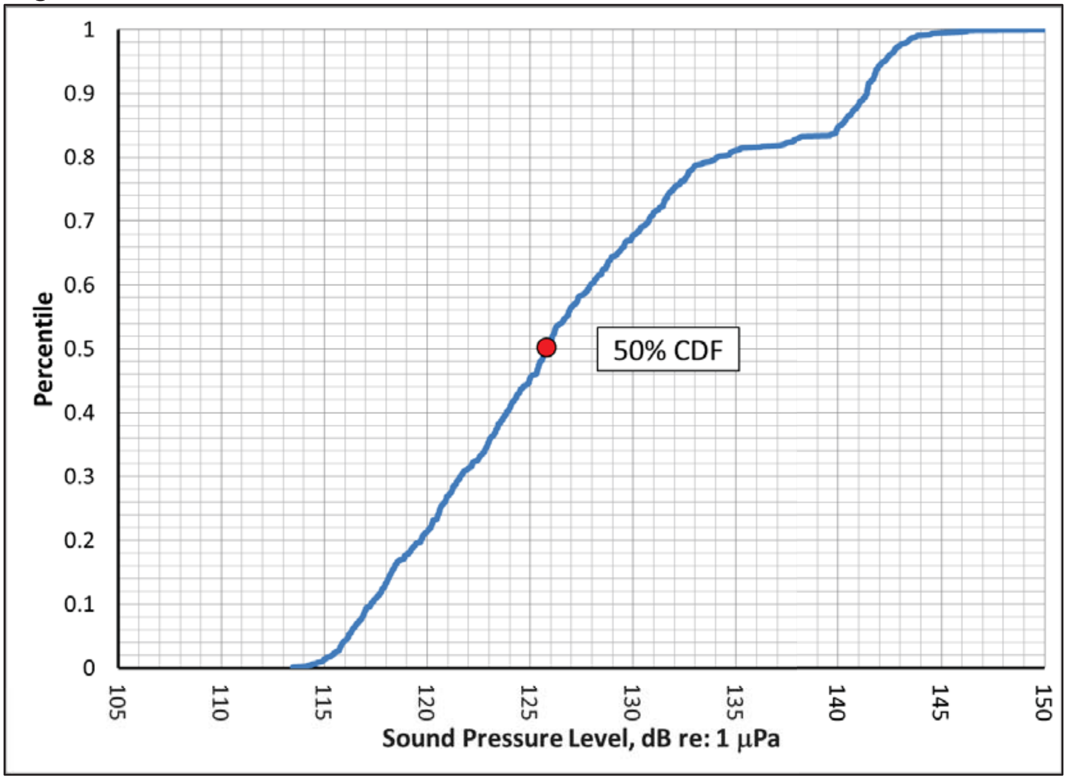
Equipment used to collect short term background sound data is shown in Figure 7.2.

Figure 7.2 Far Field Background Sound Measurement Equipment

Source: The Greenbusch Group, Inc.

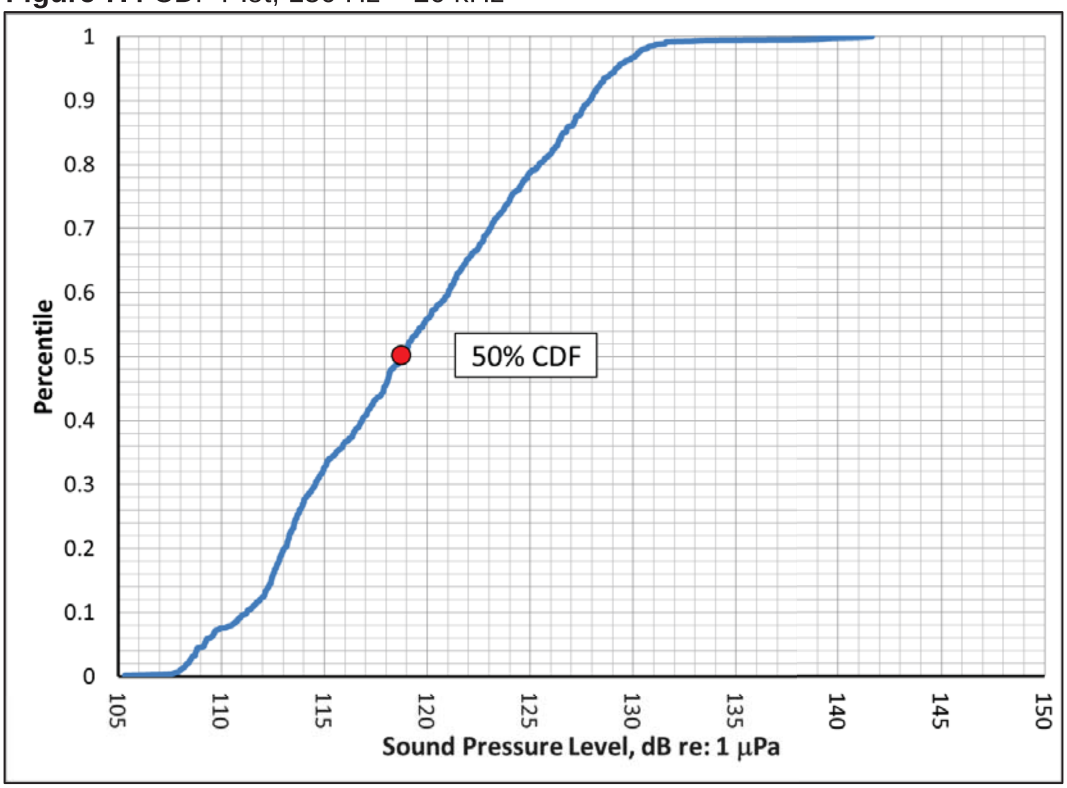
10-second RMS values were used from short term measurements conducted in February 2016 to generate CDF plots for each marine mammal functional hearing group. These CDF plots are provided in Figure 7.3 through Figure 7.6.

Figure 7.3 CDF Plot, 7 Hz – 20 kHz



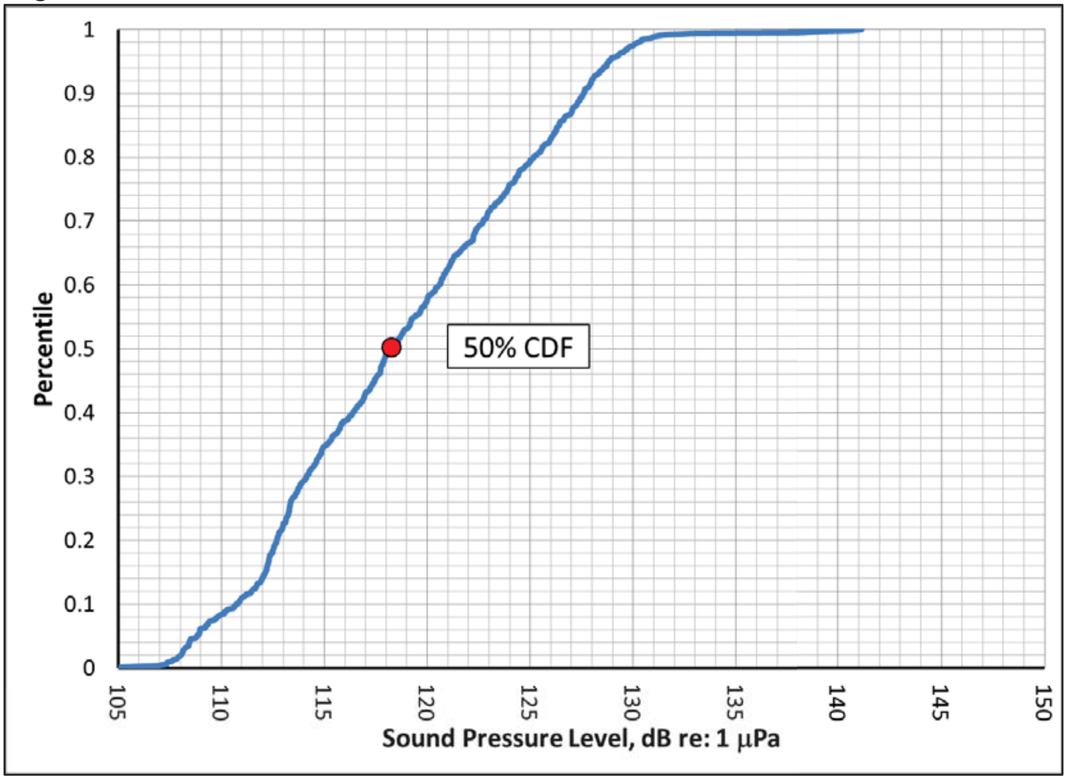
Source: The Greenbusch Group, Inc.

Figure 7.4 CDF Plot, 150 Hz – 20 kHz



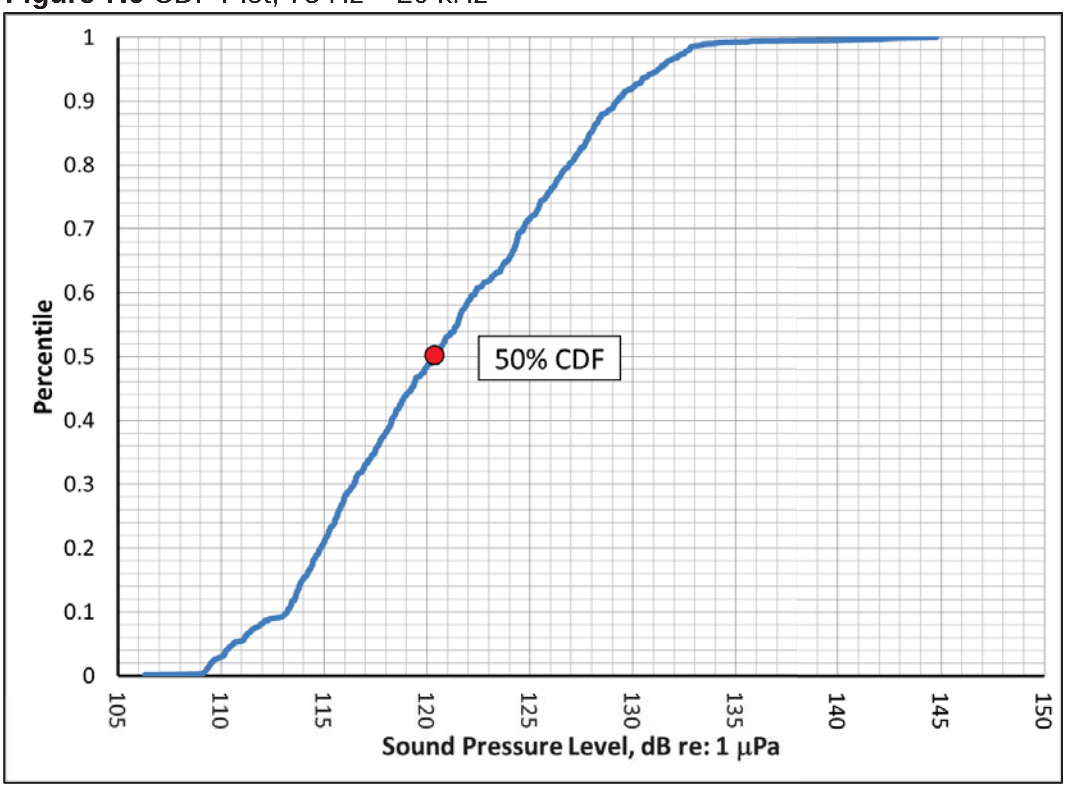
Source: The Greenbusch Group, Inc.

Figure 7.5 CDF Plot, 200 Hz – 20 kHz



Source: The Greenbusch Group, Inc.

Figure 7.6 CDF Plot, 75 Hz – 20 kHz



Source: The Greenbusch Group, Inc.

The range, average and standard deviation (SD) of background sound levels measured in February 2016, January 2015 and the long term daytime sound levels collected by WSDOT in April 2011 are presented for each functional hearing group in Table 7.2.

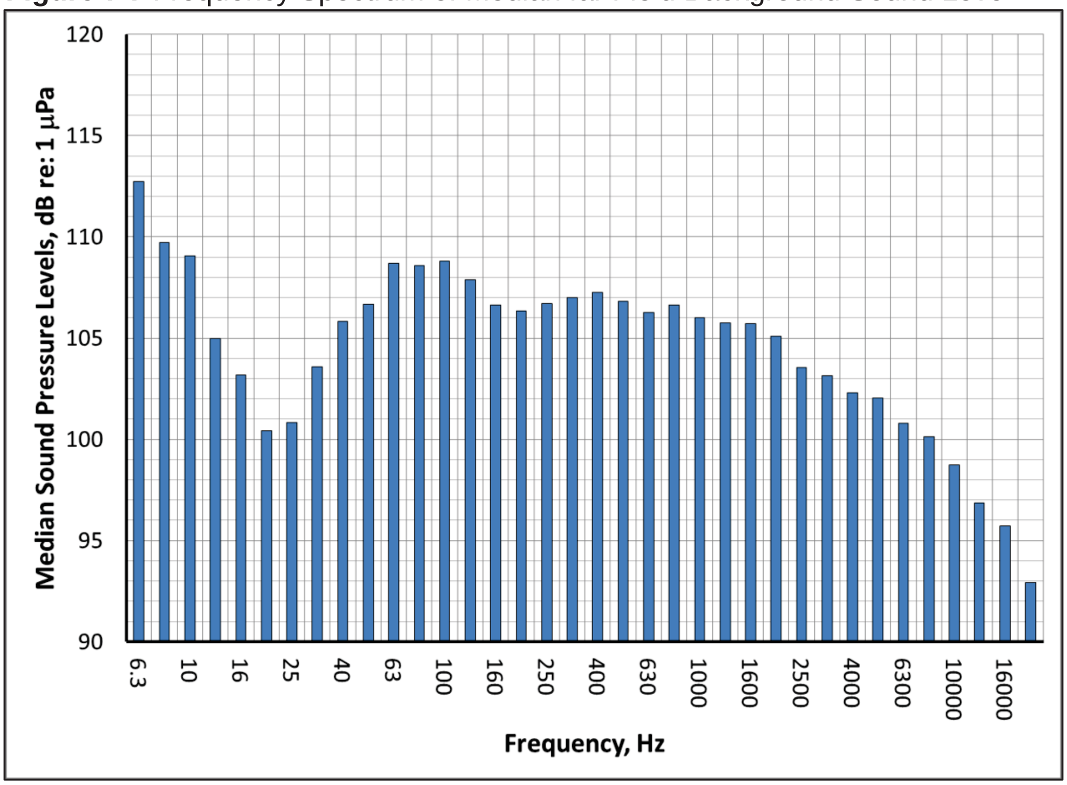
Table 7.2 Average Daytime Underwater Background Sound Levels in Elliott Bay, dB re: 1 μPa

Functional Hearing Group	Frequency Range	Background Sound Levels										
		Short Term (2016)				Short Term(2015)				WSDOT (2011)		
		Min	Max	SD	Avg[1]	Min	Max	SD	Avg[1]	Min	Max	Avg[1]
Low-Frequency Cetaceans	7 Hz–20 kHz	113	152	8	**126**	122	170	9	**140**	-	-	**130**
Mid-Frequency Cetaceans	150 Hz–20 kHz	105	142	6	**119**	111	141	6	**120**	103	143	**124**
High-Frequency Cetaceans	200 Hz–20 kHz	105	141	6	**118**	110	140	6	**120**	-	-	**124**
Pinnipeds	75 Hz–20 kHz	106	145	6	**120**	114	142	6	**123**	104	144	**127**

Note: “-“ indicates data is unknown
1. The median was used to report the average background sound levels
Source: The Greenbusch Group, WSDOT report titled “Compendium of Background Sound Levels for Ferry Terminals in Puget Sound” issued April, 2014

The underwater 1/3 octave frequency spectrum of the median far field background sound levels measured by Greenbusch in February 2016 is provided in Figure 7.7.

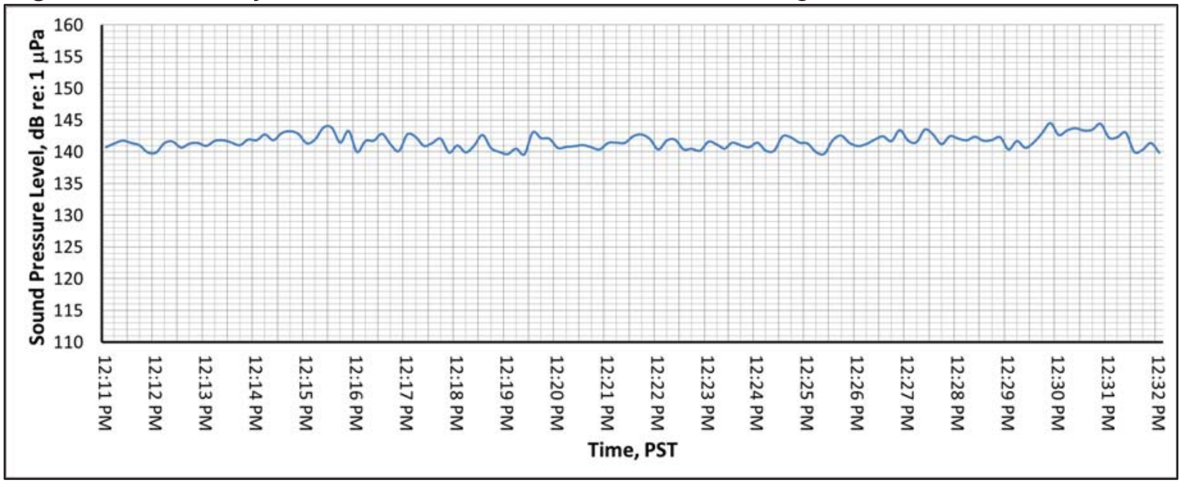
Figure 7.7 Frequency Spectrum of Median far Field Background Sound Level



Source: The Greenbusch Group, Inc.

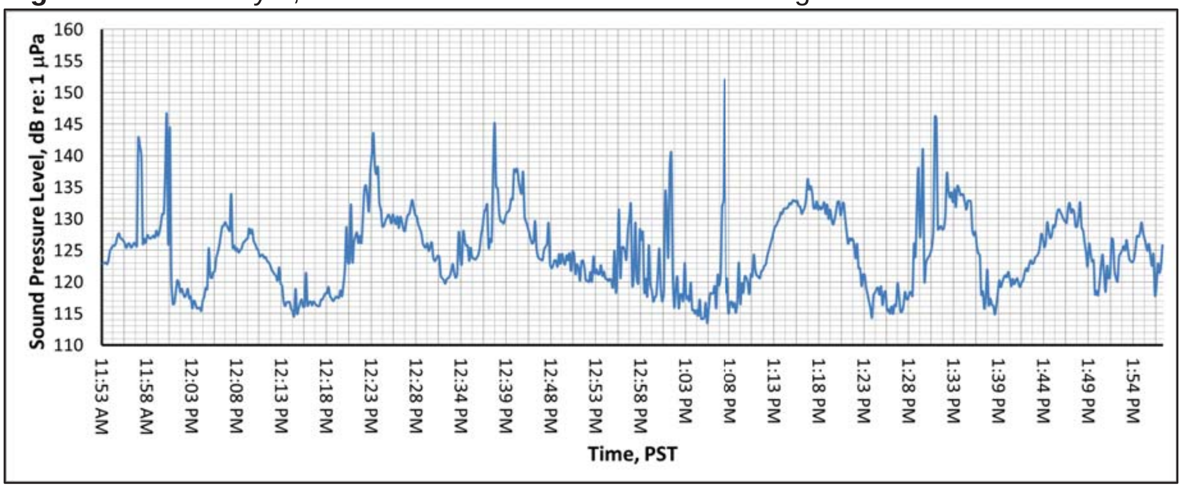
Time histories of the far field 10-second RMS background sound data collected by Greenbusch in February 2016 are provided in Figure 7.8 and Figure 7.9.

Figure 7.8 February 8, 2016 Far Field 10-Second RMS Background Sound Levels



Source: The Greenbusch Group, Inc.

Figure 7.9 February 9, 2016 Far Field 10-Second RMS Background Sound Levels



Source: The Greenbusch Group, Inc.

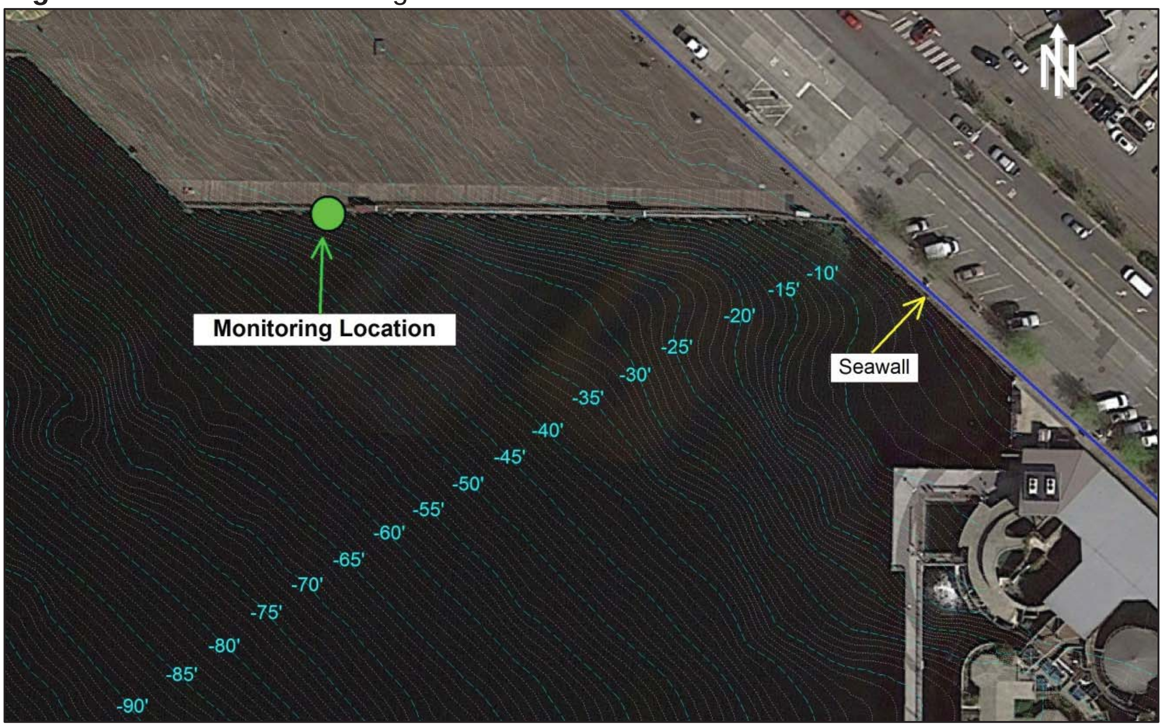
As shown in Table 7.2, the average background sound levels collected in February 2016 are within the range of daytime sound levels collected during Season 2 and by WSDOT. Due to the long term nature of the WSDOT measurements compared to the short-term data collected by Greenbusch in 2016, the average daytime background sound data collected by WSDOT were used to calculate the distance required for underwater RMS sound levels generated by pile driving to attenuate to background sound levels (see Section 10.2).

7.2 Near Shore Background Sound Levels

Long term background sound levels were measured approximately 280 feet (85 meters) west of Box 2. These measurements were made at the request of NOAA to ensure that background sound levels near the monitored piles did not influence the measurements of pile driving.

Continuous underwater sound level measurements were made between March 29 and April 1, 2016. The hydrophone was positioned at mid-water depth and secured to a pier. Figure 7.10 shows the near shore background sound level measurement location.

Figure 7.10 Near Shore Background Measurement Location



Source: The Greenbusch Group, Inc.

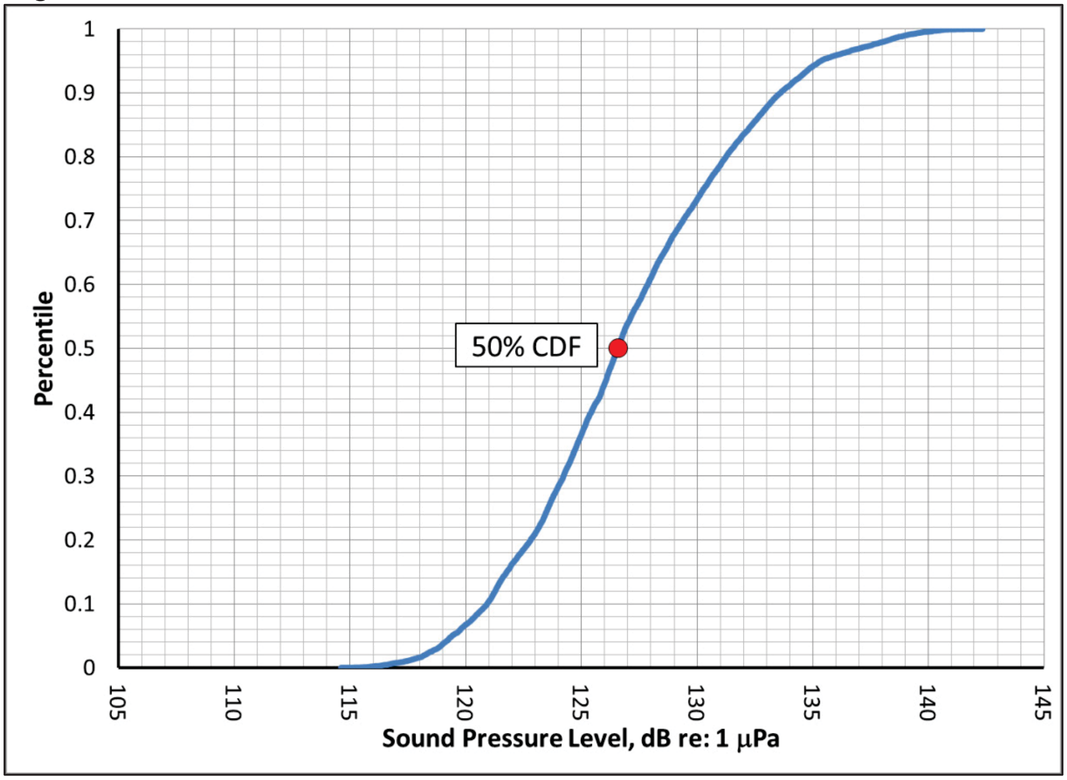
Equipment used to collect the near shore background sound level data is shown in Figure 7.11.

Figure 7.11 Near Shore Background Sound Measurement Equipment

Source: The Greenbusch Group, Inc.

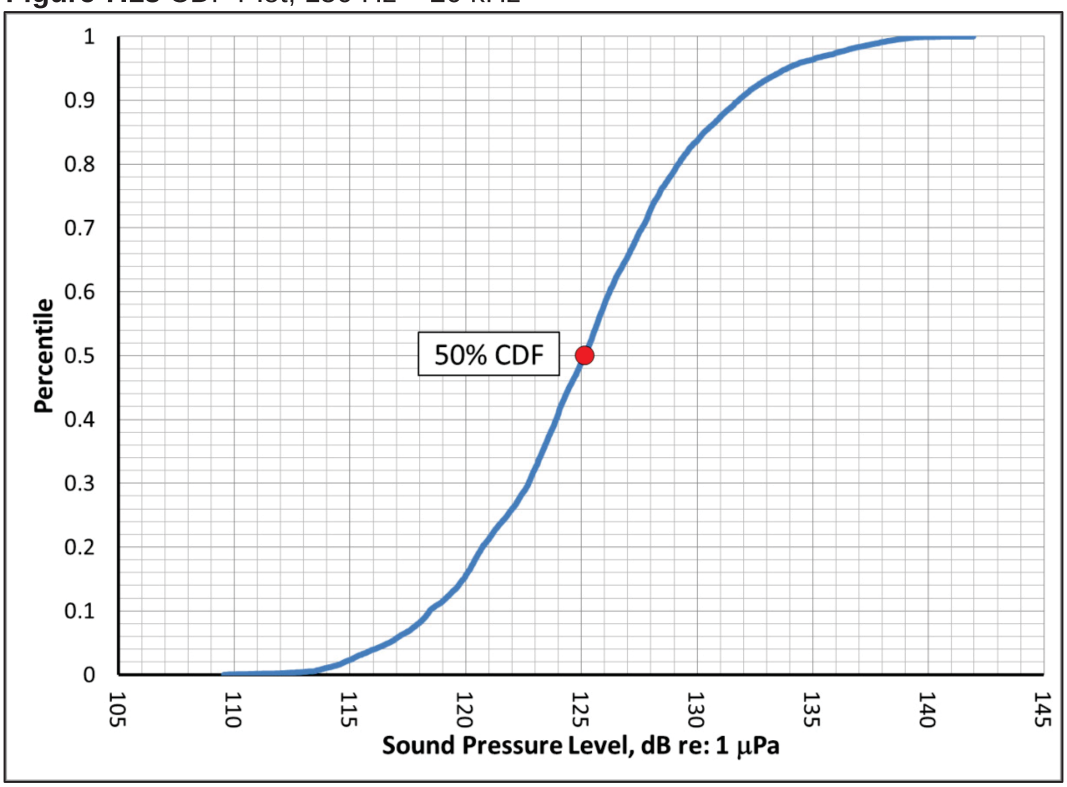
10-second daytime background RMS values were used from these long-term near shore measurements to generate CDF plots for each marine mammal functional hearing group. These CDF plots are presented in Figure 7.12 through Figure 7.15.

Figure 7.12 CDF Plot, 7 Hz – 20 kHz



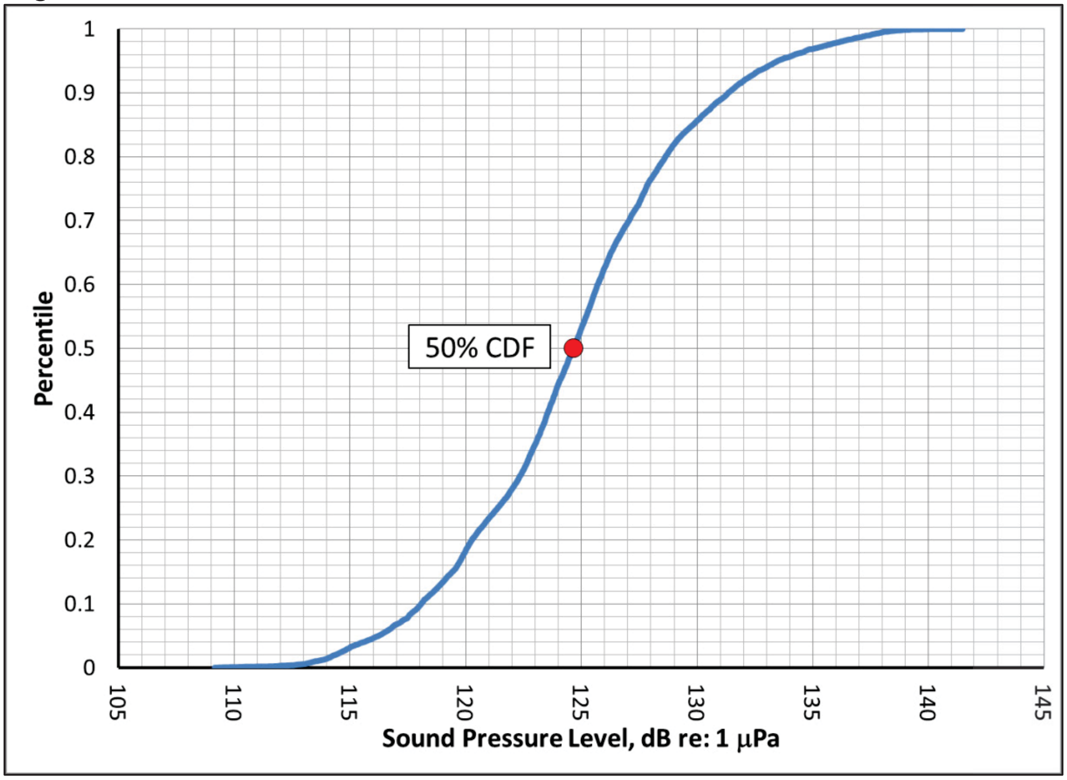
Source: The Greenbusch Group, Inc.

Figure 7.13 CDF Plot, 150 Hz – 20 kHz



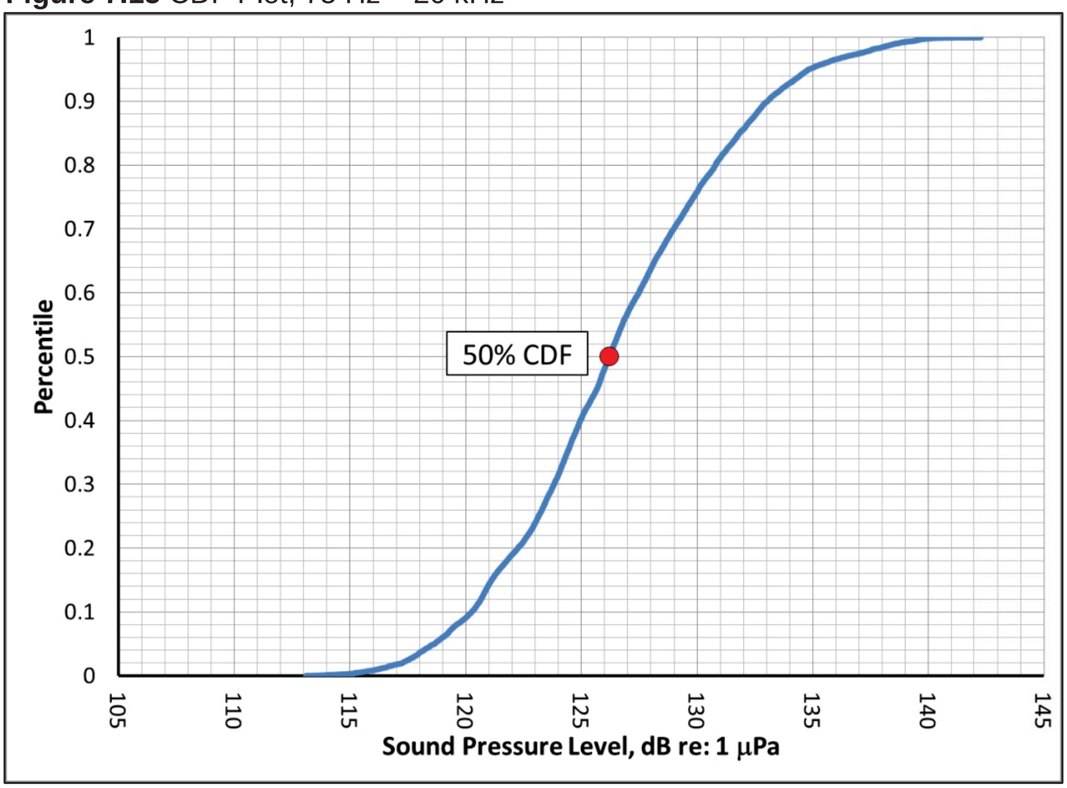
Source: The Greenbusch Group, Inc.

Figure 7.14 CDF Plot, 200 Hz – 20 kHz



Source: The Greenbusch Group, Inc.

Figure 7.15 CDF Plot, 75 Hz – 20 kHz



Source: The Greenbusch Group, Inc.

The range, average and standard deviation (SD) of daytime background sound levels for each marine mammal functional hearing group calculated from the near shore background sound data is provided in Table 7.3.

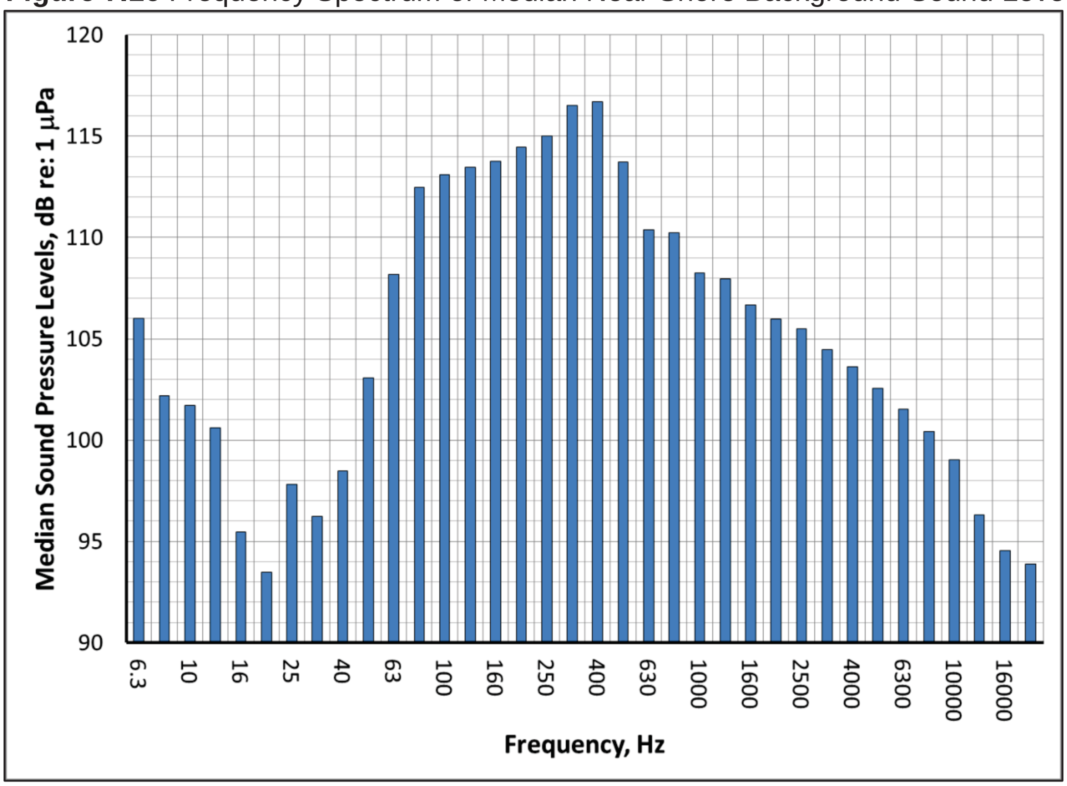
Table 7.3 Average Daytime Near Shore Background Sound Levels, dB re: 1 μPa

Functional Hearing Group	Frequency Range	Background Sound Levels (Greenbusch 2016)			
		Min	Max	SD	Average[1]
Low-Frequency Cetaceans	7 Hz – 20 kHz	115	142	5	**127**
Mid-Frequency Cetaceans	150 Hz – 20 kHz	110	142	5	**125**
High-Frequency Cetaceans	200 Hz – 20 kHz	109	141	5	**125**
Pinnipeds	75 Hz – 20 kHz	113	142	5	**126**

The median was used to report the average background sound levels
Source: The Greenbusch Group, Inc.

The underwater 1/3 octave frequency spectrum of the median near shore background sound levels is provided in Figure 7.16 below.

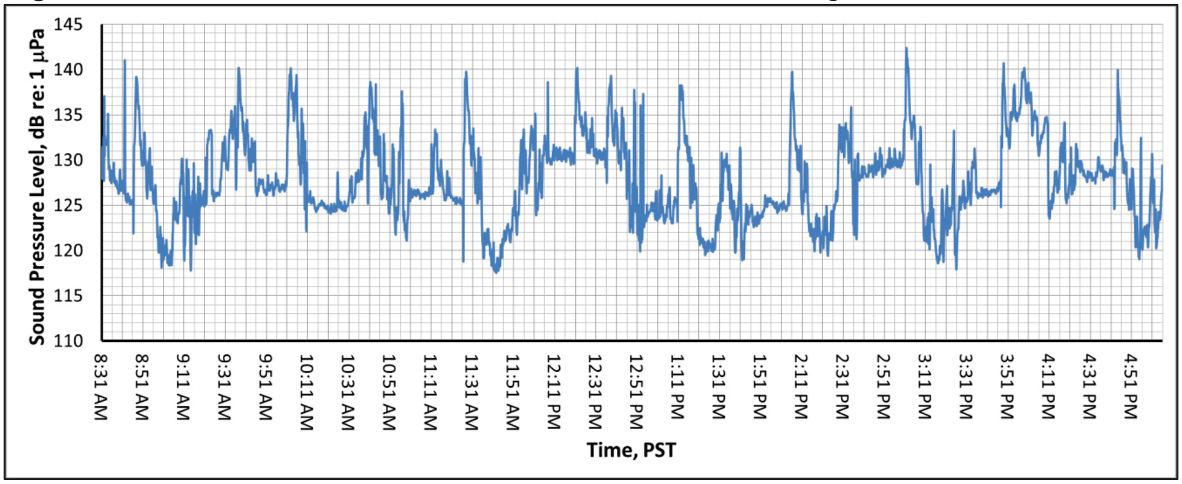
Figure 7.16 Frequency Spectrum of Median Near Shore Background Sound Level



Source: The Greenbusch Group, Inc.

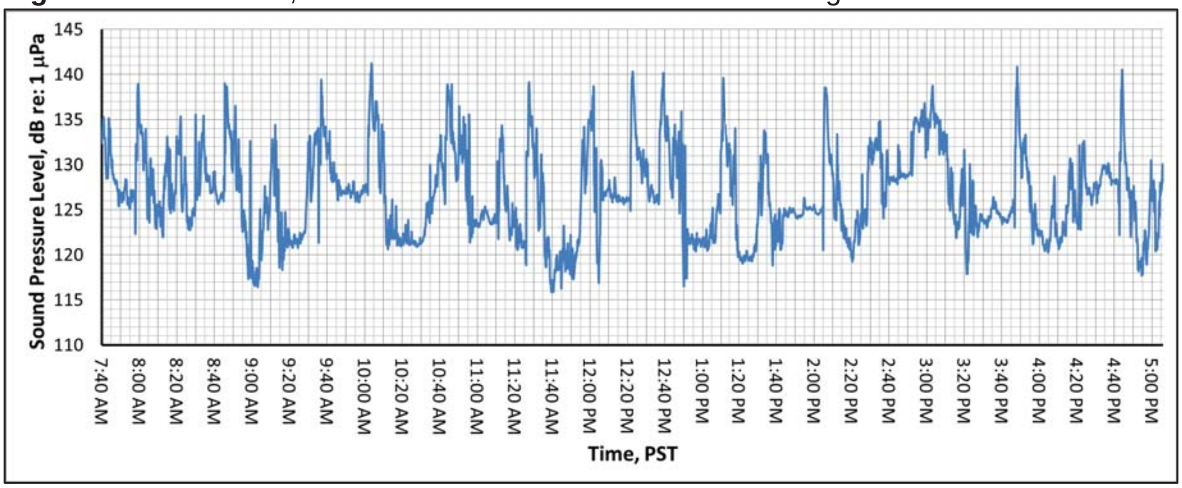
Time histories of the near shore 10-second RMS background sound data collected by Greenbusch in February 2016 are provided in Figure 7.17 through Figure 7.19.

Figure 7.17 March 29, 2016 Near Shore 10-Second RMS Background Sound Levels



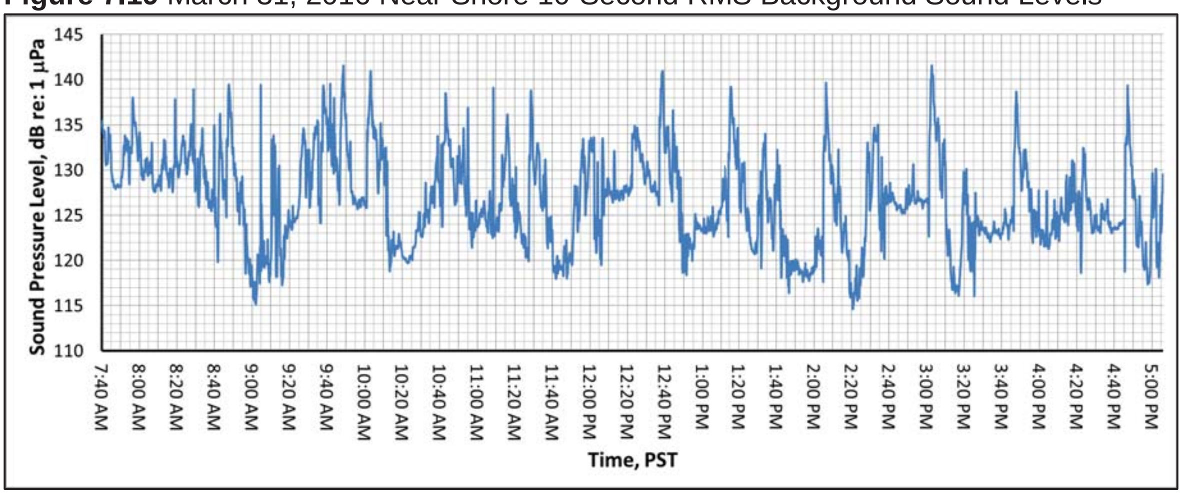
Source: The Greenbusch Group, Inc.

Figure 7.18 March 30, 2016 Near Shore 10-Second RMS Background Sound Levels



Source: The Greenbusch Group, Inc.

Figure 7.19 March 31, 2016 Near Shore 10-Second RMS Background Sound Levels



Source: The Greenbusch Group, Inc.

The data collected from near shore and far field measurements in 2016 suggest that current background sound levels in Elliott Bay are consistent with the background sound levels measured by WSDOT in 2011.

8.0 VIBRATORY SHEET PILES ANALYSIS AND RESULTS

Airborne and underwater sound level measurements were made on January 14 and January 15, 2016 of the first five unobstructed steel sheet piles driven with a vibratory hammer as required by the Project's ESA and MMPA consultation.

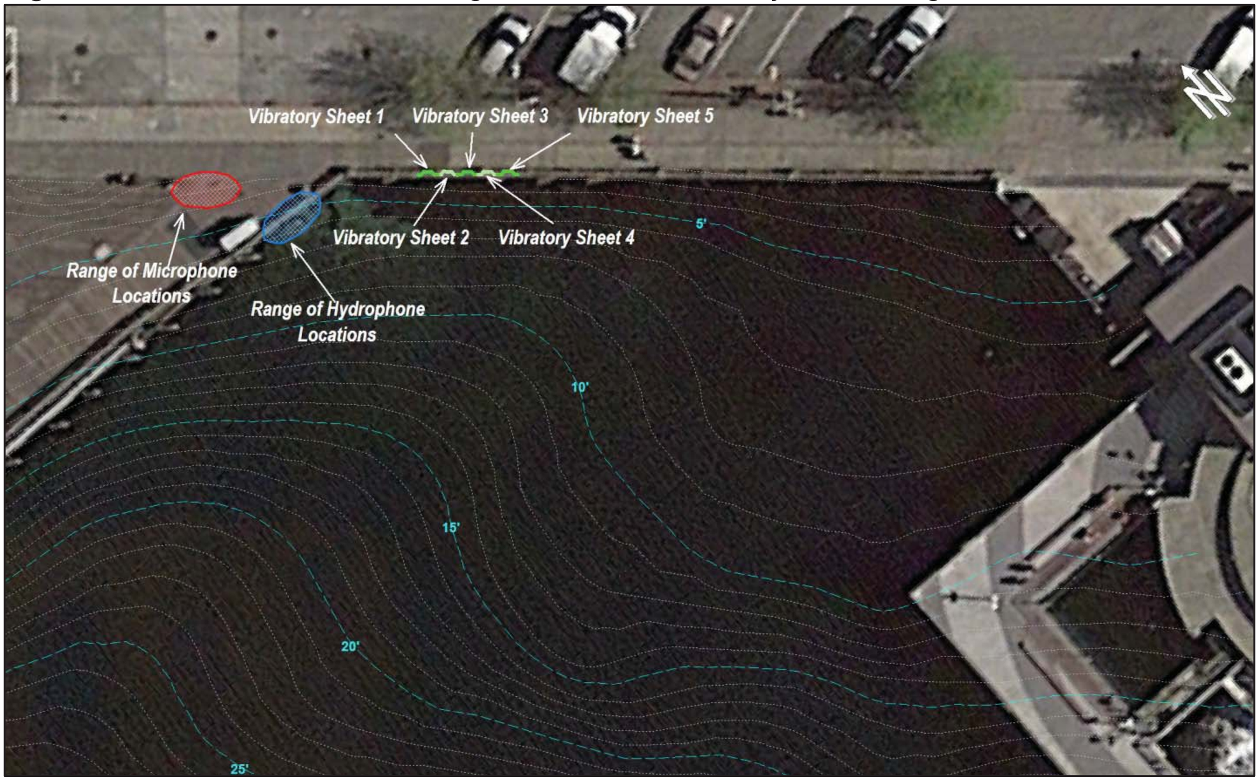
Hydroacoustic data collected during vibratory installation of the steel sheet piles was analyzed to determine the range, average and standard deviation of 10-second RMS, peak and SEL values for each marine mammal functional hearing group. Periods during the pile drive when pile installation was not occurring under full power are excluded from the analysis. Ramp-up procedures were used at the start of each day and after breaks of more than one hour. However, only one of the monitored vibratory piles, Vibratory Sheet Pile 1, met these timing requirements. Airborne and underwater sound levels measured during ramp-up procedures are reported separately from full power driving.

Data was analyzed for each functional hearing group by applying a band pass filter to remove frequencies from the signal that are not included in the functional hearing group being analyzed. This filter provides a roll off of over 40 dB per decade. SEL values were calculated using 1-second RMS values.

Reported maximum and minimum values are the maximum or minimum value from either of the two hydrophones. The standard deviation was calculated using decibel values. Average sound levels were calculated using the mean sound pressure from each hydrophone, converted to decibels and taking the logarithmic average of the two values.

During vibratory pile driving one hydrophone was deployed 3.3 feet (1 meter) below the surface and a second hydrophone was deployed 3.3 feet (1 meter) above the sea floor. Both hydrophones were positioned as close to 33 feet (10 meters) from the pile as feasible. The airborne and underwater sound level monitoring locations and the locations of the sheet piles driven with the vibratory hammer are shown in Figure 8.1.

Figure 8.1 Sheet Pile and Monitoring Locations for Vibratory Pile Driving



Source: The Greenbusch Group, Inc.

A summary of underwater sound levels produced by the vibratory installation of the only unobstructed steel sheet pile driven on January 14, 2016 is provided in Table 8.1.

Table 8.1 Underwater Sound Levels from Vibratory Pile Driving, dB re: 1 μPa (January 14, 2016)

Pile ID	Frequency Range	Peak				RMS				SEL			
		Min	Max	SD	Avg	Min	Max	SD	Avg	Min	Max	SD	Avg
VIB-1	*Ramp-Up*												
	7 Hz-20 kHz	166	180	3	**172**	142	157	4	**152**	147	159	2	**154**
	75 Hz-20 kHz	166	180	3	**172**	142	157	4	**152**	147	159	2	**154**
	150 Hz-20 kHz	166	180	3	**172**	142	157	4	**152**	147	159	2	**154**
	200 Hz-20 kHz	165	180	3	**172**	142	157	4	**152**	147	159	2	**154**
	Full Power												
	7 Hz-20 kHz	169	182	2	**176**	150	161	2	**157**	147	163	2	**157**
	75 Hz-20 kHz	169	182	3	**176**	150	161	2	**156**	147	163	2	**156**
	150 Hz-20 kHz	169	182	3	**176**	150	161	2	**156**	146	163	2	**156**
	200 Hz-20 kHz	169	182	3	**176**	150	161	2	**156**	146	163	2	**156**

Note: Underwater sound levels were measured 34 feet (10 meters) from the pile.
Source: The Greenbusch Group, Inc.

A summary of underwater sound levels produced by the vibratory installation of the first five unobstructed steel sheet pile driven on January 15, 2016 is provided in Table 8.2. Vibratory Sheet 1 that was installed on January 14, 2016 was removed and redriven on January 15, 2016.

Table 8.2 Underwater Sound Levels from Vibratory Pile Driving, dB re: 1 μPa (January 15, 2016)

Pile ID	Frequency Range	Peak				RMS				SEL			
		Min	Max	SD	Avg	Min	Max	SD	Avg	Min	Max	SD	Avg
VIB-1	*Ramp-Up*												
	7 Hz-20 kHz	174	180	2	**178**	150	159	3	**157**	148	162	2	**158**
	75 Hz-20 kHz	173	179	2	**177**	148	158	4	**155**	148	160	3	**157**
	150 Hz-20 kHz	173	179	2	**177**	148	158	4	**155**	147	160	3	**157**
	200 Hz-20 kHz	173	180	2	**177**	148	158	4	**155**	147	160	3	**157**
	Full Power												
	7 Hz-20 kHz	173	190	4	**181**	148	166	4	**160**	148	172	2	**161**
	75 Hz-20 kHz	174	190	4	**181**	147	166	4	**159**	147	172	3	**160**
	150 Hz-20 kHz	174	190	4	**181**	147	166	4	**159**	146	172	3	**160**
	200 Hz-20 kHz	174	190	4	**181**	147	166	4	**159**	143	172	3	**160**
VIB-2	7 Hz-20 kHz	175	186	2	**182**	153	168	2	**164**	150	168	2	**164**
	75 Hz-20 kHz	175	185	2	**181**	151	166	3	**162**	146	167	2	**162**
	150 Hz-20 kHz	175	185	2	**181**	150	166	3	**162**	146	167	2	**162**
	200 Hz-20 kHz	175	185	2	**181**	150	166	3	**162**	146	167	2	**162**
VIB-3	7 Hz-20 kHz	165	183	4	**175**	147	167	4	**158**	149	167	4	**159**
	75 Hz-20 kHz	165	183	4	**174**	143	163	4	**156**	145	164	4	**157**
	150 Hz-20 kHz	166	183	4	**174**	143	163	4	**156**	145	164	4	**157**
	200 Hz-20 kHz	166	183	4	**174**	143	163	4	**156**	145	164	4	**157**
VIB-4	7 Hz-20 kHz	166	188	2	**175**	141	167	2	**161**	147	167	2	**161**
	75 Hz-20 kHz	167	187	3	**174**	145	162	3	**155**	146	163	3	**156**
	150 Hz-20 kHz	166	185	3	**174**	145	162	3	**155**	146	163	3	**156**
	200 Hz-20 kHz	166	184	3	**174**	145	162	3	**155**	146	163	3	**156**
VIB-5	7 Hz-20 kHz	166	174	2	**171**	144	164	4	**157**	148	164	3	**158**
	75 Hz-20 kHz	165	174	2	**169**	143	157	3	**153**	145	159	2	**153**
	150 Hz-20 kHz	165	174	2	**169**	143	157	3	**153**	145	159	2	**153**
	200 Hz-20 kHz	165	173	2	**169**	143	157	3	**153**	145	159	2	**153**

Note: Underwater sound levels were measured 32 to 38 feet (10 to 12 meters) from the piles.
Source: The Greenbusch Group, Inc.

Airborne sound data collected during vibratory installation of the steel sheet piles was analyzed to determine the range and average of unweighted 10-second RMS values while piles were being driven under full power. These 10-second RMS values were calculated over a frequency range of 10 Hz to 20 kHz.

A summary of airborne sound levels generated by vibratory pile driving activities is provided in Table 8.3 below.

Table 8.3 Airborne Sound Levels from Vibratory Pile Driving, dB re: 20 μPa

Pile ID	Minimum	Maximum	Average
January 14, 2016			
VIB-1	*Ramp-Up*		
	92	101	96
	Full Power		
	93	105	101
January 15, 2016			
VIB-1	*Ramp-Up*		
	103	107	105
	Full Power		
	99	106	104
VIB-2	97	108	105
VIB-3	97	107	104
VIB-4	97	109	103
VIB-5	99	108	106

Note: Airborne sound levels measured 50 feet (15 meters) from the pile.
Source: The Greenbusch Group, Inc.

The airborne and underwater frequency spectrum associated with the highest 10-second RMS level, peak sound pressure levels collected during each pile drive, as well as hydrophone and pile location information are provided in the Appendix of this Report.

9.0 IMPACT SHEET PILES ANALYSIS AND RESULTS

Collection of airborne and underwater sound data occurred on February 8, 2016 during impact installation of five pairs of sheet piles. Although there was not an unobstructed path between the pile and the hydrophone, monitoring on this day allowed for simultaneous near and far field measurements of impact and vibratory pile driving. The far field measurements were conducted 10,000 feet (3,048 meters) to the southwest in order to determine whether underwater sound produced by impact pile driving exceeded relevant marine mammal thresholds.

An unobstructed path between the piles and microphone used to collected airborne sound levels was maintained throughout the duration of each pile drive. Prior to the airborne data analysis a band pass filter was applied to remove frequencies below 10 Hz and higher than 20 kHz. The resulting 100-millisecond RMS sound levels were used to analyze the airborne sound levels from the pile drives.

Hydroacoustic data collected during the impact driving of steel sheet piles were analyzed to determine the range, average and standard deviation of peak, RMS_{90}, and SEL values as well as the cSEL of each pile for each marine mammal functional hearing group as required by the ESA and MMPA consultation. Periods when pile driving was not occurring under full power were excluded from this analysis. Ramp-up procedures were used at the start of each day and after breaks of more than one hour. However, only one of the monitored impact piles, Impact Sheet Pile 1, met these timing requirements. Ramp-up activities were separated from the full power pile driving analysis and are presented separately.

Standard deviation was calculated using the decibel values and the average sound levels were calculated using the mean sound pressure levels.

Data analysis was conducted for each marine mammal functional hearing group by applying a band pass filter to remove frequencies from the signal that are not included in the functional hearing group being analyzed. This filter provides a roll off of more than -40 dB per decade.

The RMS_{90} was established between the 5^{th} percentile and 95^{th} percentile of each recorded pile strike. Figures illustrating the waveform produced by the pile strike that generated the absolute highest peak sound pressure level from each pile are provided in the Appendix of this Report. The green portion of these waveforms represents the duration of the strike containing 90% of the acoustical energy.

SEL values for impact pile driving of steel sheet piles were calculated for each pile strike over the duration of the strike containing 90% of the acoustic energy using the following formula:

$$\mathrm{SEL} = \mathrm{RMS(dB)} + 10\log_{10}(\tau)$$

Where τ is the time interval containing 90% of the acoustic energy in each pile strike.

cSEL values where calculated using the SEL value corresponding to the maximum peak pile strike using the following formula, which is required by the ESA documents:

$$\mathrm{cSEL} = \mathrm{SEL_{single}} + 10\log_{10}(n)$$

Where $\mathrm{SEL_{single}}$ is the SEL value corresponding to the pile strike which produced the highest peak sound pressure and n is the total number of pile strikes included in the analysis.

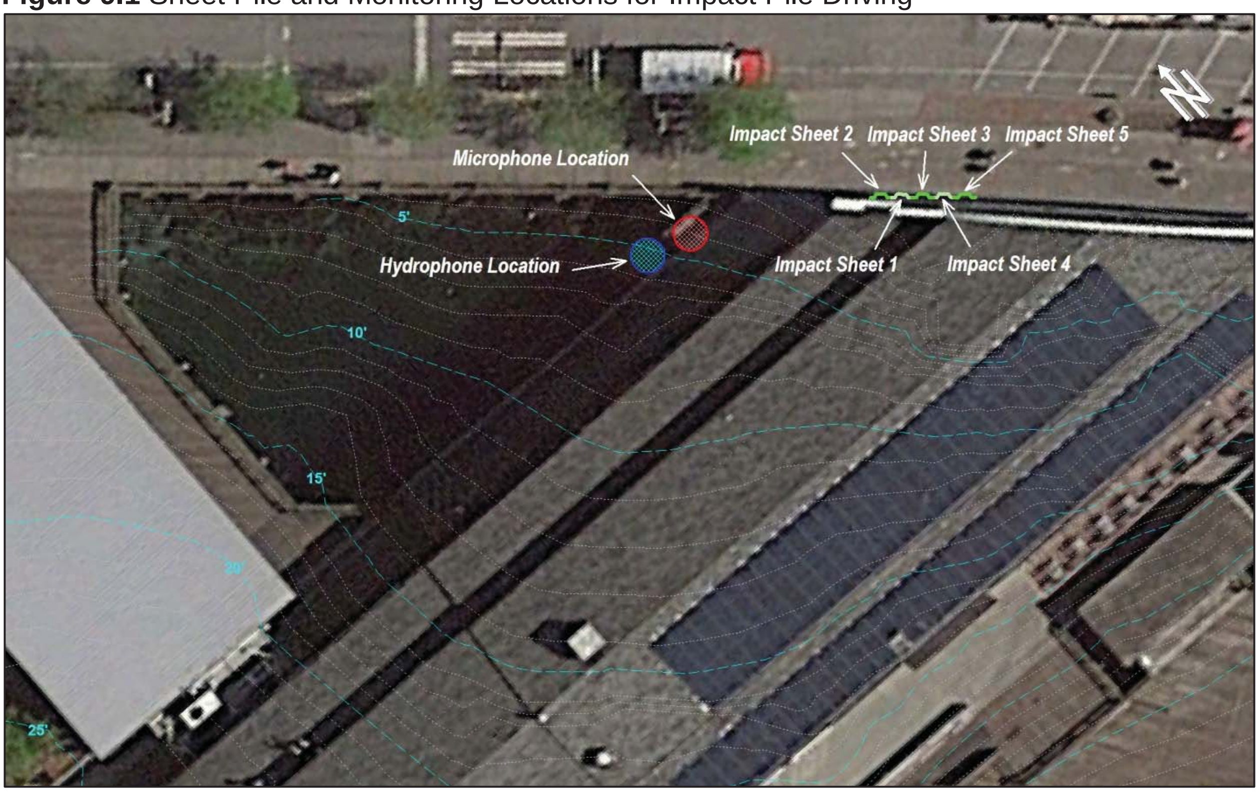
During impact pile driving one hydrophone was deployed at mid-water depth near the pile driving. Due to limited site access and safety concerns the hydrophone was not able to be positioned 33 feet (10 meters) from the piles. As a result measured sound levels were normalized to 33 feet (10 meters) using the "practical spreading model" currently used by WSDOT and the NMFS. The practical spreading formula is provided below.

$$\mathrm{SPL_{D2}} = \mathrm{SPL_{D1}} + \beta * \log_{10}\left(\frac{\mathrm{D_1}}{\mathrm{D_2}}\right)$$

Where $\mathrm{SPL_{D1}}$ is the sound pressure measured at a distance, D_1 and $\mathrm{SPL_{D2}}$ is the estimated sound pressure at a distance, D_2. β is the attenuation factor resulting from acoustic spreading over distance. The California Department of Transportation (Caltrans) has reported that β can range between 5 and 30 depending upon site specific conditions such as water depth, pile type, pile length and the substrate the pile is driven into. Currently NOAA uses the practical spreading model with β equaling 15, which results in a 4.5 dB reduction in underwater sound levels for each doubling of distance. Unless otherwise noted, this Report uses β equaling 15 to normalize measured underwater sound pressure levels to 33 feet (10 meters) and to calculate the distances required for underwater sound generated by pile driving to reach the marine mammal detection and background sound levels (see Section 10.0).

The airborne and underwater sound level monitoring locations and the locations of the sheet piles driven with the impact hammer are shown in Figure 9.1 below.

Figure 9.1 Sheet Pile and Monitoring Locations for Impact Pile Driving



Source: The Greenbusch Group, Inc.

A summary of near field underwater sound levels produced during impact pile driving on February 8, 2016 is provided in Table 9.1.

Table 9.1 Near Shore Underwater Sound Levels from Impact Pile Driving, dB re: 1 μPa

Pile ID	Frequency Range	Peak				RMS_{90}				SEL				cSEL
		Min	Max	SD	Avg	Min	Max	SD	Avg	Min	Max	SD	Avg	
IMP-1	*Ramp-Up*													
	7 Hz-20 kHz	188	193	2	**191**	175	180	2	**179**	162	167	2	**165**	**173**
	75 Hz-20 kHz	188	193	3	**191**	175	180	2	**179**	162	167	2	**165**	**173**
	150 Hz-20 kHz	188	194	3	**191**	175	180	2	**179**	162	167	2	**165**	**174**
	200 Hz-20 kHz	188	194	3	**191**	175	180	2	**179**	162	167	2	**165**	**174**
	Full Power													
	7 Hz-20 kHz	189	199	2	**193**	175	183	1	**179**	161	168	1	**165**	**188**
	75 Hz-20 kHz	189	199	2	**193**	175	183	1	**179**	161	168	1	**165**	**188**
	150 Hz-20 kHz	189	199	2	**193**	175	183	1	**179**	161	168	1	**165**	**188**
	200 Hz-20 kHz	189	199	2	**193**	175	183	1	**179**	161	168	1	**165**	**188**
IMP-2	7 Hz-20 kHz	187	194	2	**190**	175	181	1	**177**	161	167	1	**164**	**180**
	75 Hz-20 kHz	187	194	2	**190**	175	181	1	**177**	161	167	1	**164**	**180**
	150 Hz-20 kHz	187	194	2	**190**	175	181	1	**177**	161	167	1	**164**	**180**
	200 Hz-20 kHz	187	195	2	**190**	175	181	1	**177**	161	167	1	**164**	**180**
IMP-3	7 Hz-20 kHz	186	192	2	**190**	175	180	2	**177**	162	166	1	**164**	**173**
	75 Hz-20 kHz	186	192	2	**190**	175	180	2	**177**	162	166	1	**164**	**173**
	150 Hz-20 kHz	186	192	2	**190**	175	180	2	**177**	162	166	1	**164**	**173**
	200 Hz-20 kHz	187	192	2	**190**	175	180	2	**177**	162	166	1	**164**	**173**
IMP-4	7 Hz-20 kHz	182	193	2	**190**	169	178	1	**177**	156	164	1	**163**	**180**
	75 Hz-20 kHz	182	193	2	**190**	170	178	1	**177**	156	164	1	**163**	**180**
	150 Hz-20 kHz	181	193	2	**190**	170	178	1	**177**	156	164	1	**163**	**180**
	200 Hz-20 kHz	181	193	2	**190**	170	178	1	**177**	156	164	1	**163**	**180**
IMP-5	7 Hz-20 kHz	187	194	2	**191**	176	182	2	**178**	162	167	1	**165**	**180**
	75 Hz-20 kHz	187	194	2	**191**	176	182	2	**178**	162	167	1	**165**	**180**
	150 Hz-20 kHz	187	194	1	**191**	176	182	2	**178**	162	167	1	**165**	**180**
	200 Hz-20 kHz	187	194	2	**191**	182	176	2	**178**	162	167	1	**165**	**180**

Note: Reported sound levels have been normalized to 33 feet (10 meters) using the practical spreading model
Source: The Greenbusch Group, Inc.

Simultaneous far field underwater sound data was collected during the installation of Impact Sheet Piles 2 through Impact Sheet Pile 5 (refer to Figure 7.1 for the far field measurement location). Due to elevated levels of low frequency background noise in Elliott Bay, pile strikes were unable to be isolated from background sound levels when the data was filtered between 7 Hz and 20 kHz. The results of these measurements are provided in Table 9.2.

Vibratory pile driving was also occurring during the collection of far field underwater sound data. However, underwater sound levels did not appear to significantly increase during periods when the vibratory hammer was active and it was difficult to attribute fluctuations in underwater sound levels specifically to vibratory pile driving.

Table 9.2 Far Field Underwater Sound Levels from Impact Pile Driving, dB re: 1 μPa

Pile ID	Frequency Range	Peak				RMS$_{90}$				SEL				cSEL
		Min	Max	SD	Avg	Min	Max	SD	Avg	Min	Max	SD	Avg	
IMP-2	7 Hz-20 kHz	-	-	-	**-**	-	-	-	**-**	-	-	-	**-**	**-**
	75 Hz-20 kHz	142	155	3	**145**	128	135	2	**130**	118	124	1	**120**	**136**
	150 Hz-20 kHz	142	155	3	**145**	128	133	1	**130**	118	122	1	**119**	**134**
	200 Hz-20 kHz	142	155	3	**145**	128	132	1	**130**	118	121	1	**119**	**134**
IMP-3	7 Hz-20 kHz	-	-	-	**-**	-	-	-	**-**	-	-	-	**-**	**-**
	75 Hz-20 kHz	140	146	2	**143**	128	132	2	**130**	118	122	2	**120**	**128**
	150 Hz-20 kHz	140	146	2	**143**	128	131	2	**130**	118	121	1	**119**	**128**
	200 Hz-20 kHz	141	145	2	**143**	128	132	2	**129**	117	120	1	**119**	**127**
IMP-4	7 Hz-20 kHz	-	-	-	**-**	-	-	-	**-**	-	-	-	**-**	**-**
	75 Hz-20 kHz	143	155	3	**147**	131	137	1	**132**	121	127	1	**123**	**142**
	150 Hz-20 kHz	143	154	3	**147**	130	134	1	**131**	120	124	1	**122**	**139**
	200 Hz-20 kHz	143	154	3	**146**	129	134	1	**131**	120	123	1	**121**	**139**
IMP-5	7 Hz-20 kHz	-	-	-	**-**	-	-	-	**-**	-	-	-	**-**	**-**
	75 Hz-20 kHz	143	154	2	**148**	128	135	2	**132**	120	126	2	**123**	**138**
	150 Hz-20 kHz	140	154	3	**148**	123	134	3	**132**	115	125	2	**123**	**136**
	200 Hz-20 kHz	144	154	2	**148**	128	133	1	**132**	120	124	1	**123**	**136**

Note: "-" indicated data is unknown. Sound levels measured approximately 10,000 feet (3,048 meters) from pile driving.
Source: The Greenbusch Group, Inc.

Airborne sound levels generated by impact pile driving of steel sheet piles are summarized in Table 9.3.

Table 9.3 Airborne Sound Levels from Impact Pile Driving, dB re: 20 μPa

Pile ID	Minimum	Maximum	Average
IMP-1		*Ramp-Up*	
	107	111	109
		Full Power	
	106	111	108
IMP-2	105	112	108
IMP-3	105	108	106
IMP-4	105	108	107
IMP-5	105	109	106

Note: Airborne sound levels measured 50 feet (15 meters) from pile driving
Source: The Greenbusch Group, Inc.

The number of pile strikes included in the underwater noise analysis, depth of the hydrophone, the water depth at the hydrophone and pile, the distance between the hydrophone and the pile, the distance from the pile to the water's edge and the depth into the substrate the pile was driven are summarized in the Appendix of this Report.

The underwater peak sound pressure levels measured over the duration of each pile drive, the underwater frequency spectrum associated with the pile strike that generated the highest absolute peak sound pressure level and the waveform of the pile strike are provided in the Appendix.

The Appendix also includes the 100-millisecond broadband airborne sound levels measured over each pile drive and a representative frequency spectrum of airborne sound levels.

10.0 MARINE MAMMAL DETECTION DISTANCES AND DISTANCE TO BACKGROUND

Background underwater sound level measurements were used in conjunction with data collected during vibratory and impact pile driving to estimate the distance required for underwater sound levels produced from pile driving to reach the marine mammal detection thresholds and existing background sound levels.

The National Marine Fisheries Service (NMFS) has defined underwater sound level thresholds for the disturbance and injury of marine mammals. These thresholds are provided in Table 10.1.

Table 10.1 Marine Mammal Disturbance Thresholds, dB re: 1 μPa (RMS)

Functional Hearing Group	Frequency Range	Underwater Sound Thresholds		
		Vibratory Pile Driving Disturbance Threshold (Level B)	**Impact Pile Driving Disturbance Threshold (Level B)**	**Injury Threshold (Level A)**
Cetaceans (small to large)	7 Hz-20 kHz 150 Hz-20 kHz 200 Hz-20 kHz	120	160	180
Pinnipeds	75 Hz-20 kHz	120	160	190

Source: National Marine Fisheries Service

The distance required for underwater sound generated by vibratory and impact pile driving of steel sheet piles to reach the marine mammal disturbance and injury thresholds presented in Table 10.1 were calculated using the practical spreading model (see Section 9.0). The distance required for underwater sound produced by pile driving is estimated by solving the practical spreading formula for D_2 resulting in the following:

$$D_2 = D_1 * 10^{\left(\frac{SPL_{D1} - SPL_{D2}}{15}\right)}$$

Where SPL_{D1} is the sound pressure measured at a distance, D_1 and SPL_{D2} is the estimated sound pressure at a distance, D_2.

The highest measured average RMS sound levels from vibratory and impact driving of steel sheet piles were used to calculate the distance required for sound to reach the marine mammal disturbance and injury thresholds and the background sound levels measured by WSDOT.

Far field underwater sound data collected 10,000 feet (3,048 meters) southwest of impact pile driving and data collected near the pile driving was also used to calculate the site specific attenuation factor of obstructed sheet piles. The resulting attenuation factor was estimated to be 19, which results in a 6 dB reduction in underwater sound pressure levels for each doubling of distance. This site specific attenuation factor suggests that underwater sound produced by obstructed pile driving attenuates more rapidly than predicted by the practical spreading model and the distance required for sound generated by obstructed pile driving to reach the marine mammal detection and background sound levels may be significantly less than predicted by the practical spreading model. However, data to estimate the site specific attenuation factor of unobstructed pile driving was not collected. Therefore, the distances to the marine mammal detection thresholds and background sound levels have been calculated using the standard attenuation factor of 15.

10.1 Marine Mammal Detection and Injury Distances

The distances necessary for underwater sound levels to attenuate down to the marine mammal disturbance and injury thresholds were estimated using the practical spreading model (see Section 9.0) and the highest average RMS sound levels measured during vibratory and impact pile installation. The resulting distances from vibratory and impact pile driving of steel sheet piles are shown in Table 10.2 below.

Table 10.2 Distances to Marine Mammal Thresholds from Pile Driving

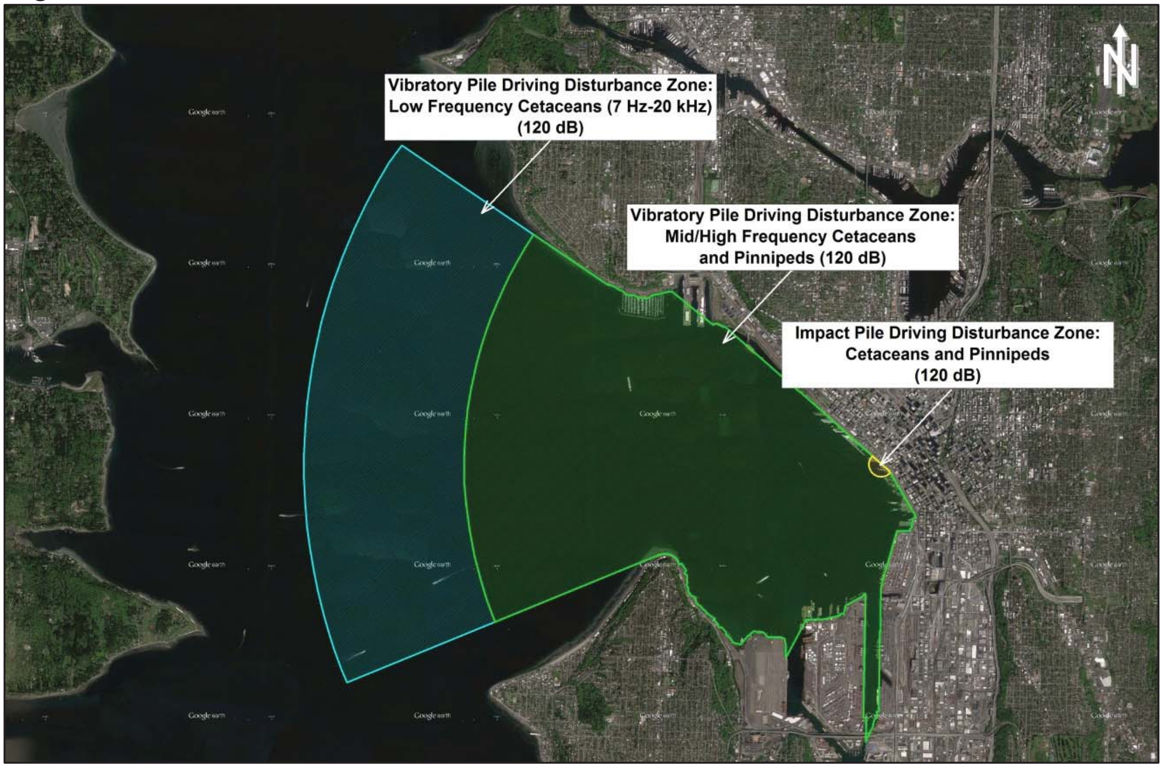
Functional Hearing Group	Frequency Range	RMS	Marine Mammal Detection Thresholds		Distance to Threshold[2]	
			Disturbance (Level B)	Injury (Level A)	Disturbance (Level B)	Injury (Level A)
Vibratory Pile Driving						
Cetaceans (small to large)	7 Hz-20 kHz	164	120[1]	180	**5.4 miles**	**3 feet**
	150 Hz-20 kHz	162			**3.9 miles**	**2 feet**
	200 Hz-20 kHz	162				
Pinnipeds	75 Hz-20 kHz	162	120[1]	190	**3.9 miles**	**½ foot**
Impact Pile Driving						
Cetaceans (small to large)	7 Hz-20 kHz	179	160	180	**610 feet**	**28 feet**
	150 Hz-20 kHz	179				
	200 Hz-20 kHz	179				
Pinnipeds	75 Hz-20 kHz	179	160	190	**610 feet**	**6 feet**

1. Background sound levels exceed the 120 dB disturbance threshold for vibratory pile driving.
2. The practical spreading model was used to calculate the distances to the marine mammal thresholds. These distances are reduced when calculated using the attenuation factor derived from measurements of obstructed pile driving.

Source: The Greenbusch Group, Inc.

As shown in Table 10.2, the estimated distance required for sound generated by vibratory pile driving to reach the 120 dB marine mammal disturbance threshold is between 5.4 and 3.9 miles (8.7 and 6.3 kilometers). Sound generated by impact pile driving is estimated to require 610 feet (186 meters) to reach the 160 dB marine mammal disturbance threshold. Figure 10.1 presents the areas where underwater sound levels are expected to exceed the marine mammal disturbance thresholds (120 dB for vibratory pile driving and 160 dB for impact pile driving).

Figure 10.1 Marine Mammal Disturbance Zones



Source: The Greenbusch Group, Inc.

10.2 Distance to Background Sound Levels

In addition to calculating the distance required for underwater sound levels to reach the marine mammal disturbance (Level B) and injury (Level A) thresholds, the distances required to reach background sound levels were also calculated. These distances were calculated using the background sound levels measured by WSDOT in April 2011. The WSDOT data was used rather than the near shore data collected by Greenbusch in 2016 because the WSDOT data more accurate describes the environment where marine mammals are likely to be present. These distances are provided in Table 10.3.

Table 10.3 Distance to Background Sound Levels Reported by WSDOT

Functional Hearing Group	Frequency Range	RMS, Highest Average (EBSP Season 3)	WSDOT Background Sound Level	Distance to Background[1]
Vibratory Pile Driving				
Cetaceans	7 Hz-20 kHz	164	130	**1.2 miles**
	150 Hz-20 kHz	162	124	**2.1 miles**
	200 Hz-20 kHz	162	124	**2.1 miles**
Pinnipeds	75 Hz-20 kHz	162	127	**1.3 miles**
Impact Pile Driving				
Cetaceans	7 Hz-20 kHz	179	130	**11.5 miles**
	150 Hz-20 kHz	179	124	**29.0 miles**
	200 Hz-20 kHz	179	124	**29.0 miles**
Pinnipeds	75 Hz-20 kHz	179	127	**18.3 miles**

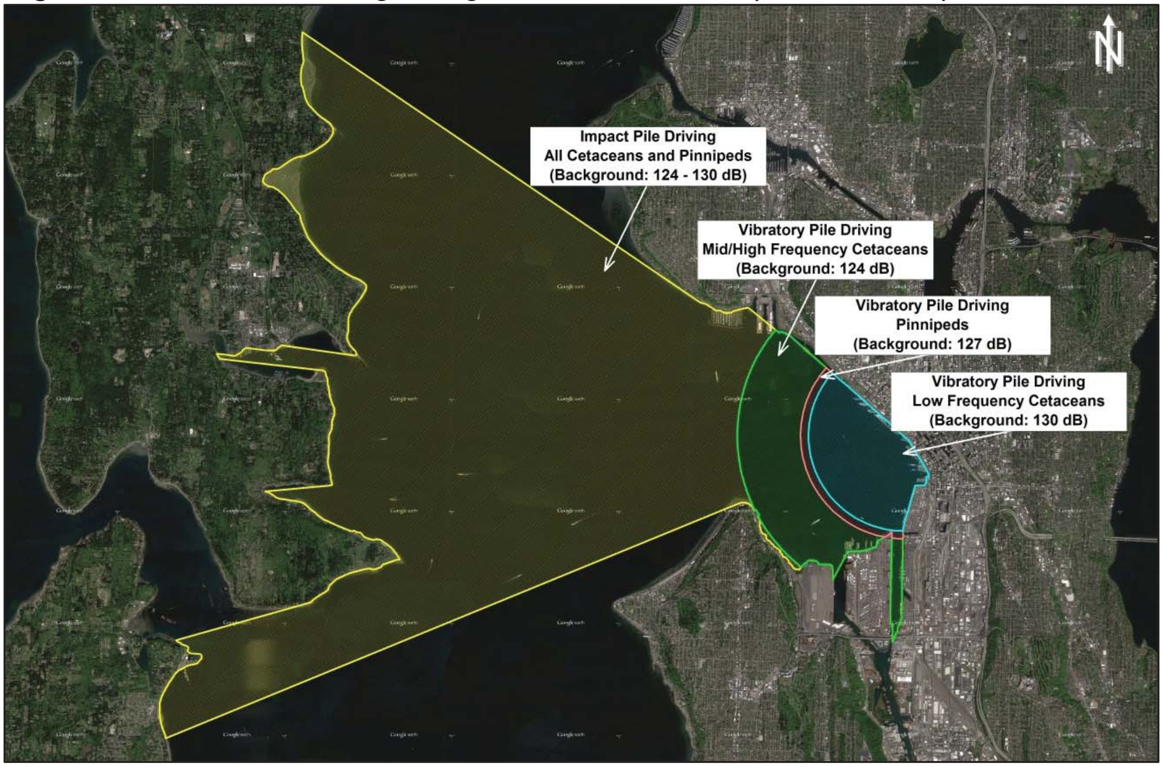
1. The practical spreading model was used to calculate the distances to the background sound levels. These distances are reduced when calculated using the attenuation factor derived from measurements of obstructed pile driving.

Source: The Greenbusch Group, Inc.

As shown in Table 10.3 the estimated distance required for underwater sound generated by the impact installation of steel sheet piles to attenuate to the background sound levels measured by WSDOT is up to 29 miles (46.7 kilometers) and up to 2.1 miles (3.4 kilometers) for sheet piles driven with the vibratory hammer. However, the distances required for impact pile driving are reduced due to the proximity of adjacent landmasses.

Figure 10.2 illustrates areas where underwater sound levels created by vibratory and impact pile driving of steel sheet piles are anticipated to exceed the background sound levels measured by WSDOT. Note that sound levels associated with vibratory pile driving are anticipated to attenuate to below background sound levels for pinnipeds well before the mooring buoys in southwest Elliott Bay where the majority of California sea lions have been sighted.

Figure 10.2 Areas Exceeding Background Sound Levels (WSDOT 2011)



Source: The Greenbusch Group, Inc.

10.3 Marine Mammal Monitoring

Monitors observed California sea lion, harbor seal, Steller sea lion, killer whale, harbor porpoise and humpback whale within the monitoring zone; however these animals did not exhibit any changes in behavior. Details of marine mammal monitoring are presented in a separate report entitled "Marine Mammal Monitoring Season 3 Annual Report, May 31, 2016."

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1.0 SHEET PILES INSTALLED WITH VIBRATORY HAMMER

VIBRATORY SHEET PILE 1

January 14, 2016

Table A-1 Vibratory Sheet Pile 1 - Hydrophone and Pile Information

Drive Time	Sound Attenuation	Hydro Depth (Feet)	Distance (Feet)			Water Depth (Feet)		
			Between Hydros	Hydro to Pile	Water's Edge	Hydros	Pile	Depth into Substrate
4.2 minutes	None	Upper: 3 Lower: 8	5	34	3	11	9	N/A

Table A-2 Vibratory Sheet Pile 1 – Airborne Sound Levels, dB re: 20 μPa

Pile ID	Minimum	Maximum	Average
VIB-1	*Ramp-Up*		
	92	101	96
	Full Power		
	93	105	101

Figure A-1 Vibratory Pile 1 Airborne 10-Sec RMS

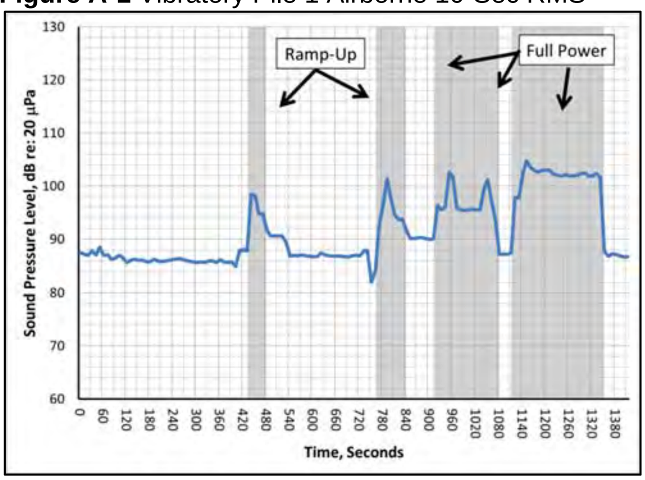


Figure A-2 Vibratory Pile 1 Airborne Spectra

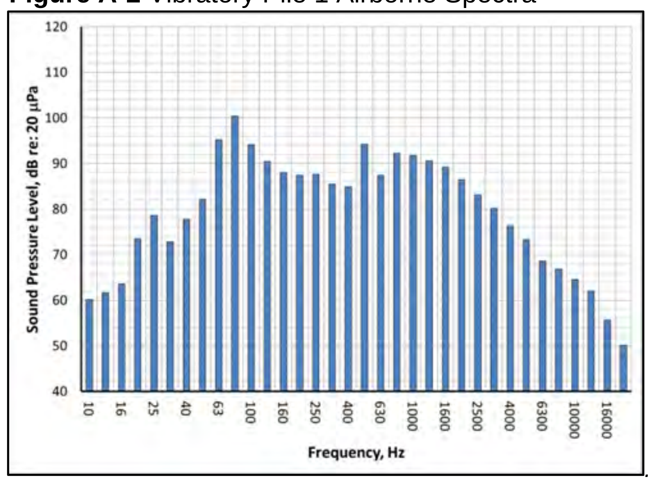


Table A-3 Vibratory Sheet Pile 1 – Underwater Sound Levels, dB re: 1 μPa

Pile ID	Frequency Range	Peak				RMS				SEL			
		Min	Max	SD	Avg	Min	Max	SD	Avg	Min	Max	SD	Avg
VIB-1	*Ramp-Up*												
	7 Hz-20 kHz	166	180	3	**172**	142	157	4	**152**	147	159	2	**154**
	75 Hz-20 kHz	166	180	3	**172**	142	157	4	**152**	147	159	2	**154**
	150 Hz-20 kHz	166	180	3	**172**	142	157	4	**152**	147	159	2	**154**
	200 Hz-20 kHz	165	180	3	**172**	142	157	4	**152**	147	159	2	**154**
	Full Power												
	7 Hz-20 kHz	169	182	2	**176**	150	161	2	**157**	147	163	2	**157**
	75 Hz-20 kHz	169	182	3	**176**	150	161	2	**156**	147	163	2	**156**
	150 Hz-20 kHz	169	182	3	**176**	150	161	2	**156**	146	163	2	**156**
	200 Hz-20 kHz	169	182	3	**176**	150	161	2	**156**	146	163	2	**156**

Figure A-3 Vibratory Sheet Pile 1- Peak Sound Pressure, Pa

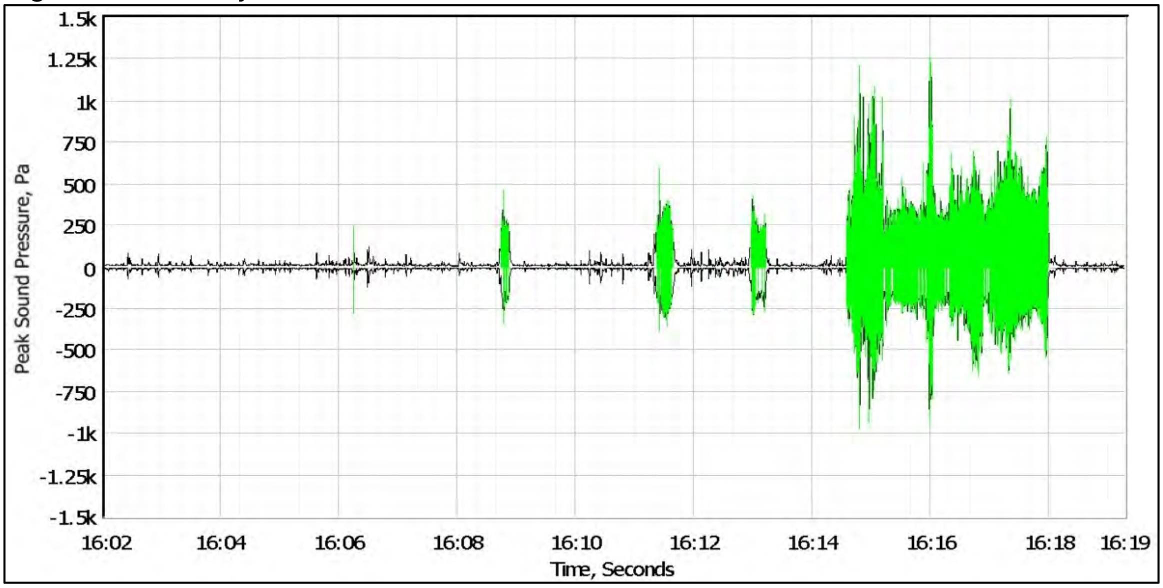
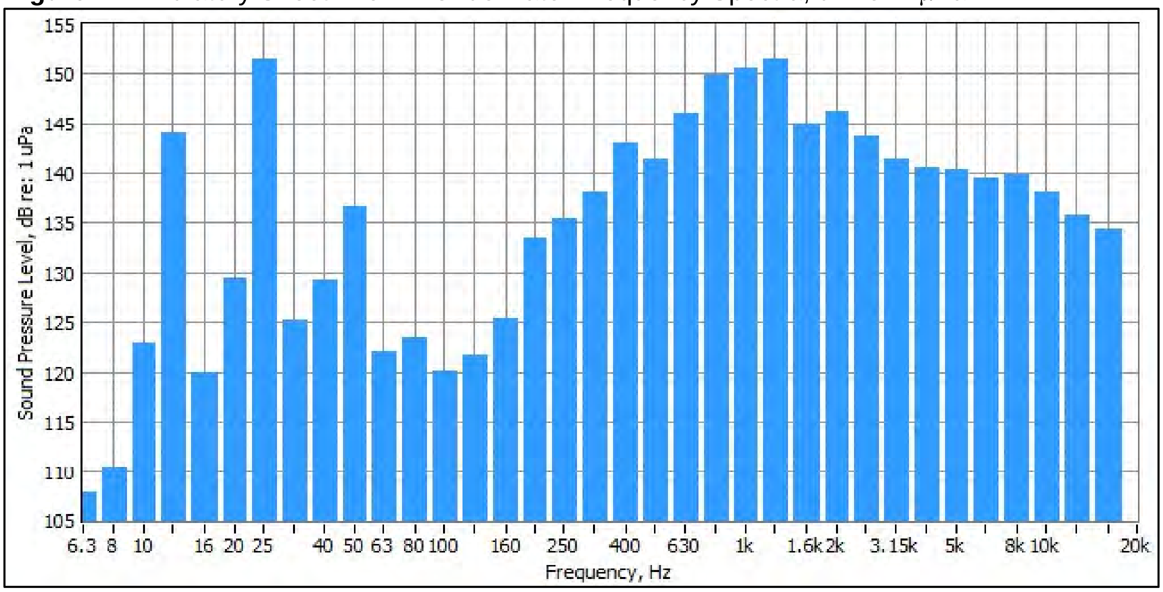


Figure A-4 Vibratory Sheet Pile 1 – Underwater Frequency Spectra, dB re: 1 μPa



VIBRATORY SHEET PILE 1

January 15, 2016

Table A-4 Vibratory Sheet Pile 1 - Hydrophone and Pile Information

Drive Time	Sound Attenuation	Hydro Depth (Feet)	Distance (Feet)			Water Depth (Feet)		
			Between Hydros	Hydro to Pile	Water's Edge	Hydros	Pile	Depth into Substrate
5.8 minutes	None	Upper: 3 Lower: 9	6	32	3	12	10	32

Table A-5 Vibratory Sheet Pile 1 – Airborne Sound Levels, dB re: 20 μPa

Pile ID	Minimum	Maximum	Average
VIB-1	*Ramp-Up*		
	103	107	105
	Full Power		
	99	106	104

Figure A-5 Vibratory Pile 1 Airborne 10-Sec RMS

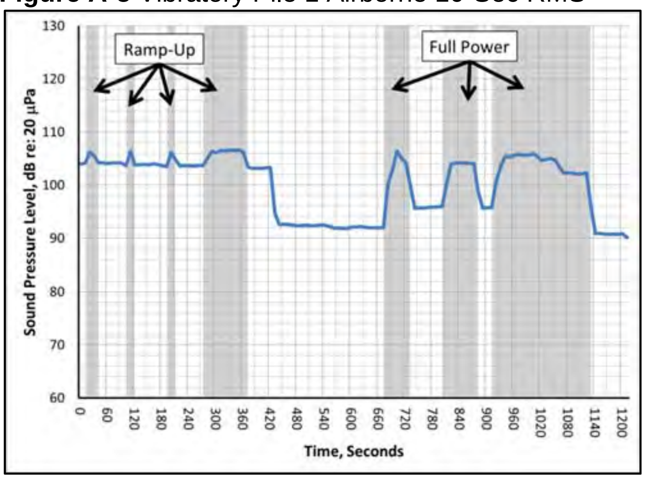


Figure A-6 Vibratory Pile 1 Airborne Spectra

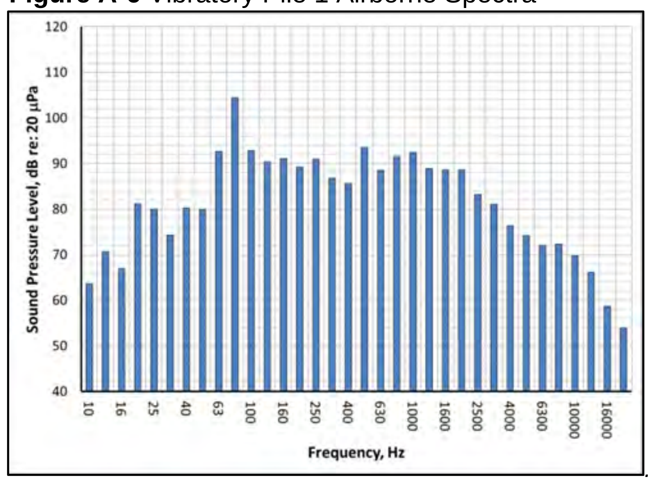


Table A-6 Vibratory Sheet Pile 1 – Underwater Sound Levels, dB re: 1 μPa

Pile ID	Frequency Range	Peak				RMS				SEL			
		Min	Max	SD	Avg	Min	Max	SD	Avg	Min	Max	SD	Avg
VIB-1	*Ramp-Up*												
	7 Hz-20 kHz	174	180	2	**178**	150	159	3	**157**	148	162	2	**158**
	75 Hz-20 kHz	173	179	2	**177**	148	158	4	**155**	148	160	3	**157**
	150 Hz-20 kHz	173	179	2	**177**	148	158	4	**155**	147	160	3	**157**
	200 Hz-20 kHz	173	180	2	**177**	148	158	4	**155**	147	160	3	**157**
	Full Power												
	7 Hz-20 kHz	173	190	4	**181**	148	166	4	**160**	148	172	2	**161**
	75 Hz-20 kHz	174	190	4	**181**	147	166	4	**159**	147	172	3	**160**
	150 Hz-20 kHz	174	190	4	**181**	147	166	4	**159**	146	172	3	**160**
	200 Hz-20 kHz	174	190	4	**181**	147	166	4	**159**	143	172	3	**160**

Figure A-7 Vibratory Sheet Pile 1- Peak Sound Pressure, Pa

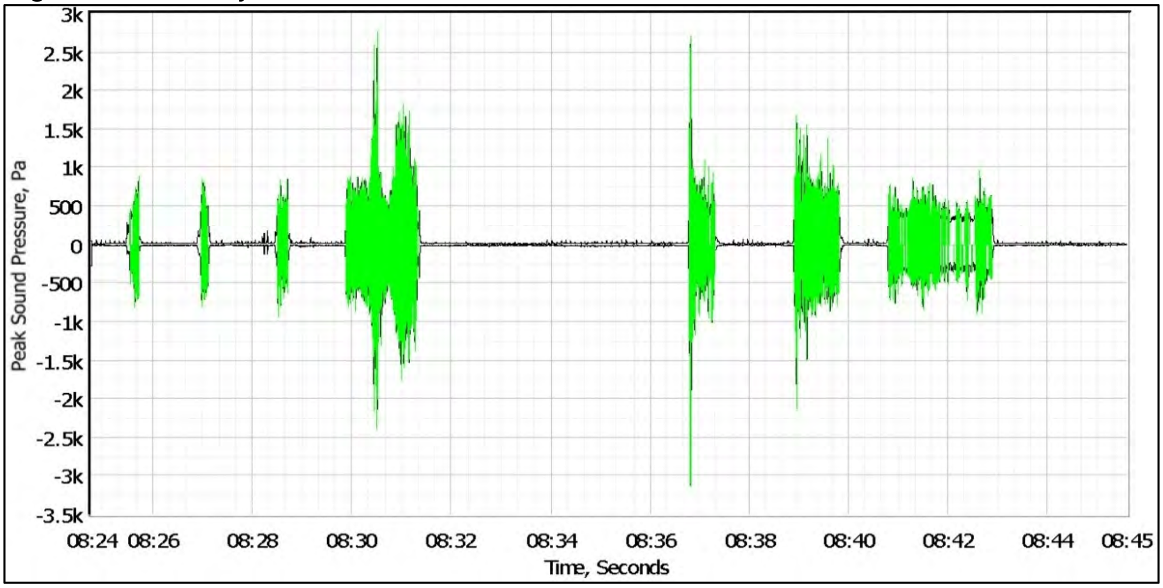
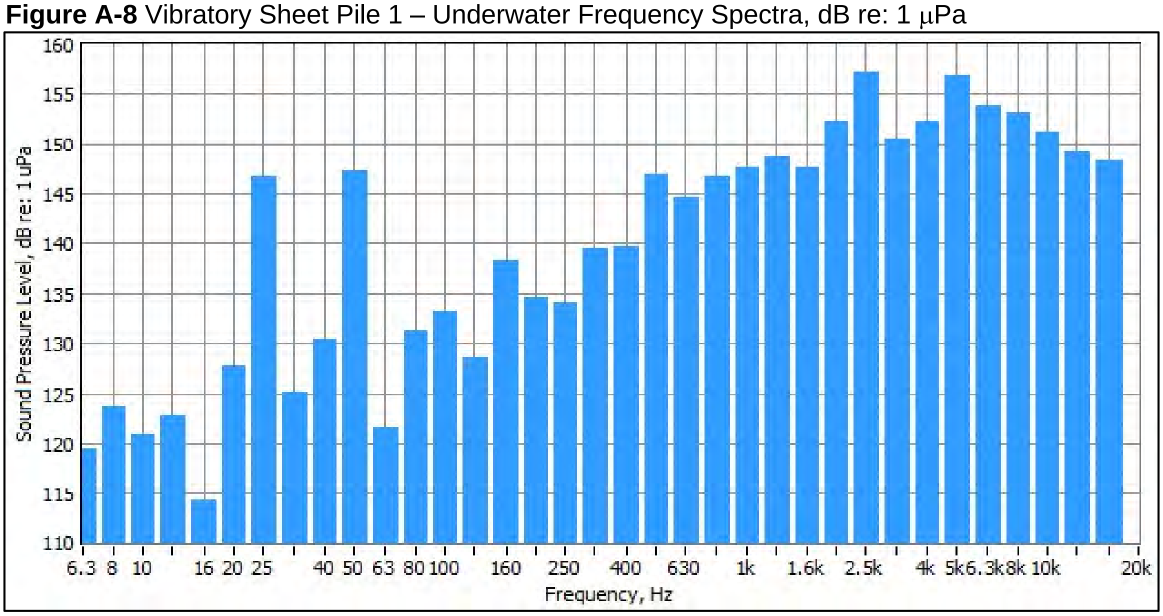


Figure A-8 Vibratory Sheet Pile 1 – Underwater Frequency Spectra, dB re: 1 μPa



VIBRATORY SHEET PILE 2

January 15, 2016

Table A-7 Vibratory Sheet Pile 2 - Hydrophone and Pile Information

Drive Time	Sound Attenuation	Hydro Depth (Feet)	Distance (Feet)			Water Depth (Feet)		
			Between Hydros	Hydro to Pile	Water's Edge	Hydros	Pile	Depth into Substrate
17 minutes	None	Upper: 3	6	33	3	12	10	37
		Lower: 9						

Table A-8 Vibratory Sheet Pile 2 – Airborne Sound Levels, dB re: 20 μPa

Pile ID	Minimum	Maximum	Average
VIB-2	97	108	105

Figure A-9 Vibratory Pile 2 Airborne 10-Sec RMS

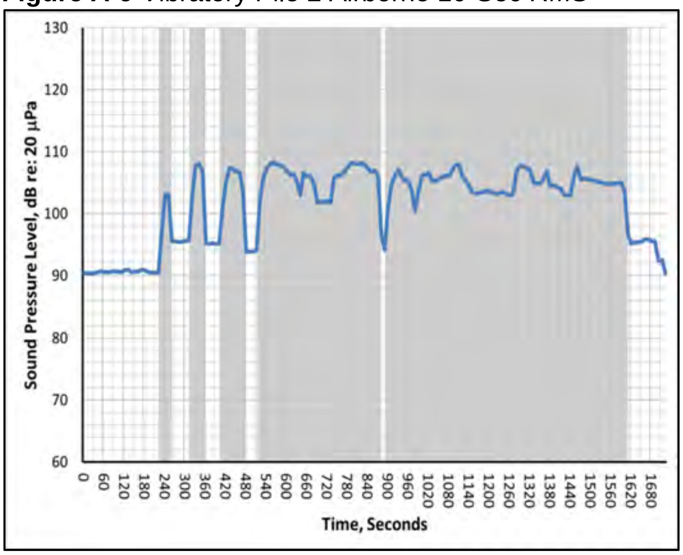


Figure A-10 Vibratory Pile 2 Airborne Spectra

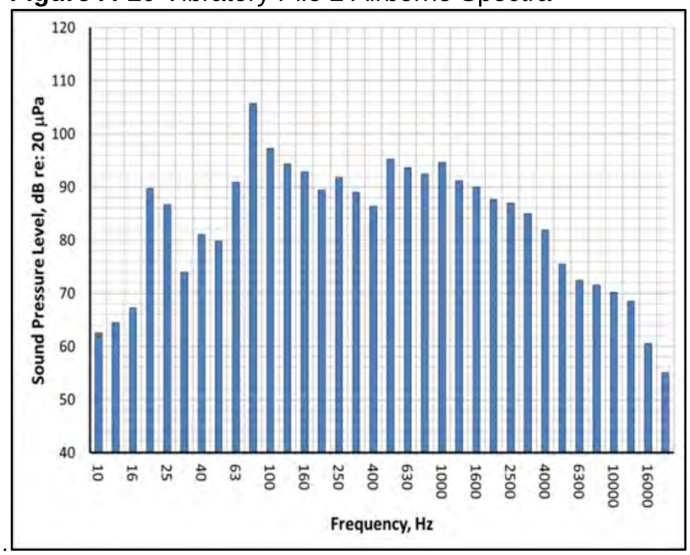


Table A-9 Vibratory Sheet Pile 2 – Underwater Sound Levels, dB re: 1 μPa

Pile ID	Frequency Range	Peak				RMS				SEL			
		Min	Max	SD	Avg	Min	Max	SD	Avg	Min	Max	SD	Avg
VIB-2	7 Hz-20 kHz	175	186	2	**182**	153	168	2	**164**	150	168	2	**164**
	75 Hz-20 kHz	175	185	2	**181**	151	166	3	**162**	146	167	2	**162**
	150 Hz-20 kHz	175	185	2	**181**	150	166	3	**162**	146	167	2	**162**
	200 Hz-20 kHz	175	185	2	**181**	150	166	3	**162**	146	167	2	**162**

Figure A-11 Vibratory Sheet Pile 2- Peak Sound Pressure, Pa

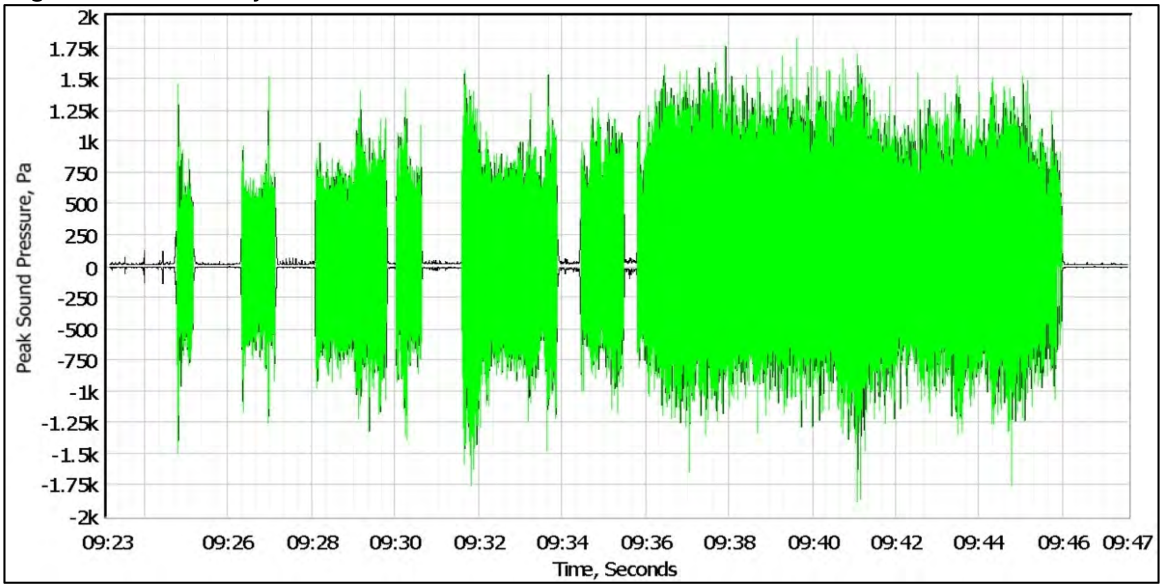
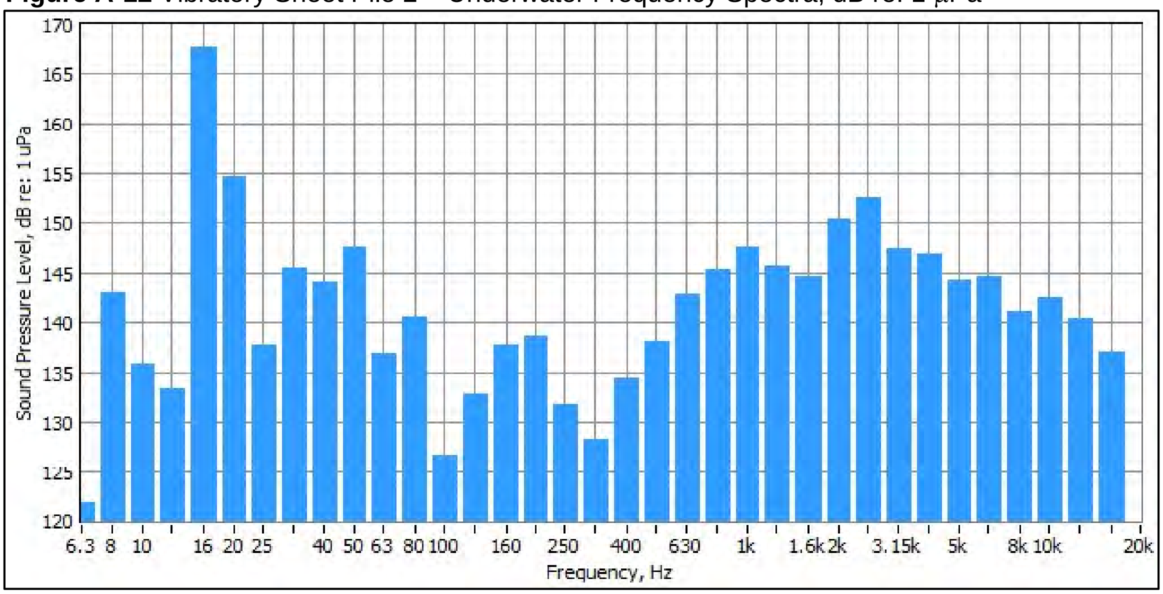


Figure A-12 Vibratory Sheet Pile 2 – Underwater Frequency Spectra, dB re: 1 μPa



VIBRATORY SHEET PILE 3

January 15, 2016

Table A-10 Vibratory Sheet Pile 3 - Hydrophone and Pile Information

Drive Time	Sound Attenuation	Hydro Depth (Feet)	Distance (Feet)			Water Depth (Feet)		
			Between Hydros	Hydro to Pile	Water's Edge	Hydros	Pile	Depth into Substrate
9 minutes	None	Upper: 3	5	35	3	11	9	32
		Lower: 8						

Table A-11 Vibratory Sheet Pile 3 – Airborne Sound Levels, dB re: 20 μPa

Pile ID	Minimum	Maximum	Average
VIB-3	97	107	104

Figure A-13 Vibratory Pile 3 Airborne 10-Sec RMS

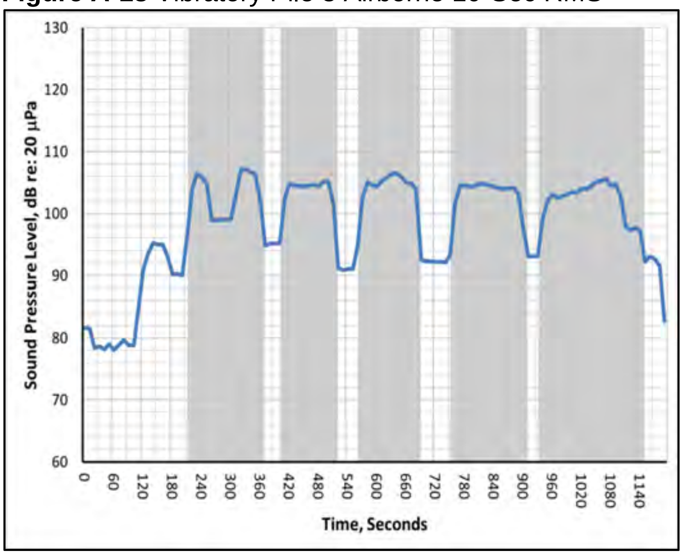


Figure A-14 Vibratory Pile 3 Airborne Spectra

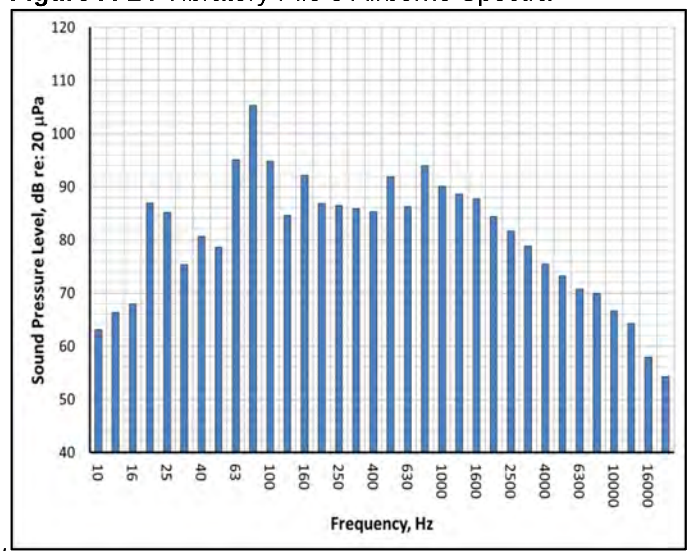


Table A-12 Vibratory Sheet Pile 3 – Underwater Sound Levels, dB re: 1 μPa

Pile ID	Frequency Range	Peak				RMS				SEL			
		Min	Max	SD	Avg	Min	Max	SD	Avg	Min	Max	SD	Avg
VIB-3	7 Hz-20 kHz	165	183	4	**175**	147	167	4	**158**	149	167	4	**159**
	75 Hz-20 kHz	165	183	4	**174**	143	163	4	**156**	145	164	4	**157**
	150 Hz-20 kHz	166	183	4	**174**	143	163	4	**156**	145	164	4	**157**
	200 Hz-20 kHz	166	183	4	**174**	143	163	4	**156**	145	164	4	**157**

Figure A-15 Vibratory Sheet Pile 3- Peak Sound Pressure, Pa

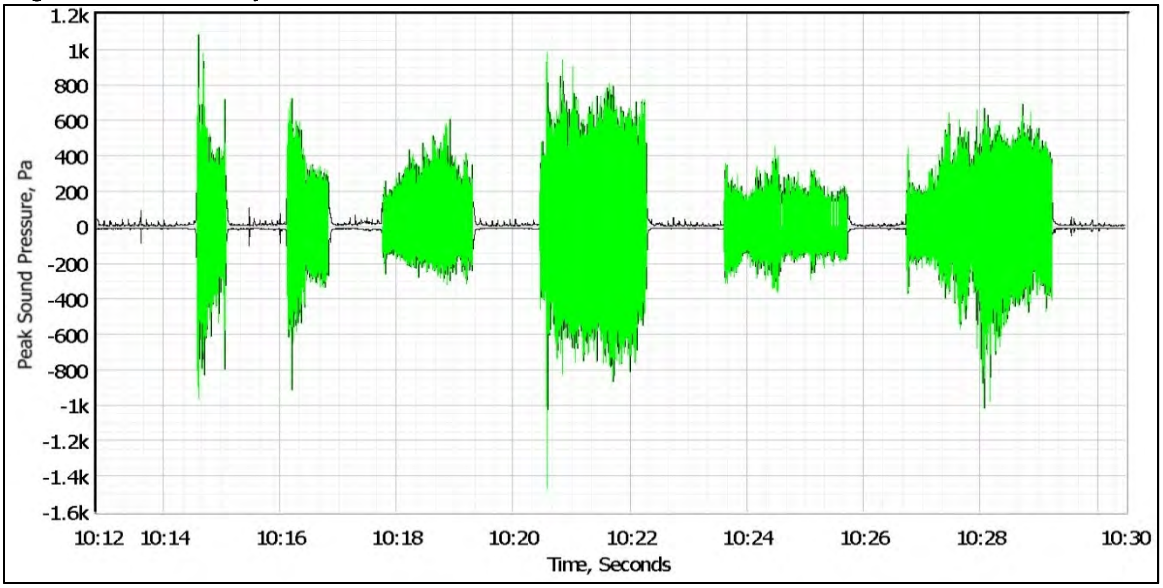
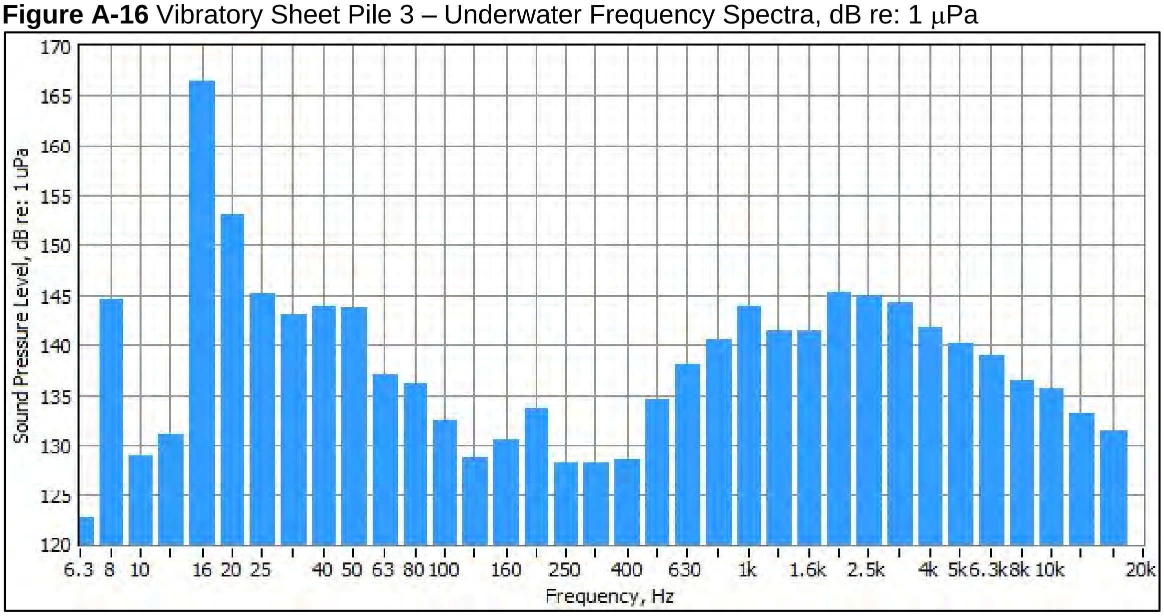


Figure A-16 Vibratory Sheet Pile 3 – Underwater Frequency Spectra, dB re: 1 μPa



VIBRATORY SHEET PILE 4

January 15, 2016

Table A-13 Vibratory Sheet Pile 4 - Hydrophone and Pile Information

Drive Time	Sound Attenuation	Hydro Depth (Feet)	Distance (Feet)			Water Depth (Feet)		
			Between Hydros	Hydro to Pile	Water's Edge	Hydros	Pile	Depth into Substrate
68 minutes	None	Upper: 3 Lower: 6	3	37	3	10	8	37

Table A-14 Vibratory Sheet Pile 4 – Airborne Sound Levels, dB re: 20 μPa

Pile ID	Minimum	Maximum	Average
VIB-4	97	109	103

Figure A-17 Vibratory Pile 4 Airborne 10-Sec RMS

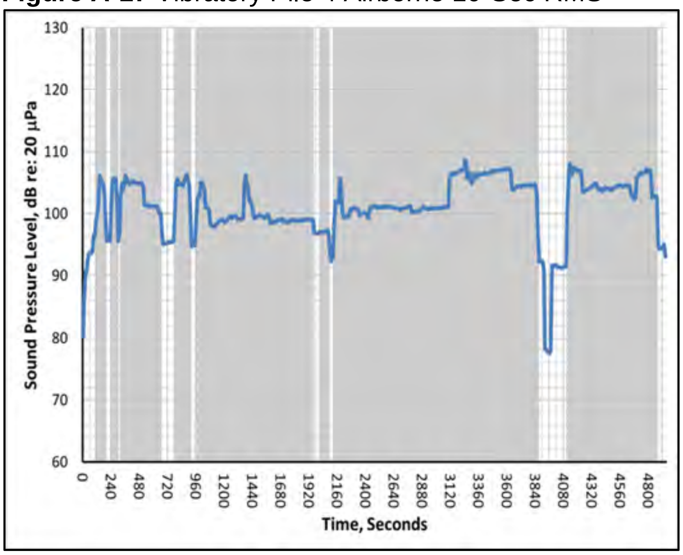


Figure A-18 Vibratory Pile 4 Airborne Spectra

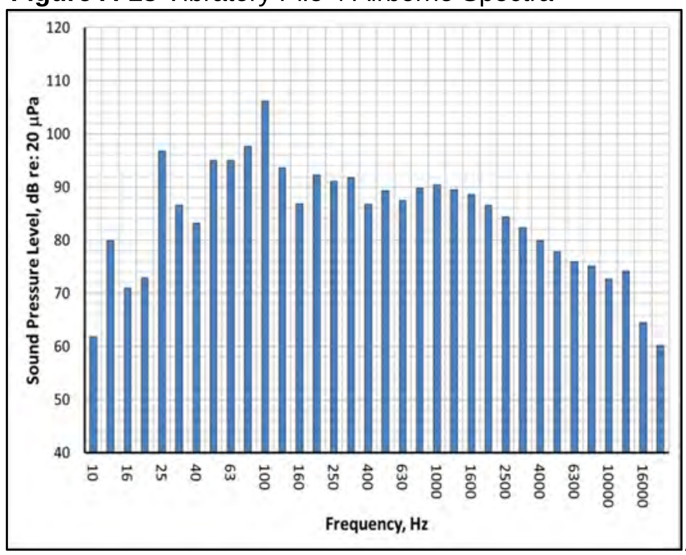


Table A-15 Vibratory Sheet Pile 4 – Underwater Sound Levels, dB re: 1 μPa

Pile ID	Frequency Range	Peak				RMS				SEL			
		Min	Max	SD	Avg	Min	Max	SD	Avg	Min	Max	SD	Avg
VIB-4	7 Hz-20 kHz	166	188	2	**175**	141	167	2	**161**	147	167	2	**161**
	75 Hz-20 kHz	167	187	3	**174**	145	162	3	**155**	146	163	3	**156**
	150 Hz-20 kHz	166	185	3	**174**	145	162	3	**155**	146	163	3	**156**
	200 Hz-20 kHz	166	184	3	**174**	145	162	3	**155**	146	163	3	**156**

Figure A-19 Vibratory Sheet Pile 4 (Morning Pile Drive) - Peak Sound Pressure, Pa

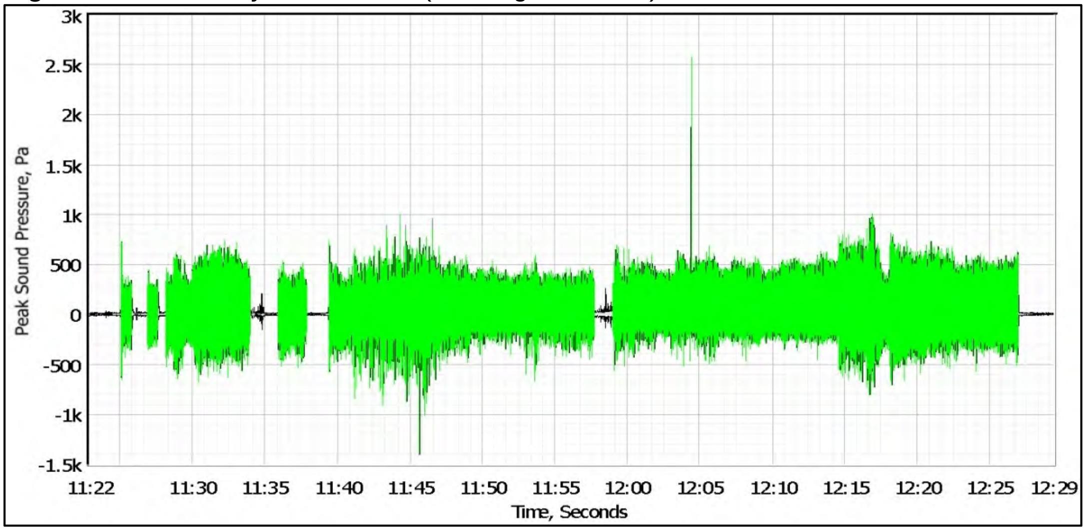


Figure A-20 Vibratory Sheet Pile 4 (Afternoon Pile Drive) - Peak Sound Pressure, Pa

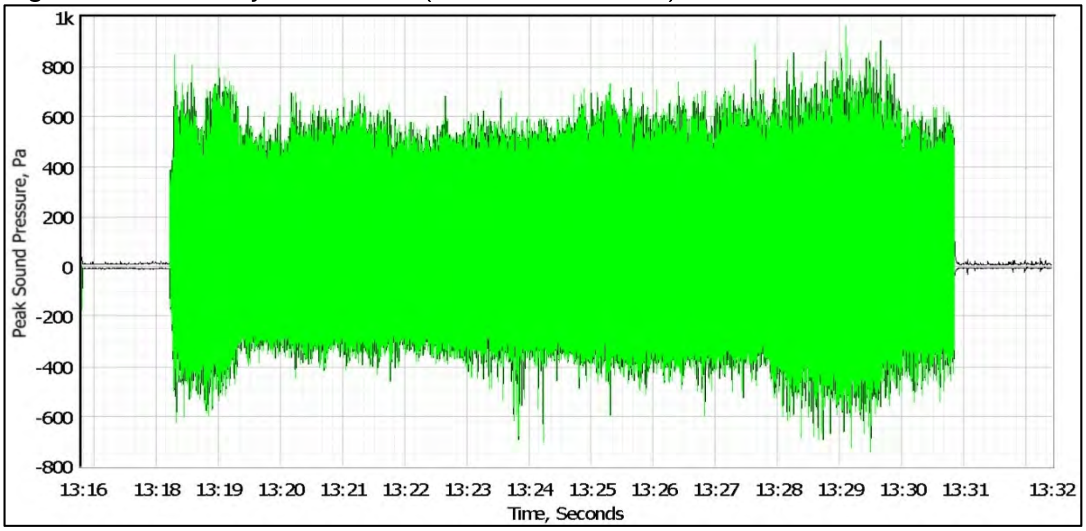
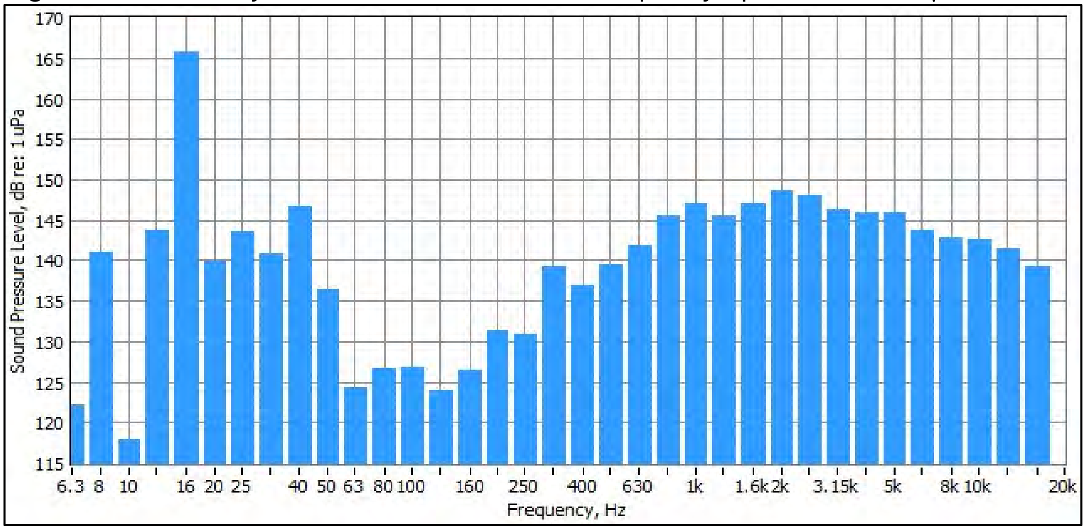


Figure A-21 Vibratory Sheet Pile 4 – Underwater Frequency Spectra, dB re: 1 μPa



VIBRATORY SHEET PILE 5

January 15, 2016

Table A-16 Vibratory Sheet Pile 5 - Hydrophone and Pile Information

Drive Time	Sound Attenuation	Hydro Depth (Feet)	Distance (Feet)			Water Depth (Feet)		
			Between Hydros	Hydro to Pile	Water's Edge	Hydros	Pile	Depth into Substrate
8 minutes	None	Upper: 1 Lower: 3	2	38	3	4	2	32

Table A-17 Vibratory Sheet Pile 5 – Airborne Sound Levels, dB re: 20 µPa

Pile ID	Minimum	Maximum	Average
VIB-5	99	108	106

Figure A-22 Vibratory Pile 5 Airborne 10-Sec RMS

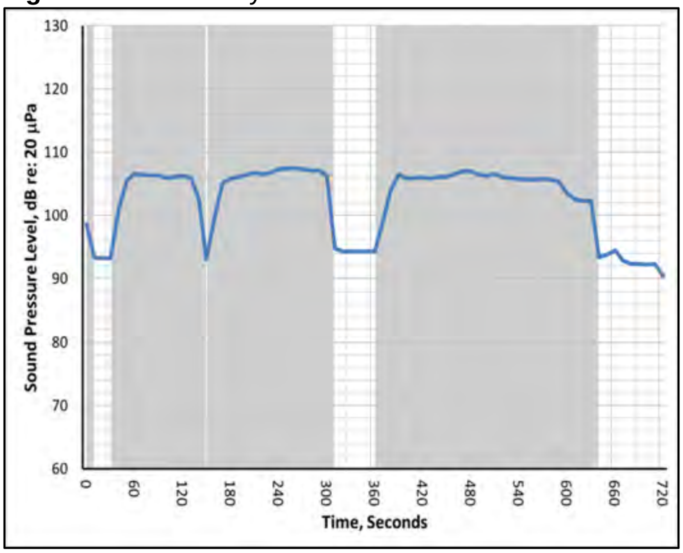


Figure A-23 Vibratory Pile 5 Airborne Spectra

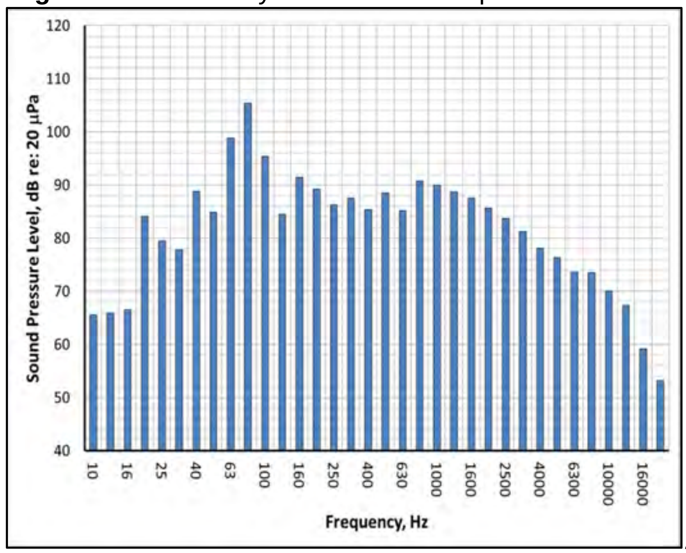


Table A-18 Vibratory Sheet Pile 5 – Underwater Sound Levels, dB re: 1 µPa

Pile ID	Frequency Range	Peak				RMS				SEL			
		Min	Max	SD	Avg	Min	Max	SD	Avg	Min	Max	SD	Avg
VIB-5	7 Hz-20 kHz	166	174	2	**171**	144	164	4	**157**	148	164	3	**158**
	75 Hz-20 kHz	165	174	2	**169**	143	157	3	**153**	145	159	2	**153**
	150 Hz-20 kHz	165	174	2	**169**	143	157	3	**153**	145	159	2	**153**
	200 Hz-20 kHz	165	173	2	**169**	143	157	3	**153**	145	159	2	**153**

Figure A-24 Vibratory Sheet Pile 5- Peak Sound Pressure, Pa

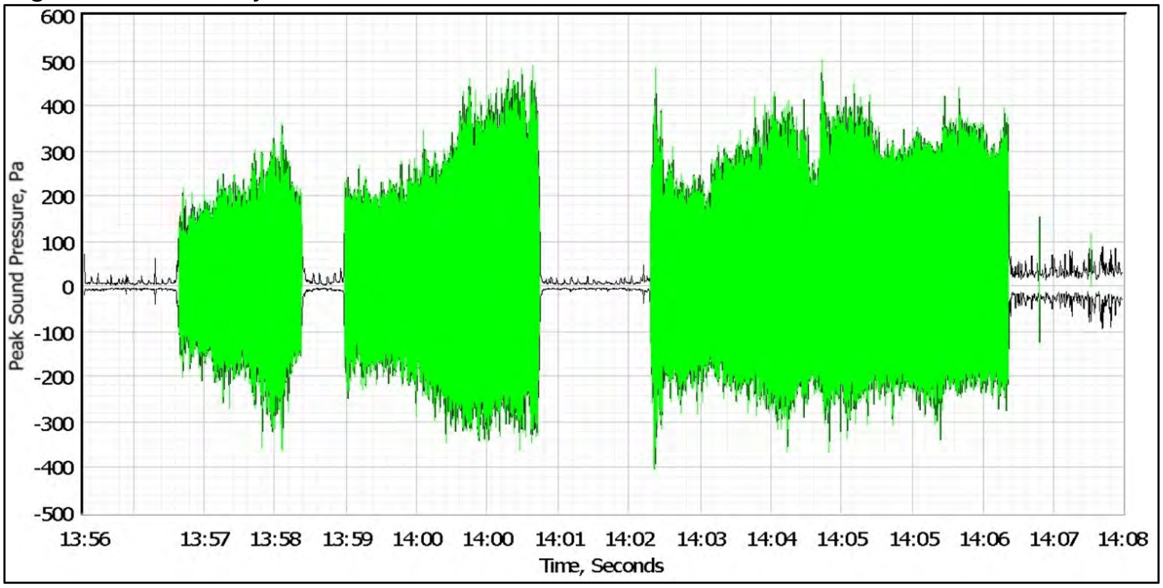
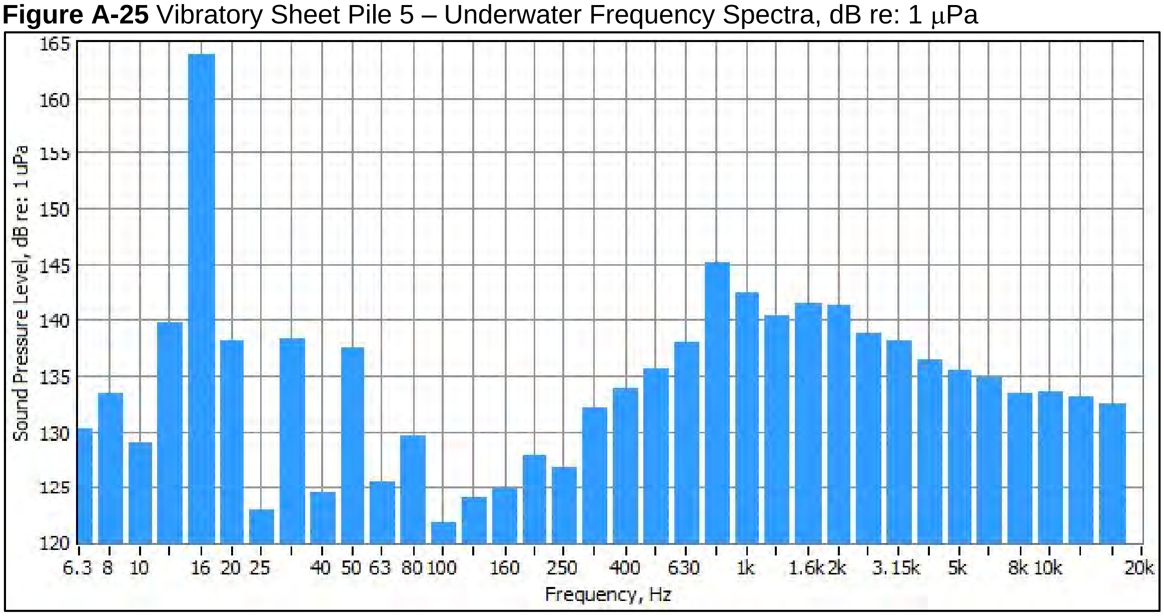


Figure A-25 Vibratory Sheet Pile 5 – Underwater Frequency Spectra, dB re: 1 μPa



2.0 SHEET PILES INSTALLED WITH IMPACT HAMMER

IMPACT SHEET PILE 1

February 8, 2016

Table A-19 Impact Sheet Pile 1 - Hydrophone and Pile Information

Number of Strikes (ramp-up/full power)	Sound Attenuation	Hydro Depth (Feet)	Distance (Feet)		Water Depth (Feet)		
			Hydro to Pile	Water's Edge	Hydros	Pile	Depth into Substrate
5 / 142	None	3	50	3	8	5	37

Table A-20 Impact Sheet Pile 1 – Airborne Sound Levels, dB re: 20 μPa

Pile ID	Minimum	Maximum	Average
IMP-1	*Ramp-Up*		
	107	111	109
	Full Power		
	106	111	108

Figure A-26 Impact Pile 1 Airborne 100-ms RMS

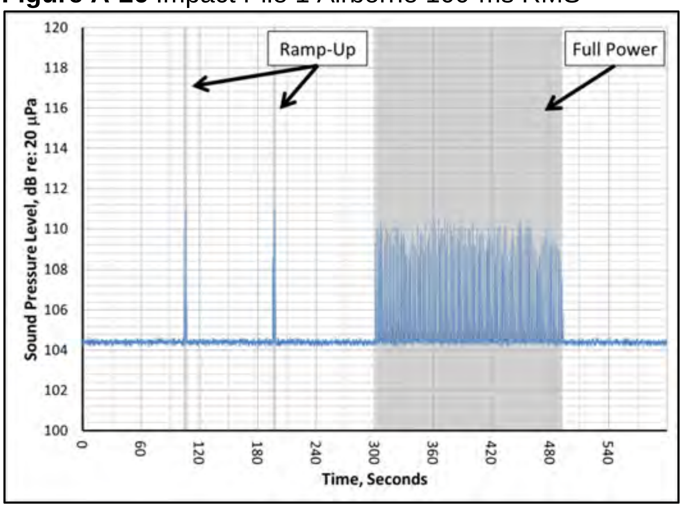


Figure A-27 Impact Pile 1 Airborne Spectra

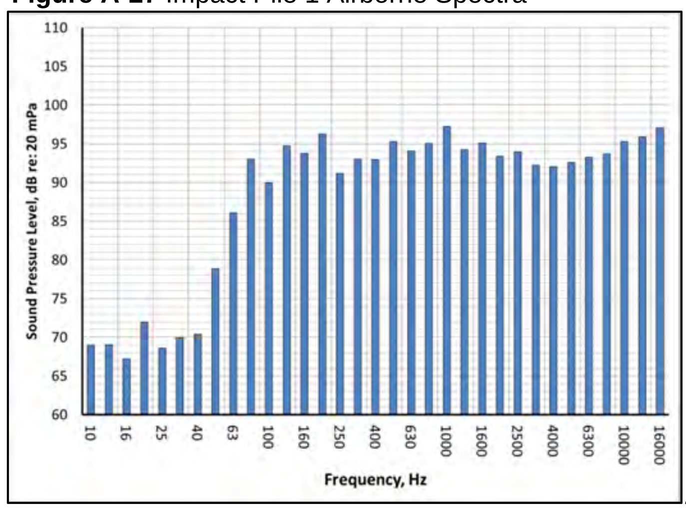


Table A-21 Impact Sheet Pile 1 – Underwater Sound Levels, dB re: 1 μPa

Pile ID	Frequency Range	Peak				RMS_{90}				SEL				cSEL
		Min	Max	SD	Avg	Min	Max	SD	Avg	Min	Max	SD	Avg	
IMP-1	*Ramp-Up*													
	7 Hz-20 kHz	188	193	2	**191**	175	180	2	**179**	162	167	2	**165**	**173**
	75 Hz-20 kHz	188	193	3	**191**	175	180	2	**179**	162	167	2	**165**	**173**
	150 Hz-20 kHz	188	194	3	**191**	175	180	2	**179**	162	167	2	**165**	**174**
	200 Hz-20 kHz	188	194	3	**191**	175	180	2	**179**	162	167	2	**165**	**174**
	Full Power													
	7 Hz-20 kHz	189	199	2	**193**	175	183	1	**179**	161	168	1	**165**	**188**
	75 Hz-20 kHz	189	199	2	**193**	175	183	1	**179**	161	168	1	**165**	**188**
	150 Hz-20 kHz	189	199	2	**193**	175	183	1	**179**	161	168	1	**165**	**188**
	200 Hz-20 kHz	189	199	2	**193**	175	183	1	**179**	161	168	1	**165**	**188**

Figure A-28 Impact Sheet Pile 1- Peak Sound Pressure, Pa

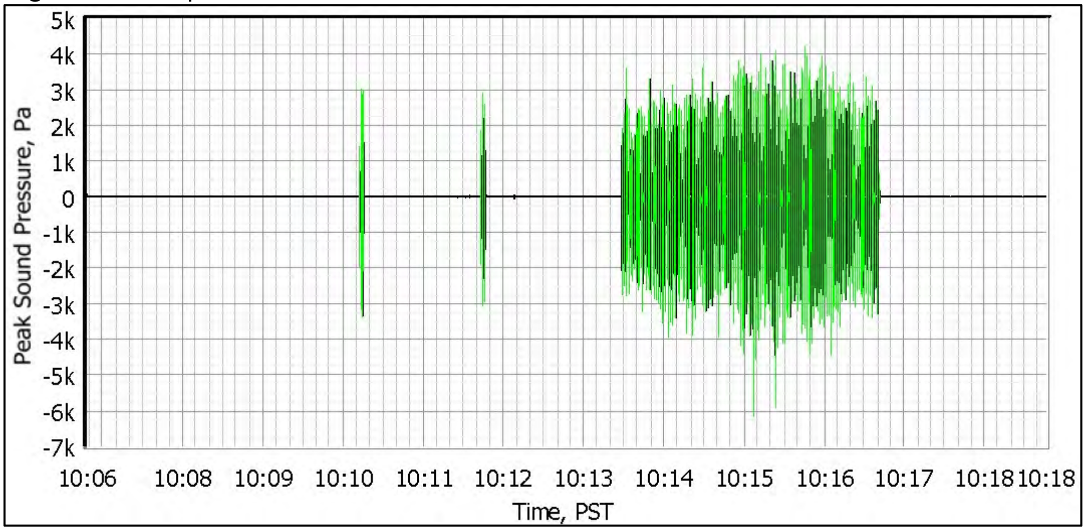


Figure A-29 Impact Sheet Pile 1 – Underwater Frequency Spectra, dB re: 1 μPa

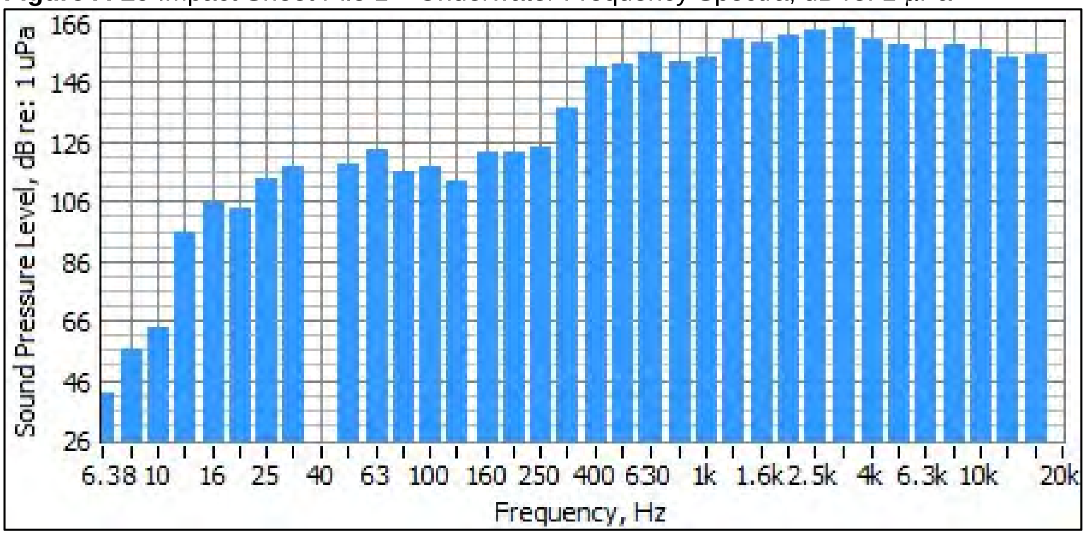
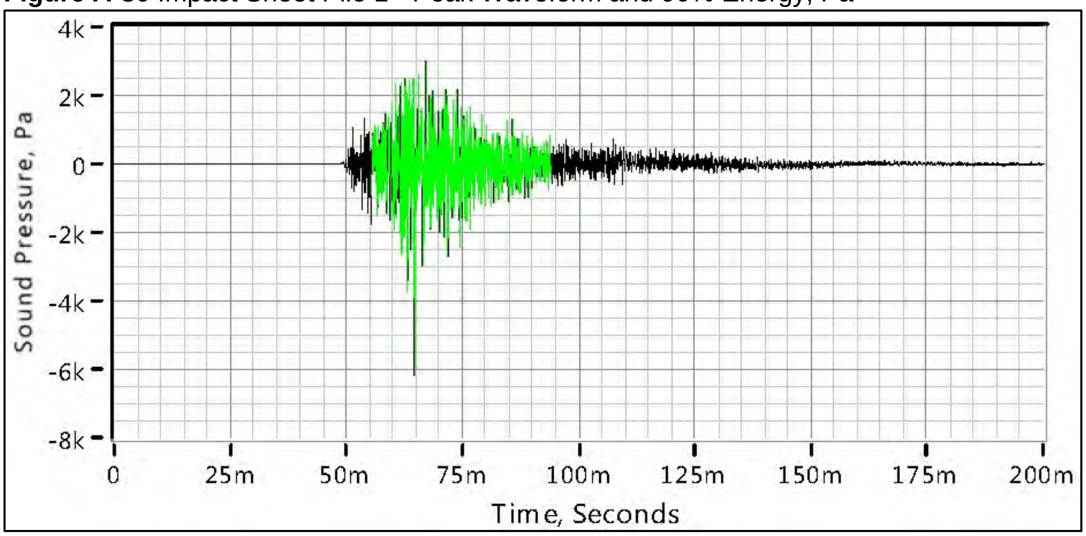


Figure A-30 Impact Sheet Pile 1 - Peak Waveform and 90% Energy, Pa



IMPACT SHEET PILE 2

February 8, 2016

Table A-22 Impact Sheet Pile 2 - Hydrophone and Pile Information

Number of Strikes	Sound Attenuation	Hydro Depth (Feet)	Distance (Feet)		Water Depth (Feet)		
			Hydro to Pile	Water's Edge	Hydros	Pile	Depth into Substrate
20	None	3	45	3	8	5	32

Table A-23 Impact Sheet Pile 2 – Airborne Sound Levels, dB re: 20 µPa

Pile ID	Minimum	Maximum	Average
IMP-2	105	112	108

Figure A-31 Impact Pile 2 Airborne 100-ms RMS

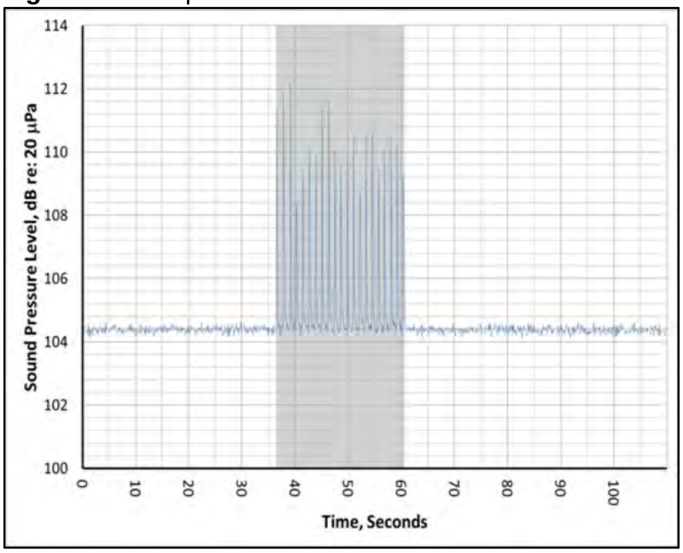


Figure A-32 Impact Pile 2 Airborne Spectra

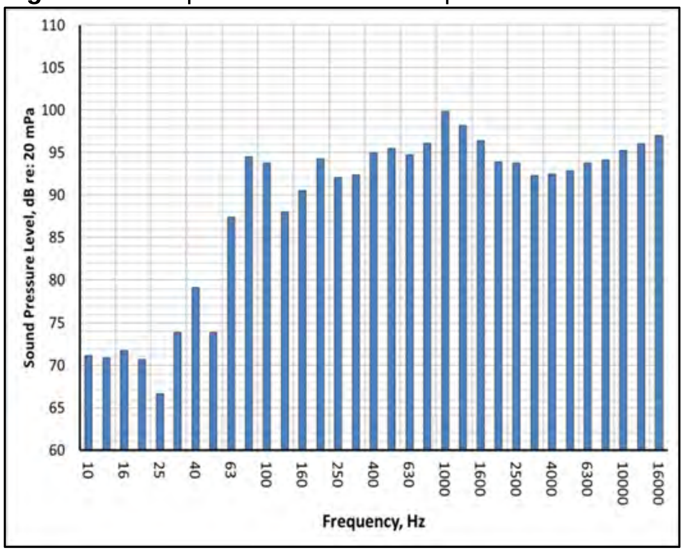


Table A-24 Impact Sheet Pile 2 – Underwater Sound Levels, dB re: 1 µPa

Pile ID	Frequency Range	Peak				RMS_{90}				SEL				cSEL
		Min	Max	SD	Avg	Min	Max	SD	Avg	Min	Max	SD	Avg	
IMP-2	7 Hz-20 kHz	187	194	2	**190**	175	181	1	**177**	161	167	1	**164**	**180**
	75 Hz-20 kHz	187	194	2	**190**	175	181	1	**177**	161	167	1	**164**	**180**
	150 Hz-20 kHz	187	194	2	**190**	175	181	1	**177**	161	167	1	**164**	**180**
	200 Hz-20 kHz	187	195	2	**190**	175	181	1	**177**	161	167	1	**164**	**180**

Figure A-33 Impact Sheet Pile 2- Peak Sound Pressure, Pa

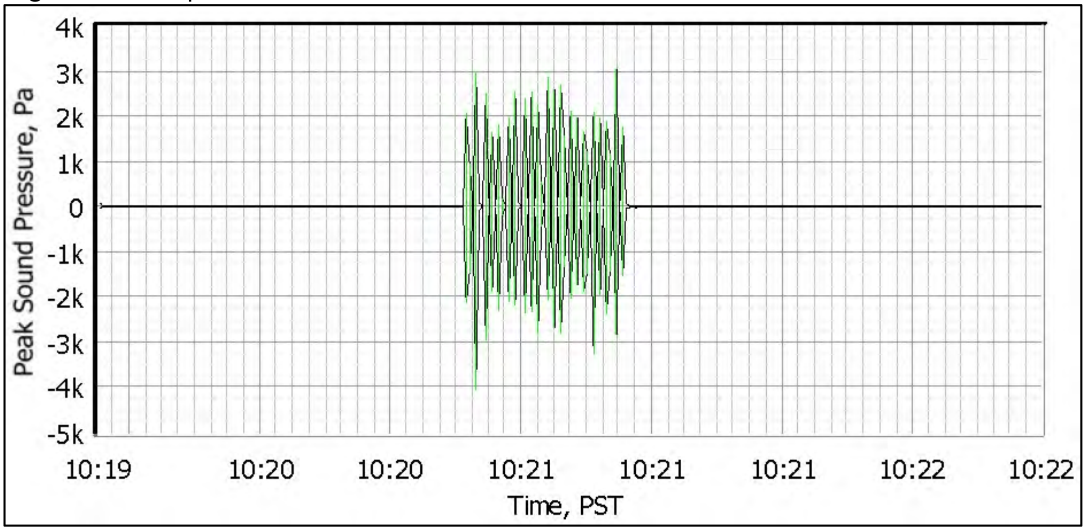


Figure A-34 Impact Sheet Pile 2 – Underwater Frequency Spectra, dB re: 1 μPa

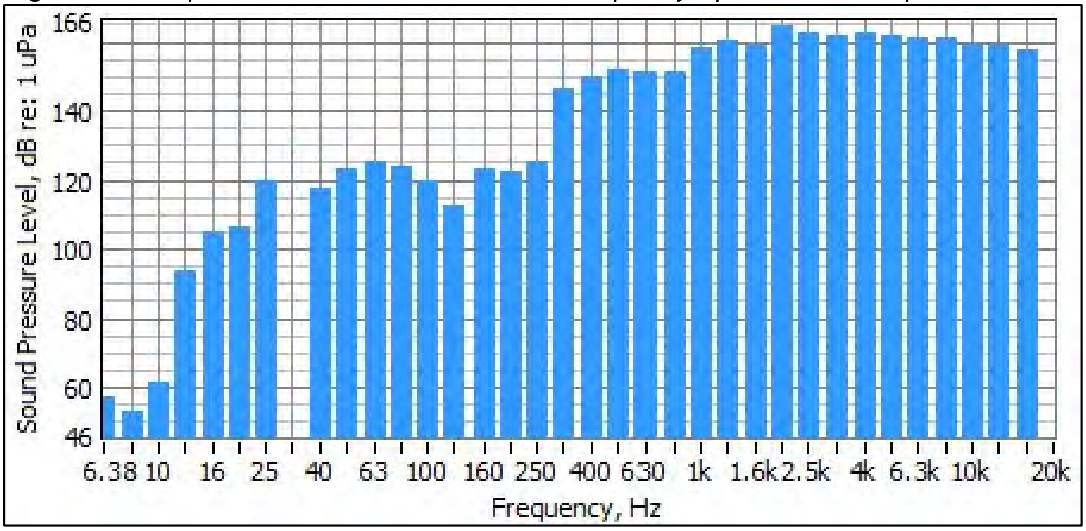
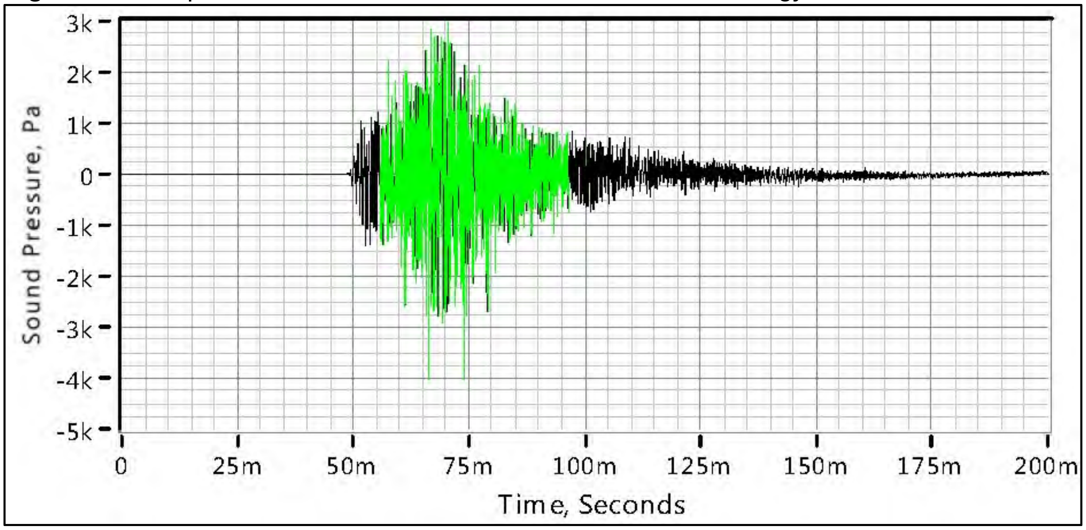


Figure A-35 Impact Sheet Pile 2 - Peak Waveform and 90% Energy, Pa



IMPACT SHEET PILE 3

February 8, 2016

Table A-25 Impact Sheet Pile 3 - Hydrophone and Pile Information

Number of Strikes	Sound Attenuation	Hydro Depth (Feet)	Distance (Feet)		Water Depth (Feet)		
			Hydro to Pile	Water's Edge	Hydros	Pile	Depth into Substrate
5	None	3	50	3	8	5	37

Table A-26 Impact Sheet Pile 3 – Airborne Sound Levels, dB re: 20 μPa

Pile ID	Minimum	Maximum	Average
IMP-3	105	108	106

Figure A-36 Impact Pile 3 Airborne 100-ms RMS

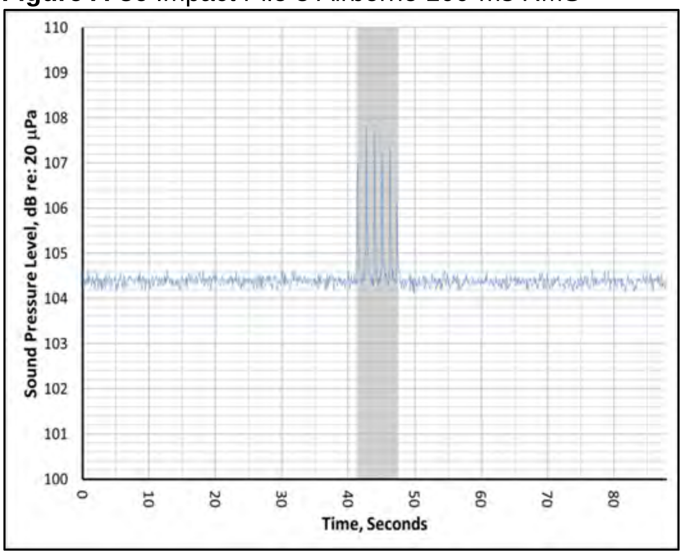


Figure A-37 Impact Pile 3 Airborne Spectra

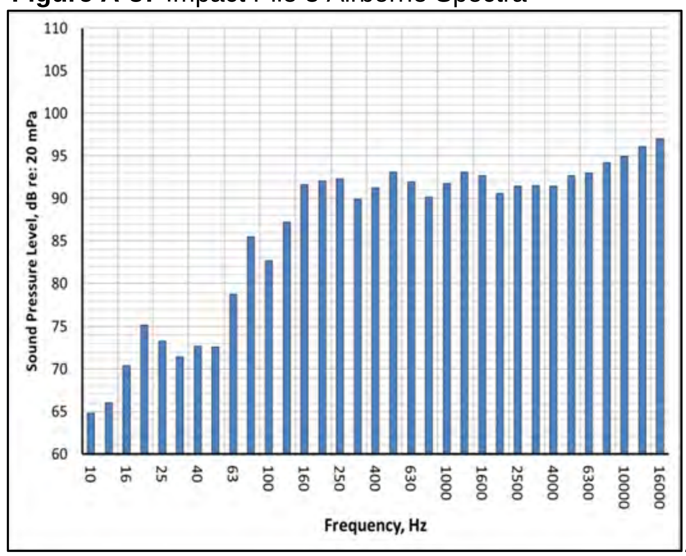


Table A-27 Impact Sheet Pile 3 – Underwater Sound Levels, dB re: 1 μPa

Pile ID	Frequency Range	Peak				RMS_{90}				SEL				cSEL
		Min	Max	SD	Avg	Min	Max	SD	Avg	Min	Max	SD	Avg	
IMP-3	7 Hz-20 kHz	186	192	2	**190**	175	180	2	**177**	162	166	1	**164**	**173**
	75 Hz-20 kHz	186	192	2	**190**	175	180	2	**177**	162	166	1	**164**	**173**
	150 Hz-20 kHz	186	192	2	**190**	175	180	2	**177**	162	166	1	**164**	**173**
	200 Hz-20 kHz	187	192	2	**190**	175	180	2	**177**	162	166	1	**164**	**173**

Figure A-38 Impact Sheet Pile 3- Peak Sound Pressure, Pa

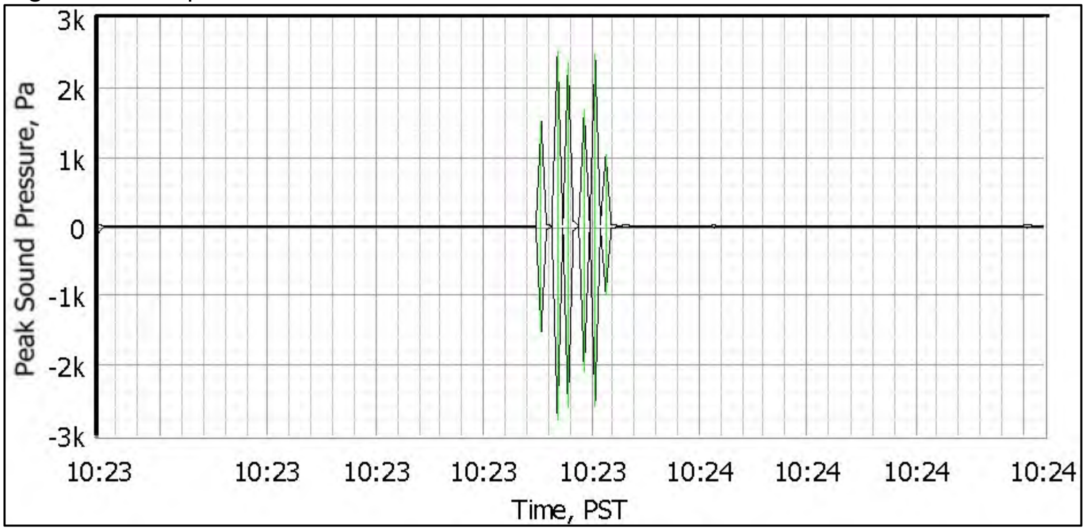


Figure A-39 Impact Sheet Pile 3 – Underwater Frequency Spectra, dB re: 1 μPa

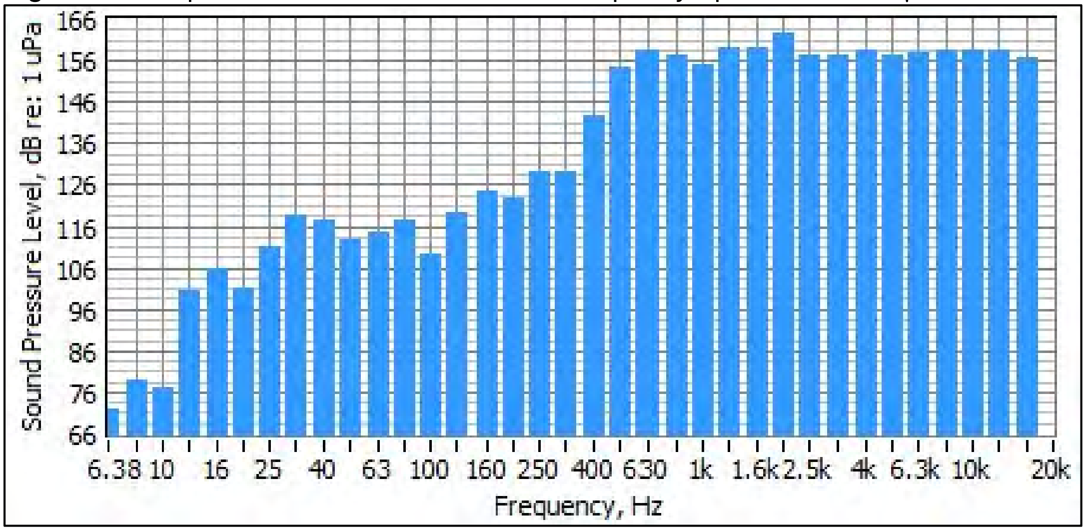
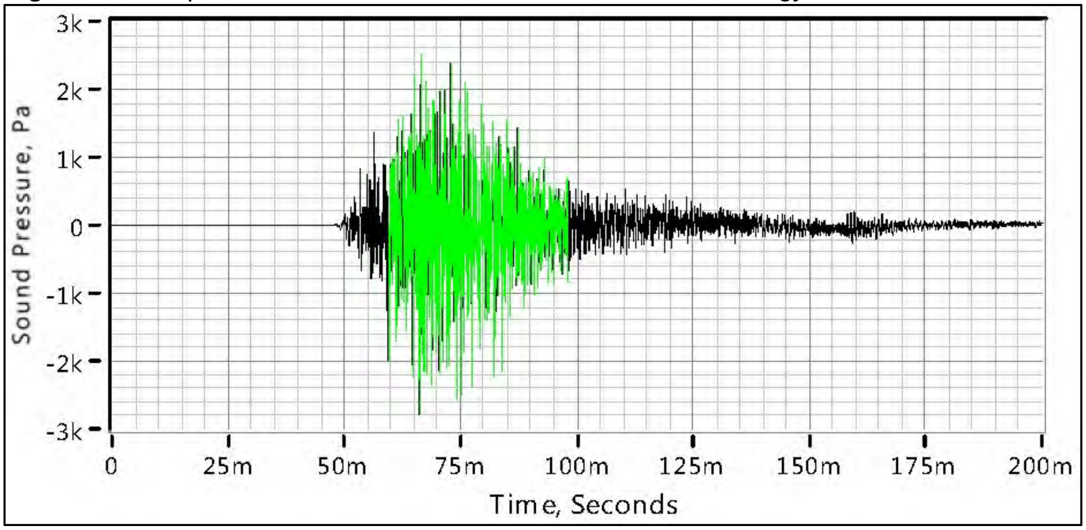


Figure A-40 Impact Sheet Pile 3 - Peak Waveform and 90% Energy, Pa



IMPACT SHEET PILE 4

February 8, 2016

Table A-28 Impact Sheet Pile 4 - Hydrophone and Pile Information

Number of Strikes	Sound Attenuation	Hydro Depth (Feet)	Distance (Feet)		Water Depth (Feet)		
			Hydro to Pile	Water's Edge	Hydros	Pile	Depth into Substrate
40	None	3	55	3	8	5	32

Table A-29 Impact Sheet Pile 4 – Airborne Sound Levels, dB re: 20 μPa

Pile ID	Minimum	Maximum	Average
IMP-4	105	108	107

Figure A-41 Impact Pile 4 Airborne 100-ms RMS

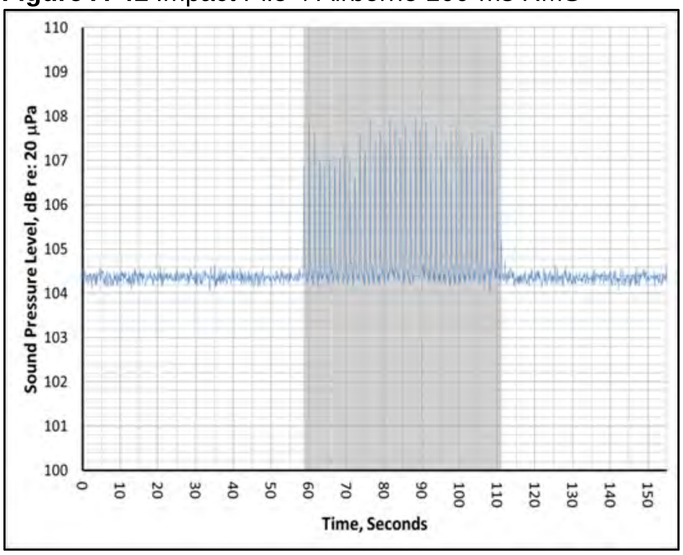


Figure A-42 Impact Pile 4 Airborne Spectra

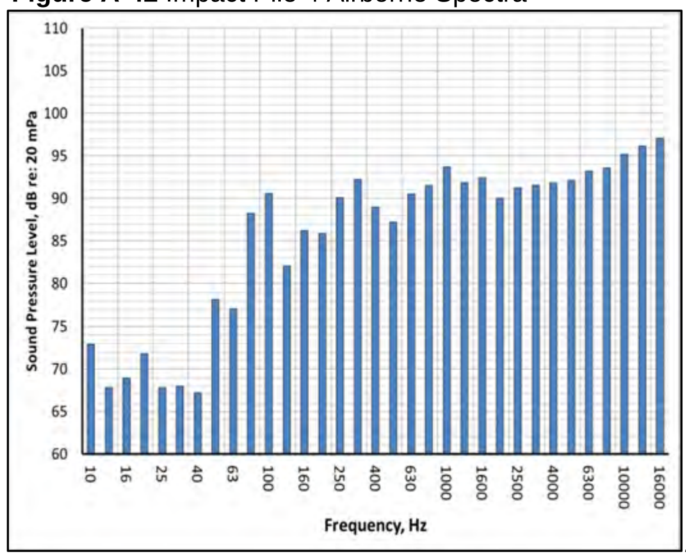


Table A-30 Impact Sheet Pile 4 – Underwater Sound Levels, dB re: 1 μPa

Pile ID	Frequency Range	Peak				RMS_{90}				SEL				cSEL
		Min	Max	SD	Avg	Min	Max	SD	Avg	Min	Max	SD	Avg	
IMP-4	7 Hz-20 kHz	182	193	2	**190**	169	178	1	**177**	156	164	1	**163**	**180**
	75 Hz-20 kHz	182	193	2	**190**	170	178	1	**177**	156	164	1	**163**	**180**
	150 Hz-20 kHz	181	193	2	**190**	170	178	1	**177**	156	164	1	**163**	**180**
	200 Hz-20 kHz	181	193	2	**190**	170	178	1	**177**	156	164	1	**163**	**180**

Figure A-43 Impact Sheet Pile 4- Peak Sound Pressure, Pa

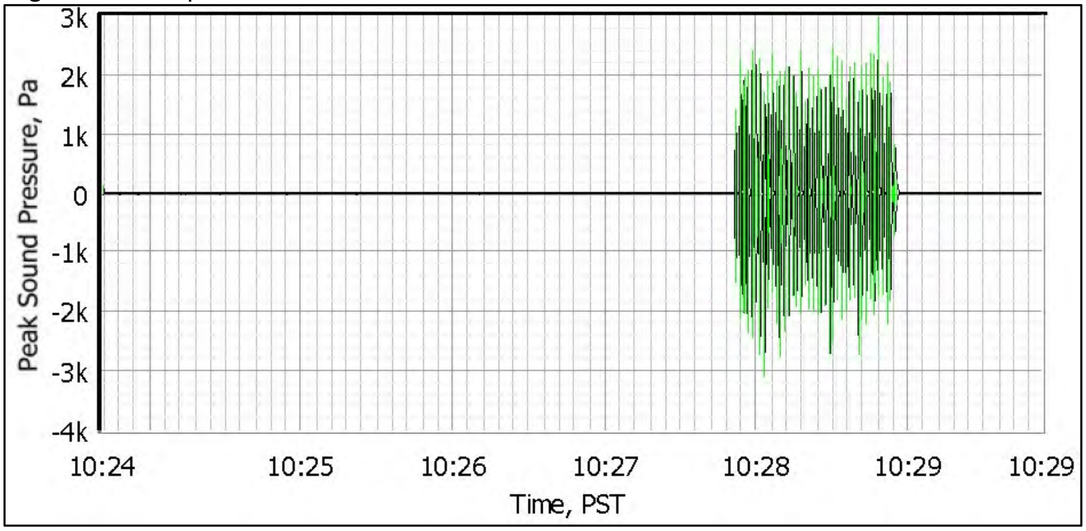


Figure A-44 Impact Sheet Pile 4 – Underwater Frequency Spectra, dB re: 1 μPa

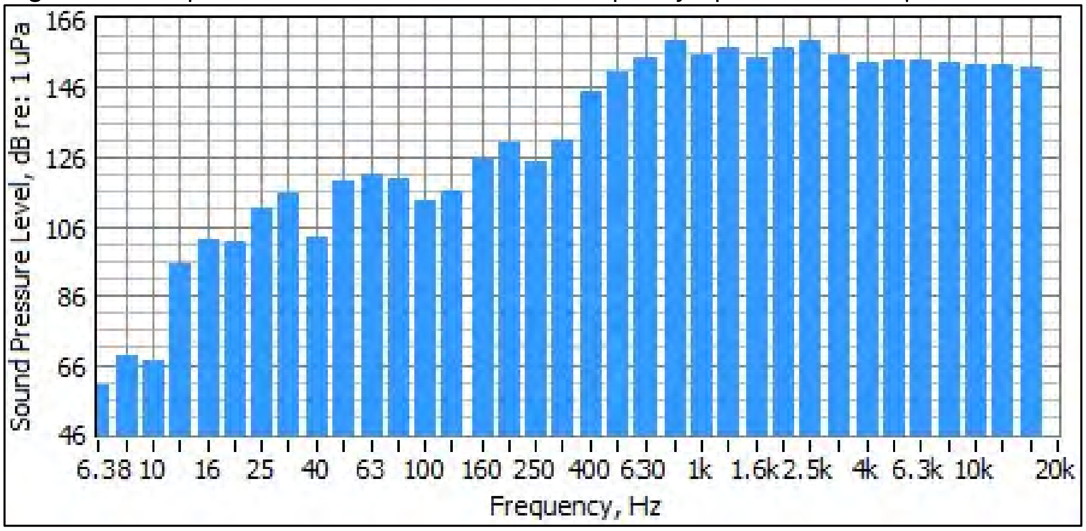
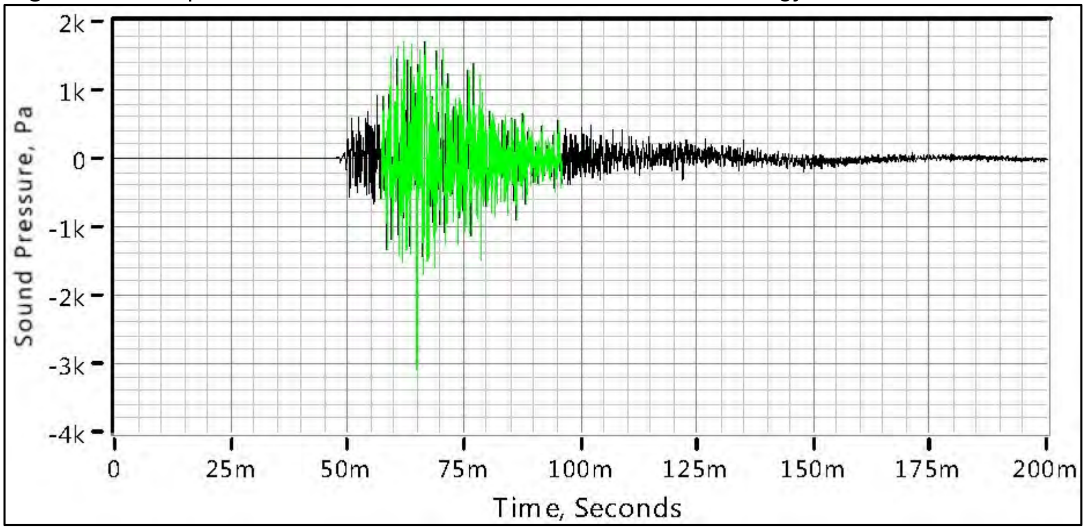


Figure A-45 Impact Sheet Pile 4 - Peak Waveform and 90% Energy, Pa



IMPACT SHEET PILE 5

February 8, 2016

Table A-31 Impact Sheet Pile 5 - Hydrophone and Pile Information

Number of Strikes	Sound Attenuation	Hydro Depth (Feet)	Distance (Feet)		Water Depth (Feet)		
			Hydro to Pile	Water's Edge	Hydros	Pile	Depth into Substrate
18	None	3	60	3	8	5	37

Table A-32 Impact Sheet Pile 5 – Airborne Sound Levels, dB re: 20 µPa

Pile ID	Minimum	Maximum	Average
IMP-5	105	109	106

Figure A-46 Impact Pile 5 Airborne 100-ms RMS

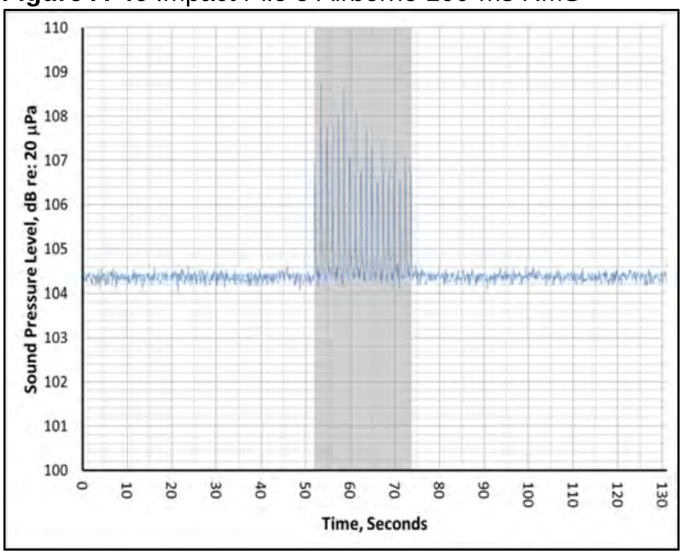


Figure A-47 Impact Pile 5 Airborne Spectra

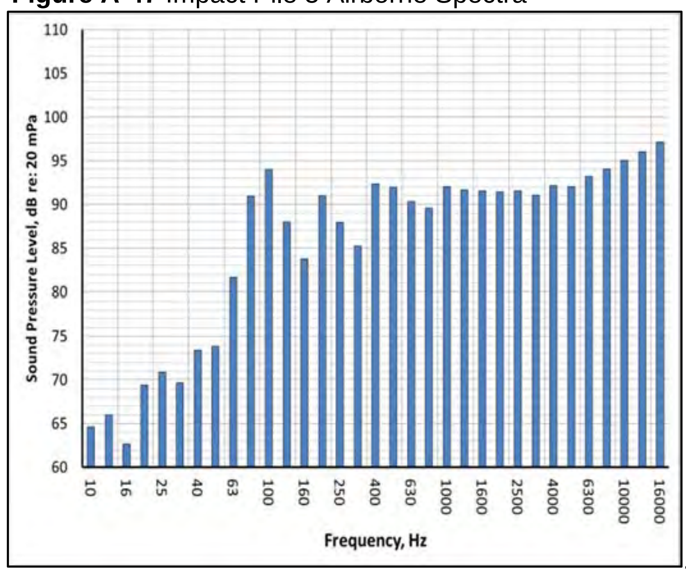


Table A-33 Impact Sheet Pile 5 – Underwater Sound Levels, dB re: 1 µPa

Pile ID	Frequency Range	Peak				RMS_{90}				SEL				cSEL
		Min	Max	SD	Avg	Min	Max	SD	Avg	Min	Max	SD	Avg	
IMP-5	7 Hz-20 kHz	187	194	2	**191**	176	182	2	**178**	162	167	1	**165**	**180**
	75 Hz-20 kHz	187	194	2	**191**	176	182	2	**178**	162	167	1	**165**	**180**
	150 Hz-20 kHz	187	194	1	**191**	176	182	2	**178**	162	167	1	**165**	**180**
	200 Hz-20 kHz	187	194	2	**191**	182	176	2	**178**	162	167	1	**165**	**180**

Figure A-48 Impact Sheet Pile 5- Peak Sound Pressure, Pa

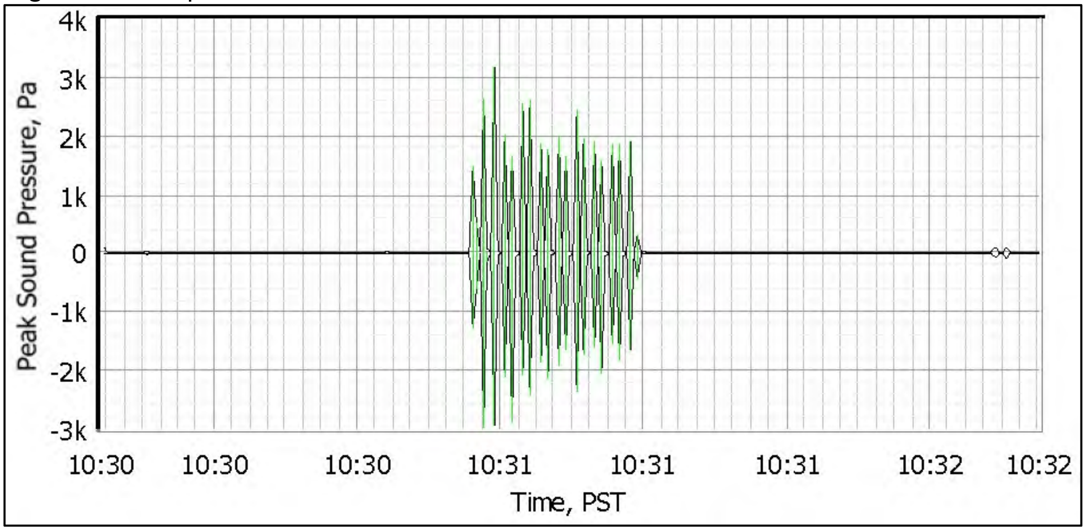


Figure A-49 Impact Sheet Pile 5 – Underwater Frequency Spectra, dB re: 1 μPa

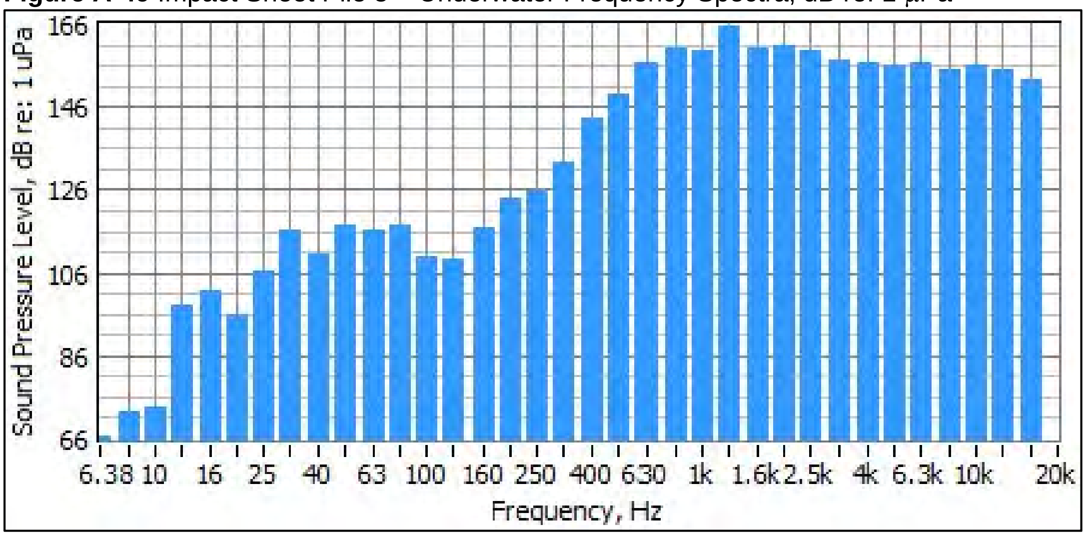
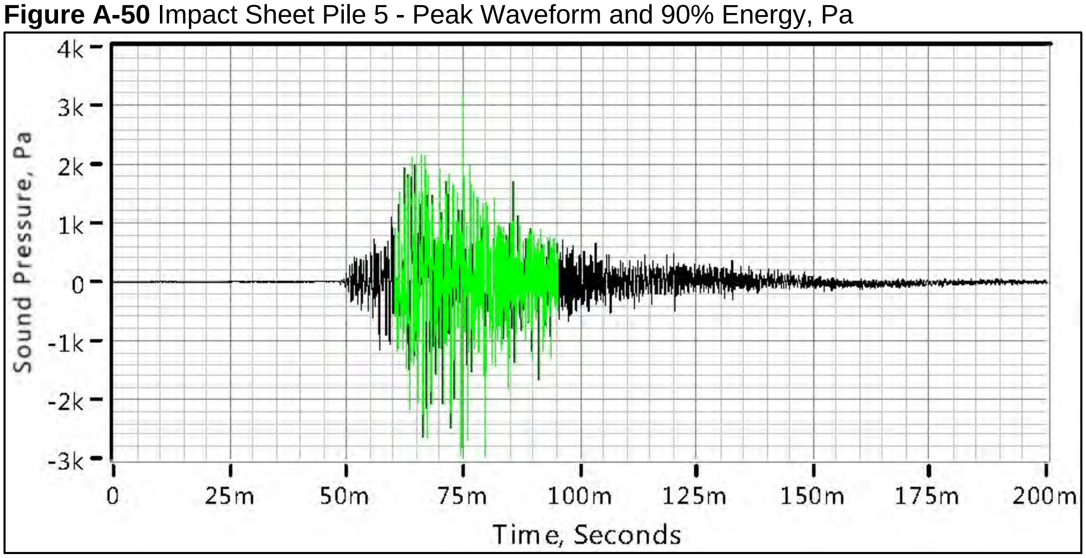


Figure A-50 Impact Sheet Pile 5 - Peak Waveform and 90% Energy, Pa



3.0 PILE DRIVER INFORMATION

Figure A-51 APE Model 250 Variable Moment Vibratory Driver/Extractor Information

APE Model 250 Variable Moment Vibratory Driver Extractor

The Worlds Largest Provider of Foundation Construction Equipment

SPECIFICATIONS	DATA
Eccentric Moment	4,500 in-lbs (51.85 kgm)
Drive Force	269 tons (2,389 kN)
Frequency Maximum (VPM)	0 - 2,050 vpm
Max Line Pull	99 tons (881 kN)
Bare Hammer Weight w/o Clamp	15,400 lbs (6,985 kg)
Throat Width	14.00 in (36 cm)
Length	69.00 in (175 cm)
Height w/o Clamp	102.00 in (259 cm)

APE Model 765 Power Unit

SPECIFICATIONS	DATA
Engine Type	Caterpillar C18 Tier II
Horse Power	765 HP (563 kW)
Drive Pressure	0 - 4,500 psi (310 bar)
Drive Flow	220 gpm (833 lpm)
Clamp Pressure	4,800 psi (69,618 bar)
Clamp Flow	10 gpm (3 lpm)
Engine Speed	2,100 rpm
Weight	20,000 lbs (9,072 kg)
Length	152 in (385 cm)
Width	82 in (208 cm)
Height	94 in (239 cm)
Hydraulic Reservoir	450 gal (1,703 L)
Fuel Capacity	150 gal (568 L)

Specifications may vary due to site conditions, specific hammer conditions or product setup.
Specifications may change without notice.
Consult the factory for details on any specific product (800) 248-8498.

WWW.APEVIBRO.COM
(800) 248-8498
webmaster@apevibro.com

Figure A-52 APE Model D50-52 Single Acting Diesel Impact Hammer Information

APE Model D50-52 Single Acting Diesel Impact Hammer

D50-52 in a stand-off

MODEL D50-52 (5.0 metric ton ram)

SPECIFICATIONS

Stroke at maximum rated energy	135 in (343 cm)
Maximum rated energy (Setting 4)	124,031 ft-lbs (167.44 kNm)
Setting 3	102,946 ft-lbs (138.98 kNm)
Setting 2	81,861 ft-lbs (110.51 kNm)
Minimum rated energy (Setting 1)	60,775 ft-lbs (82.05 kNm)

(Variable throttle allows for infinite fuel settings)

Maximum obtainable stroke	150 in (381 cm)
Maximum obtainable energy	144,243 ft-lbs (196 kNm)
Speed (blows per minute)	34-53

WEIGHTS (Approximate)

Ram	11,025 lbs (5,000 kg)
Anvil	2,255 lbs (1,023 kg)
Anvil cross sectional area	367.94 in² (2373.80 cm²)
Hammer weight (includes trip device)	25,882 lbs (11,737 kg)
Typical operating (weight with DB32 and pipe insert)	31,184 lbs (14,142 kg)

CAPACITIES

Fuel tank (runs on diesel or bio-diesel)	23.1 gal (87.4 liters)
Oil tank	4.4 gal (16.65 liters)

CONSUMPTION

Diesel or Bio-diesel fuel	4.16 gal/hr (16 liters/hr)
Lubrication	0.39 gal/hr (1.47 liters/hr)
Grease	8 to 10 pumps every 20 minutes of operation time.

Optional Variable Throttle Control.

STRIKER PLATE

Weight	1,036 lbs (470 kg)
Diameter	25 in (63.5 cm)
Area	491 in² (3167.74 cm²)
Thickness	8 in (20.32 cm)

CUSHION MATERIAL

Type/Qty	Micarta / 2 each
Diameter	25 in (63.5 cm)
Thickness	1 in (25.4 mm)

Type/Qty	Aluminum / 3 each
Thickness	1/2 in (12.7 mm)
Diameter	25 in (63.5 cm)
Total Combined Thickness	3.5 in (8.89 cm) 491 in² (3167.74 cm²)
Area	
Elastic-modulus	285 ksi (1,965 mpa)
Coeff. of restitution	0.8

Drive Base Assembly.

DRIVE CAP

DB 32:	2,436 lbs (1,104 kg)

INSERT WEIGHT

H-Beam insert for 12" (305 mm) and 14" (355 mm):	948 lbs (430 kg)
Large pipe insert for sizes 12" to 24" diameter:	1,830 lbs (830 kg)

MINIMUM BOX LEAD SIZE/OPERATING LENGTH

Minimum box leader size	8 in x 32 in (20.32 cm x 81.28 cm)
Operating length as described above	354 in (900 cm)

Corporate Offices
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