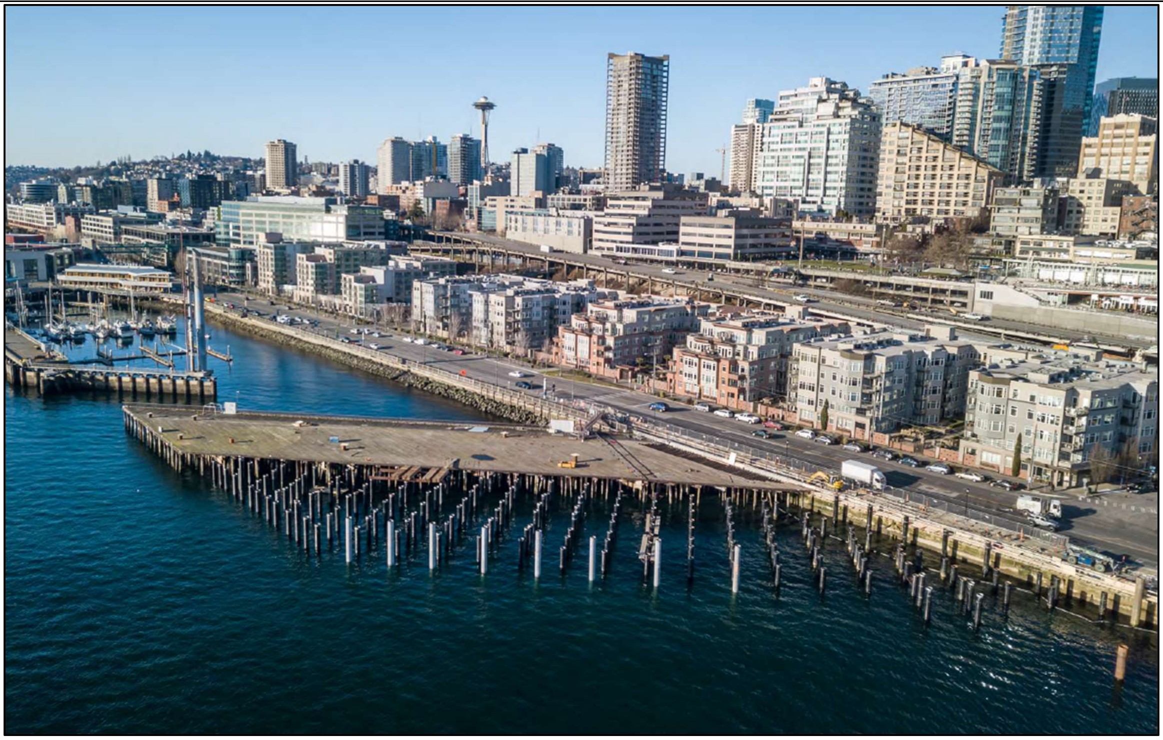

PIER 62 PROJECT
ACOUSTIC MONITORING SEASON 2 (2018/2019) REPORT
(NWS-2016-296-WRD, WCR-2018-9367, WCR-2018.10166, 01EWF00-2016-F-1325)

July 19, 2019

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1.0 EXECUTIVE SUMMARY

This Technical Report presents the results of airborne and underwater sound level measurements conducted during the installation of steel piles driven with three sizes of vibratory pile drivers and a diesel impact hammer during Season 2 (2018/2019 in-water work window) of the Pier 62/63 Replacement Project (“Project”).

Average unweighted underwater 10-second root mean square (RMS) sound levels produced during the installation of 30-inch steel pipe piles with an APE 200 Vibratory Driver/Extractor ranged between 138 and 151 decibels (dB) re: 1 re: 1 micropascal (μPa) and peak values ranged between 153 and 168 dB re: 1 μPa. Average RMS sound levels generated by the APE 400 “King Kong” Vibratory Driver/Extractor ranged between 159 and 162 dB re: 1 μPa and peak values ranged between 180 and 182 dB re: 1 μPa. The APE 600 “Super Kong” Vibratory Driver/Extractor produced RMS sound levels between 147 and 163 dB re: 1 μPa and peak levels between 155 and 168 dB re: 1 μPa.

Median 1-second unweighted RMS airborne sound levels ranged between 92 and 94 dB re: 20 μPa from the APE 200, 92 and 100 dB re: 20 μPa from the APE 600 “Super Kong” and were 95 dB re: 20 μPa from the APE 400 “King Kong” at a distance of 50 feet (15 meters).

A Delmag D100 diesel impact hammer was used to complete pile installation after they reached refusal with the vibratory hammers. Underwater unweighted RMS_{90} sound levels generate by the impact hammer ranged between 158 and 180 dB re: 1 μPa and peak sound pressure levels ranged between 169 and 193 dB re: 1 μPa.

Median 1-second unweighted RMS airborne sound levels from the impact hammer ranged between 102 and 104 dB re: 20 μPa.

Median underwater sound levels measured during vibratory and impact pile driving are shown in Table 1.1. The sound levels discussed in the body of this Report are from measurements made between 33 feet (10 meters) and 65 feet (20 meters) from the piles. Additional piles were measured at distances greater than 65 feet (20 meters) and are included in the Appendix of this Report.

Table 1.1 Median Underwater Sound Levels, dB re: 1 μPa

Hearing Group	Vibratory			Impact		
	Peak	RMS	SEL	Peak	RMS_{90}	SEL
Unweighted	163	150	160	178	167	155
Low-frequency (LF) cetaceans	162	140	150	178	162	148
Mid-frequency (MF) cetaceans	162	144	154	178	161	150
High-frequency (HF) cetaceans	162	145	155	178	161	150
Phocid pinnipeds (PW) (underwater)	162	140	150	178	158	145
Otariid pinnipeds (OW) (underwater)	162	140	150	178	160	145

Based on the highest average weighted RMS (158 dB re: 1 μPa for High Frequency Cetaceans) and highest daily weighted cSEL sound levels (190 dB re: 1 μPa for High Frequency Cetaceans on September 25, 2018) measured during vibratory pile installation and marine mammal threshold criteria, the distance required for underwater sound levels to reach the marine mammal injury threshold (Level A) is up to 476 feet (145 meters). Up to 11,203 feet (3,415 meters) may be needed to reach the marine mammal disturbance threshold (Level B) of 120 dB re: 1 μPa. Airborne sound levels are anticipated to reach the 90 dB re: 20 μPa disturbance threshold for harbor seals 158 feet (48 meters) from vibratory pile installation and reach the 100 dB re: 20 μPa disturbance threshold for other pinnipeds at a distance of 50 feet (15 meters).

Up to 9,644 feet (2,939 meters) are estimated to be required for the highest daily cSEL (192 dB re: 1 μPa for High Frequency Cetaceans measured on September 13, 2018) sound levels measured during impact pile driving to reach the marine mammal injury threshold (Level A) for High Frequency Cetaceans. 383 feet (117 meters) may be required for RMS_{90} sound levels from impact pile driving to reach the 160 dB re: 1 μPa marine mammal disturbance threshold (Level B). Airborne sound levels are estimated to reach the 90 dB re: 20 μPa disturbance threshold for harbor seals 250 feet (76 meters) from impact pile driving and the 100 dB re: 20 μPa disturbance threshold for other pinnipeds 79 feet (24 meters) away.

Based on the highest average 10-second RMS and RMS_{90} underwater sound level measured during pile installation and the background sound level measured during Season 1 of the Project, a distance of up to 2.1 miles (3.4 kilometers) could be needed for underwater noise from vibratory pile driving to reach background sound levels and up to 73 miles (117 kilometers) could be required for underwater sound levels from impact pile driving to reach background sound levels.

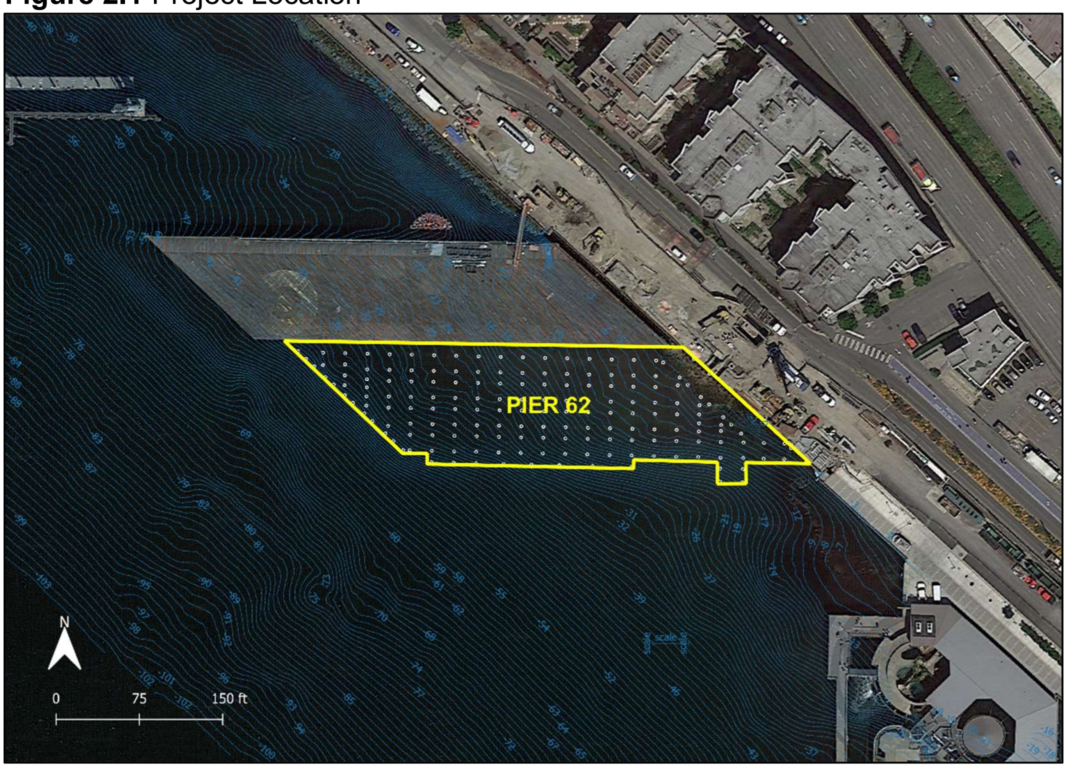
2.0 INTRODUCTION

This Technical Report presents the results of airborne and underwater sound levels measured during the installation of steel pipe piles with three sizes of vibratory pile drivers and a diesel impact hammer during Season 2 (2018/2019 in-water work window) of the Pier 62/63 Replacement 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) required airborne and underwater noise monitoring during two days of each pile driving method, or if multiple hammers will be used, each combination of driving methods. This Acoustic Monitoring Technical Report fulfills the requirements of the Project’s Biological Opinion issued by NOAA and USFWS, and the MMPA Incidental Harassment Authorization (IHA), issued by NOAA.

The Project area is located at Pier 62/63 on Alaskan Way near Pine Street in Seattle, Washington (see Figure 2.1). Measurements of airborne and underwater sound levels were conducted in September 2018 during the installation of steel pipe piles with three different vibratory hammers and a diesel impact hammer. Due to site access and safety issues not all the hydroacoustic measurements were able to establish a 33-foot (10 meter) measurement distance from the piles. Measurements that were made further than 65 feet (20 meters) away from the piles are excluded from the body of this Report but are included in the Appendix.

Figure 2.1 Project Location



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).

- **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 combining the single strike SEL values for each pile and each day.

4.0 REGULATORY CRITERIA

Anticipated underwater sound levels 33 feet (10 meters) from pile driving are listed in the Project's Biological Opinion and are provided in Table 4.1 below.

Table 4.1 Predicted Underwater Sound Levels

Pile Type	Installation/Removal	Source Sound Levels (RMS)
Installation		
30-inch Steel Pile	Vibration	180
30-inch Steel Pile	Impact	189
Removal		
14-inch Timber Pile	Vibration	161

National Marine Fisheries Service and United States Fish and Wildlife Service Biological Opinion WCR-2018-9367, WRC-2018-10166, 01EWFW00-2016-F-1325-R001 (July 31, 2018)

The Project's IHA and Biological Opinion require hydroacoustic monitoring for at least two days of each pile type and driving method shown in Table 4.1 above. At least two hydrophones and one microphone are required and must have a direct line of acoustic transmission between the hydrophones and piles whenever possible.

Reported sound levels from underwater noise monitoring must include frequency spectra for each marine mammal hearing group outlined in the NOAA 2016 Guidance as well as the range, standard deviation and average of 10-second RMS and peak sound pressure levels for each marine mammal hearing group normalized to 33 feet (10 meters) from the piles. These sound levels must be used to estimate the distances at which RMS values reach relevant marine mammal disturbance and injury thresholds as well as background sound levels.

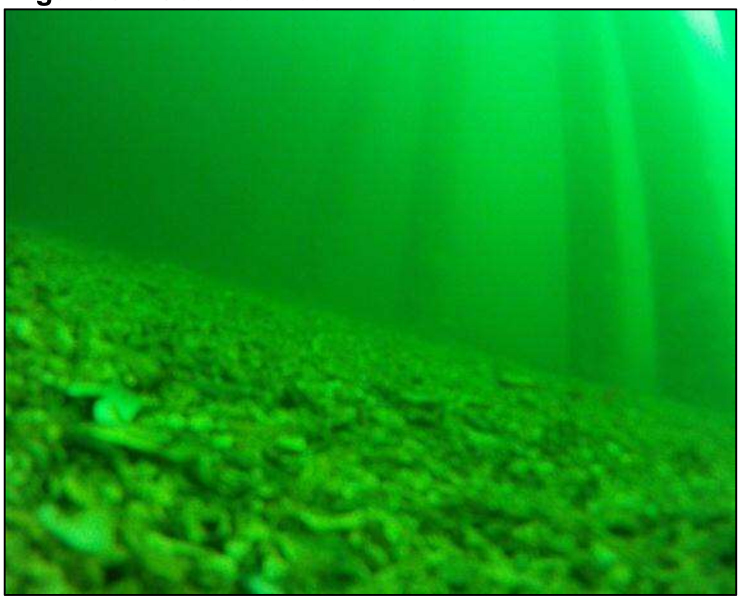
The NMFS Biological Opinion requires reporting of the range and average unweighted RMS sound levels from airborne measurements and the estimated distance for airborne sound to attenuate to species specific criteria, which are included in the Project's Request for Incidental Harassment Authorization under the Marine Mammal Protection Act for harbor seals and other pinnipeds. Airborne sound levels are to be normalized to 50 feet (15 meters) from pile driving or removal activities and the frequency spectra between 10 Hz and 20 kHz must also be reported.

Additionally, the size and type of piles, description of any noise attenuation used, description of the vibratory or impact hammers, description of sound monitoring equipment, distance between the hydrophones, depth of water at the monitoring and pile locations, depth of the hydrophones, distances from the piles to the water's edge, depth into the substrate the piles were driven into and the physical characteristics of the substrate must be reported.

5.0 PILE AND PILE DRIVING EQUIPMENT INFORMATION

During Season 2, all piles were initially driven to refusal with a vibratory pile driver and an impact hammer was used for the remainder of the pile drive. The steel pipe piles were 30-inches in diameter and had wall thicknesses of ¾ inch and 1-inch. Piles ranged in length between 70 and 135 feet (21.3 and 41.1 meters). Generally, the substrate was hard, rocky and covered with silt and marine debris. A photo of the typical seafloor is provided in Figure 5.1.

Figure 5.1 Seafloor Near Pier 62



Three different vibratory pile drivers were used to install the piles; an APE Model 200 Vibratory Driver/Extractor, APE Model 400 "King Kong" Vibratory Driver/Extractor, and an APE Model 600 "Super Kong" Vibratory Driver/Extractor.

An APE Model 200 Vibratory Driver/Extractor was used to drive piles during hydroacoustic measurements on September 7 and September 25, 2018. The APE Model 200 Vibratory Driver/Extractor operates at a maximum frequency of 1,650 VPM with a maximum driving force of 170 tons. The suspended weight without the clamp is 12,760 pounds. A cut sheet of the APE 200 Vibratory Driver/Extractor can be found in the Appendix of this Report. Table 5.1 presents a summary of piles driven with the APE 200 Vibratory Driver/Extractor during acoustic monitoring.

Table 5.1 Summary of Piles Driven with APE 200 Vibratory Hammer, Feet (Meters)

Pile ID	Date Driven	Sound Attenuation	Distance to Water's Edge	Water Depth	Drive Time (minutes)[1]
79	9/7/18	None	87(26.5)	13(4)	15
87			78(23.8)	10(3.1)	54
151	9/25/18		23(7)	2(0.6)	31

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

Piles installed on September 12, 2018 were driven with an APE Model 400 “King Kong” Vibratory Driver/Extractor. The APE Model 400 “King Kong” Vibratory Driver/Extractor operates at a maximum frequency of 1,350 VPM and has a maximum driving force of 298 tons. The weight of the hammer without the clamp is 31,570 pounds. A cut sheet of the APE Model 400 “King Kong” Vibratory Driver/Extractor can be found in the Appendix of this Report. A summary of the piles driven with the APE Model 400 “King Kong” Vibratory Driver/Extractor during acoustic monitoring is shown in Table 5.2.

Table 5.2 Summary of Piles Driven with APE 400 Vibratory Hammer, Feet (Meters)

Pile ID	Date Driven	Sound Attenuation	Distance to Water’s Edge	Water Depth	Drive Time (minutes)[1]
19	9/12/18	None	193(58.8)	32(9.8)	39

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

The APE Model 600 “Super Kong” Vibratory Driver/Extractor operates at a maximum frequency of 1,400 VPM and was used to drive piles during acoustic monitoring on September 25, 2018. The APE Model 600 “Super Kong” has a maximum driving force of 556 tons and weighs 55,000 pounds without the clamp. A cut sheet of the APE Model 600 “Super Kong” Vibratory Driver/Extractor can be found in the Appendix of this Report. Table 5.3 shows a summary of piles driven with the APE Model 600 “Super Kong” during acoustic monitoring.

Table 5.3 Summary of Piles Driven with APE Model 600 Vibratory Hammer, Feet (Meters)

Pile ID	Date Driven	Sound Attenuation	Distance to Water’s Edge	Water Depth	Drive Time (minutes)[1]
151	9/25/18	None	23(7)	2(0.6)	13
163			4(1.2)	2(0.6)	11
152			23(7)	2(0.6)	10

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

After the piles were driven to refusal with the vibratory hammers, a Delmag D100 diesel impact hammer was used for the remainder of the pile drive. Acoustic measurements of the Delmag D100 were made on September 13 and September 14, 2018. The Delmag D100 has an energy rating of 248,063 foot-pounds, a ram weight of 22,050 pounds, and a stroke length of 11.25 feet. A cut sheet of the Delmag D100 diesel impact hammer can be found in the Appendix of this Report. Table 5.4 provides a summary of the piles driven with the Delmag D100 diesel impact hammer while acoustic monitoring was being conducted.

Table 5.4 Summary of Piles Driven with Delmag D100 Impact Hammer, Feet (Meters)

Pile ID	Date Driven	Sound Attenuation	Distance to Water’s Edge	Water Depth	Number of Pile Strikes[1]
19	9/13/18	Bubble Curtain	193(58.8)	32(9.7)	661
47			144(4.8)	24(7.3)	293
63			117(35.6)	17(5.1)	188
79	9/14/18		91(27.7)	13(3.9)	241
87			78(23.7)	11(3.3)	401

1. Number of strikes included in noise analysis

An unconfined bubble curtain was used during all impact pile driving. The unconfined bubble curtain consisted of six 2.5-inch nominal diameter aluminum rings with four rows of 1/16th inch diameter bubble release holes in the axial direction. Photos of the bubble curtain are shown in Figure 5.2 and Figure 5.3. The system design calculations and drawings of the bubble curtain are provided in the Appendix.

Figure 5.2 Bubble Curtain

Figure 5.3 Bubble Curtain Operational

6.0 MEASUREMENT METHODOLOGY

6.1 Equipment

Equipment used to collect airborne and underwater sound data during pile installation are identified in Table 6.1 and Table 6.2.

Table 6.1 Airborne Sound Measurement Equipment

Make and Model	Quantity	Description	Serial Number
Brüel & Kjaer Type 2250	1	Sound Level Analyzer	3006756
PCB 426E01	1	Preamplifier	47476
Brüel & Kjaer 4189	1	Microphone	2550228
Brüel & Kjaer 4231	1	Acoustic Calibrator	2545696

Table 6.2 Hydroacoustic Monitoring Equipment

Make and Model	Quantity	Description	Serial Number
Brüel & Kjaer Type 2270	1	Sound Level Analyzer	2679351
Reson TC-4013	2	Hydrophone	2513032
			0712213
Brüel & Kjaer Type 2647-A	2	Charge Converter (1 mV/pC)	2638260
			2638259
G.R.A.S. Type 42AC	1	Pistonphone	201835
Brüel & Kjaer 1704-A-002	1	Signal Conditioner	101161
Tascam DR-100MKIII	1	Digital Audio Recorder	1690316

Measurement equipment used to collect airborne and underwater sound data were factory calibrated within 1 year of the measurement date. Calibration tones were also recorded before and after each day of monitoring for verification of calibration factors used during post-processing. The microphone was calibrated using the Brüel & Kjaer 4231 acoustic calibrator and the G.R.A.S. pistonphone was used to calibrate the hydrophones.

Airborne sound levels were monitored using the Brüel & Kjaer 2250 which recorded a WAV file at a sample rate of 48,000 samples per second for subsequent signal analysis. Underwater sound levels were measured using two Reason TC-4013 hydrophones connected to Brüel & Kjaer Type 2647-A charge converters and Brüel & Kjaer 1704-A-002 signal conditioner. The signal conditioner was connected to the Tascam DR-100MKIII digital audio recorder, which recorded the signal as a WAV file at a sample rate of 48,000 samples per second to allow for post processing of the audio signals. The Brüel & Kjaer Type 2270 was used to allow for real-time approximations of peak and cSEL sound levels while the measurements were being performed. The Brüel & Kjaer Type 2270 was only used to measure real-time sound levels from the lower hydrophone. The lower hydrophone was selected based on previous measurements made during the Elliott Bay Seawall Project and Season 1 of the Pier 62 Project, which showed sound levels from the deeper hydrophone were typically louder than those from hydrophones located at shallower depths. Photos of the airborne and hydroacoustic measurement equipment are shown in Figure 6.1 and Figure 6.2.

Figure 6.1 Airborne Monitoring Equipment

Figure 6.2 Hydroacoustic Equipment

6.2 Measurement Locations

Airborne sound data were collected 50 feet (15 meters) from the piles whenever possible but ranged between 50 and 100 feet (15.2 and 30.5 meters). The distances between the piles and the microphone was determined using a laser distance measurement device. During all measurements, the microphone was positioned 5 to 7 feet (1.5 to 2 meters) above the Pier with a direct line of site between the microphone and piles.

The hydrophones were lowered from the deck of Pier 62 to the appropriate measurement depths and secured to the pier. Between pile drives the hydrophones were relocated to maintain an unobstructed acoustical transmission path distance of approximately 33 feet (10 meters) to the piles. However, due to site access limitations resulting from safety concerns, an unobstructed acoustical transmission distance of 33 feet (10 meter) between the hydrophones and piles was not able to be established for all the measurements. Care was taken in selecting the monitoring locations to maximize the number of unobstructed piles and the number of piles located approximately 33 feet (10 meters) from the hydrophones.

The distance between the monitoring locations and the piles were verified using a laser distance measurement device. Water depth at all hydroacoustic measurement locations were measured prior to deploying the hydrophones. In addition to water depth measurements made prior to the deployment of the hydrophones, tidal information obtained from NOAA Station #9447130 was used to track tidal changes during pile drives. The depth of the upper hydrophone was checked frequently to ensure it maintained the proper depth during tidal changes and the lower hydrophone was fixed 3.3 feet (1 meter) above the sea floor by securing the cable to Pier 62.

Table 6.3 through Table 6.7 present the depth of the hydrophones, water depth at the measurement location, distance between the hydrophones, and distance between the hydrophones and the pile. Figures showing the airborne and hydroacoustic measurement locations are presented in Sections 7.1 and 7.2 of this Report.

Table 6.3 Hydrophone Locations for Vibratory Monitoring on September 7, 2018, Feet (Meters)

Pile ID	Hydrophone	Depth at Measurement Location[1]	Hydrophone Depth	Distance Between Hydrophones	Distance to Pile
79 (APE 200)	Upper	14(4.3)	3(0.9)	8(2.4)	31(9.4)
	Lower		11(3.4)		
87 (APE 200)	Upper	14(4.3)	3(0.9)	8(2.4)	40(12.2)
	Lower		11(3.4)		

1. Depth at start of pile drive

Table 6.4 Hydrophone Locations for Vibratory Monitoring on September 12, 2018, Feet (Meters)

Pile ID	Hydrophone	Depth at Measurement Location[1]	Hydrophone Depth	Distance Between Hydrophones	Distance to Pile
19 (APE 400)	Upper	41(12.5)	3(0.9)	35(10.7)	33(10)
	Lower		38(11.6)		

1. Depth at start of pile drive

Table 6.5 Hydrophone Locations for Vibratory Monitoring on September 25, 2018, Feet (Meters)

Pile ID	Hydrophone	Depth at Measurement Location[1]	Hydrophone Depth	Distance Between Hydrophones	Distance to Pile
151 (APE 200)	Upper	12(3.7)	3(0.9)	7(2.1)	49(14.9)
	Lower		10(3.1)		
151 (APE 600)	Upper	15(4.6)	3(0.9)	9(2.7)	49(14.9)
	Lower		12(3.7)		
152 (APE 600)	Upper	15(4.6)	3(0.9)	9(2.7)	67(20.4)
	Lower		12(3.7)		

1. Depth at start of pile drive

Table 6.6 Hydrophone Locations for Impact Monitoring on September 13, 2018, Feet (Meters)

Pile ID	Hydrophone	Depth at Measurement Location[1]	Hydrophone Depth	Distance Between Hydrophones	Distance to Pile
19	Upper	46(14)	3(0.9)	40(12.2)	33(10)
	Lower		43(13.1)		
47	Upper	32(9.8)	3(0.9)	25(7.6)	33(10)
	Lower		28(8.5)		
63	Upper	28(8.5)	3(0.9)	22(6.7)	33(10)
	Lower		25(7.6)		

1. Depth at start of pile drive

Table 6.7 Hydrophone Locations for Impact Monitoring on September 14, 2018, Feet (Meters)

Pile ID	Hydrophone	Depth at Measurement Location[1]	Hydrophone Depth	Distance Between Hydrophones	Distance to Pile
79	Upper	23(7)	3(0.9)	17(5.2)	33(10)
	Lower		20(6.1)		
87	Upper	20(6.1)	3(0.9)	14(4.3)	33(10)
	Lower		17(5.2)		

1. Depth at start of pile drive

7.0 PILE INSTALLATION ANALYSIS AND RESULTS

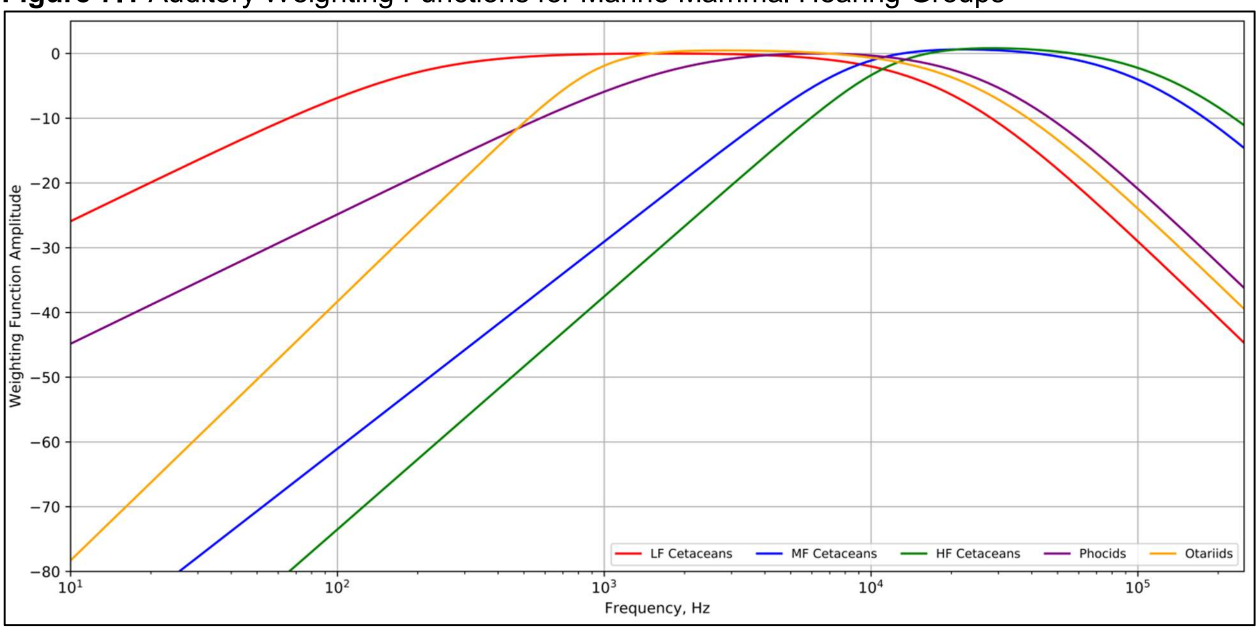
During post-processing the hydroacoustic data were frequency-weighted for each of the marine mammal hearing groups defined in the NOAA technical guidance document titled "Technical Guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammal Hearing" dated July 2016. This Technical Guidance divides marine mammals into five hearing groups, as summarized in Table 7.1.

Table 7.1 Marine Mammal Hearing Groups

Hearing Group	Generalized Hearing Range
Low-frequency (LF) cetaceans (baleen whales)	7 Hz – 35 kHz
Mid-frequency (MF) cetaceans (dolphins, toothed whales, beaked whaled, bottlenose whales)	150 Hz – 160 kHz
High-frequency (HF) cetaceans (true porpoise, *Kogia*, river dolphins, cephalorhynchid, *Lagenorhynchus cruciger & L. australis*)	275 Hz – 160 kHz
Phocid pinnipeds (PW) (underwater) (true seals)	50 Hz – 86 kHz
Otariid pinnipeds (OW) (underwater) (sea lions and fur seals)	60 Hz -39 kHz

The auditory weighting functions for each of the marine mammal hearing groups are illustrated in Figure 7.1.

Figure 7.1 Auditory Weighting Functions for Marine Mammal Hearing Groups



A bandpass filter was applied to the airborne data to remove frequencies below 10 Hz and above 20 kHz. No additional weighting functions were applied to airborne data during post-processing.

Reported underwater sound levels have been normalized to 33 feet (10 meters) and airborne levels have been normalized to 50 feet (15 meters).

7.1 Vibratory Pile Installation

Airborne and underwater sound levels were measured on September 7, September 12, and September 25, 2018 during vibratory pile driving. Although only two days of monitoring were required by the project permits, additional monitoring was conducted to document sound levels from the different sizes of vibratory hammers that were used during the project.

An unobstructed path between the piles and microphone used to measure airborne sound levels was maintained throughout the duration of each pile drive. 1-second RMS sound levels were used to analyze the airborne data.

Hydroacoustic data were analyzed to determine the range, mean, median, and standard deviation of 10-second peak and RMS values were calculated for each pile during periods when the vibratory hammer was operational. RMS values were calculated from unweighted data and each marine mammal hearing group. Peak sound levels are unweighted.

Sound levels are reported from either the hydrophone closest to the pile, or the lower hydrophone. Sound levels from both hydrophones are provided in the Appendix. Standard deviation values were calculated using decibel values. Average sound levels were determined by calculating the decibel level (re: 1 µPa) of the average sound pressure (Pascals).

The measurement locations and the locations of the piles driven with the vibratory hammer are shown in Figure 7.2 through Figure 7.4. These figures include the locations of the measurements made over 65 feet (20 meters) from the piles. Additional information about these piles is provided in the Appendix of this Report.

Figure 7.2 Pile and Monitoring Locations for APE200 Vibratory Pile Driving

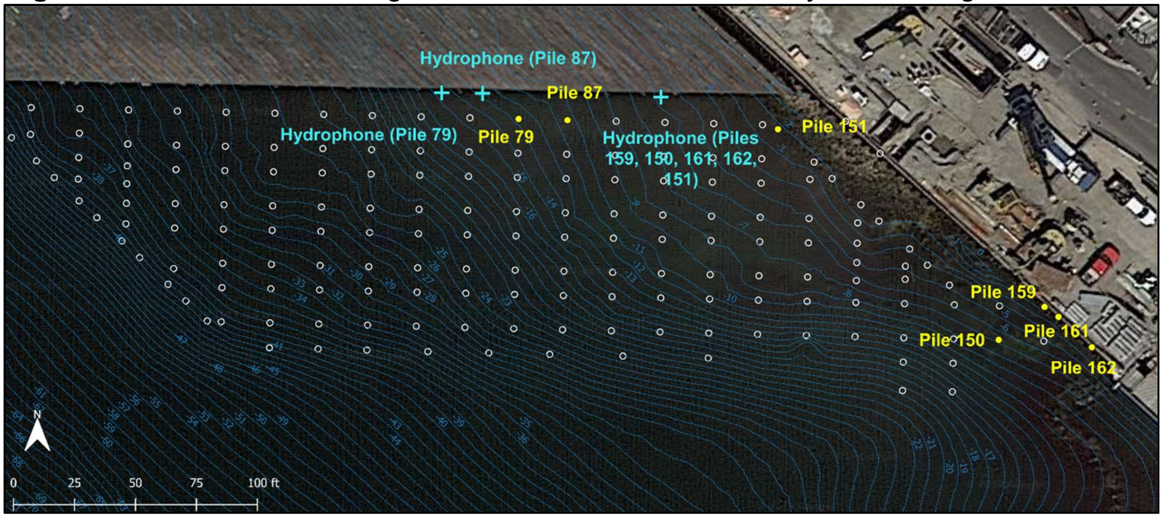


Figure 7.3 Pile and Monitoring Locations for APE400 King Kong Vibratory Pile Driving

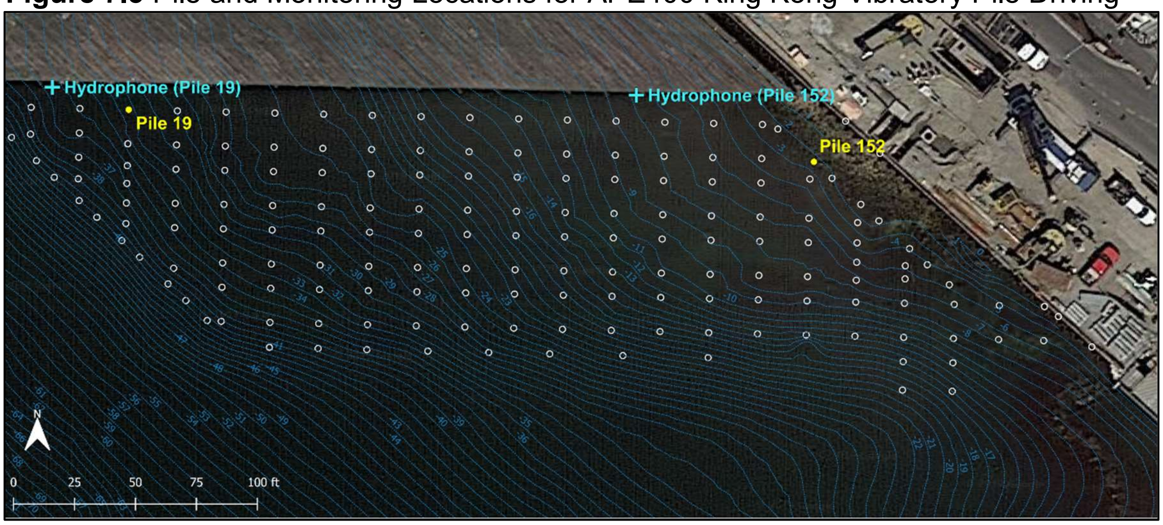
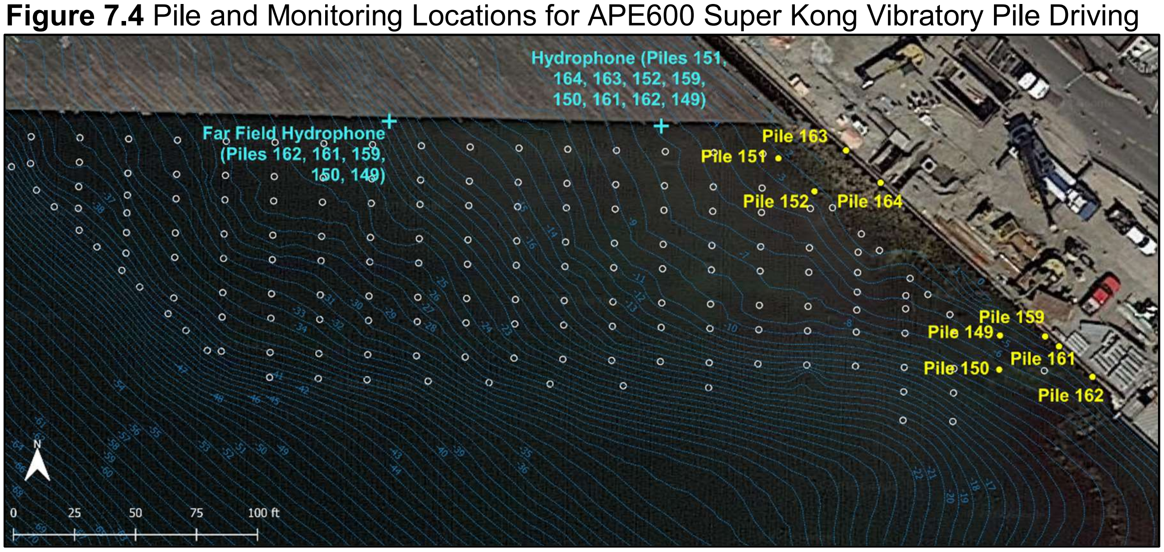


Figure 7.4 Pile and Monitoring Locations for APE600 Super Kong Vibratory Pile Driving



The ranges of mean underwater sound levels for each marine mammal hearing group measured during vibratory pile driving are shown in Table 7.2. Underwater sound levels from individual piles, underwater sound levels measured over the duration of each pile drive, the waveform that produced the highest peak sound pressure level, and the average unweighted frequency spectrum and average frequency spectrum for each marine mammal hearing group are provided in the Appendix.

Table 7.2 Average Underwater Sound Levels from Vibratory Pile Driving, dB re: 1 μPa

Metric	Hydrophone	Unweighted	Cetaceans			Pinnipeds	
			LF	MF	HF	Phocids	Otariids
APE 200							
Peak	Upper	157-168	157-168	157-168	157-168	157-168	157-168
	Lower	153-166	153-166	153-166	153-166	153-166	153-166
RMS	Upper	144-151	137-145	138-145	139-145	134-142	134-143
	Lower	138-149	132-144	134-143	134-144	129-141	130-141
SEL	Upper	154-161	147-155	148-155	149-155	144-152	144-153
	Lower	148-159	142-154	144-153	144-154	139-151	140-151
APE 400 King Kong							
Peak	Upper	180	180	180	180	180	180
	Lower	182	182	182	182	182	182
RMS	Upper	162	153	156	157	152	153
	Lower	159	153	154	157	152	153
SEL	Upper	172	163	166	167	162	163
	Lower	169	163	164	164	162	163
APE 600 Super Kong							
Peak	Upper	162-168	162-168	162-168	162-168	162-168	162-168
	Lower	155-160	155-160	155-160	155-160	155-160	155-160
RMS	Upper	156-163	137-143	150-157	151-158	141-147	138-145
	Lower	147-154	129-135	141-148	142-148	132-138	129-136
SEL	Upper	166-173	147-153	160-167	161-168	151-157	148-155
	Lower	157-164	139-145	151-158	152-158	142-148	139-146

Note: Reported sound levels are normalized to 33 feet (10 meters) from piles using the practical spreading model.

The range of median airborne sound levels measured during vibratory pile installation are summarized in Table 7.3. The average frequency spectrum and measured sound levels from each pile is provided in the Appendix.

Table 7.3 Median Airborne Sound Levels from Vibratory Pile Driving, dB re: 20 μPa

Metric	Vibratory Hammer		
	APE 200	APE 400 King Kong	APE 600 Super Kong
RMS	92-94	95	92-100

Note: Reported sound levels are normalized to 50 feet (15 meters) from piles.

7.2 Impact Pile Installation

Airborne and underwater sound data were collected on September 13 and September 14, 2018 during impact pile driving of five steel pipe piles as required by the Project's ESA and MMPA consultation.

An unobstructed path between the piles and microphone used to measure airborne sound levels was maintained throughout the duration of each pile drive. 1-second RMS sound levels were used to analyze the airborne data.

Hydroacoustic data were analyzed to determine the range, mean, median, and standard deviation of peak, $RMS_{90,}$ SEL, and cSEL values of each pile for each marine mammal hearing group as required by the ESA and MMPA consultations. RMS_{90} and SEL values were calculated from unweighted data and for each marine mammal hearing group. Peak sound levels are unweighted.

Sound levels reported in this section were measured by the lower hydrophone. Measured sound levels from both hydrophones are reported in the Appendix. Standard deviation values were calculated using decibel values. Average sound levels were determined by calculating the decibel level (re: 1 μPa) of the average sound pressure (Pascals).

The RMS_{90} was established between the 5^{th} percentile and 95^{th} percentile for each recoded pile strike. Figures illustrating the waveforms produced by the pile strikes 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. The duration of the pile strikes containing 90% of the acoustical energy are also reported.

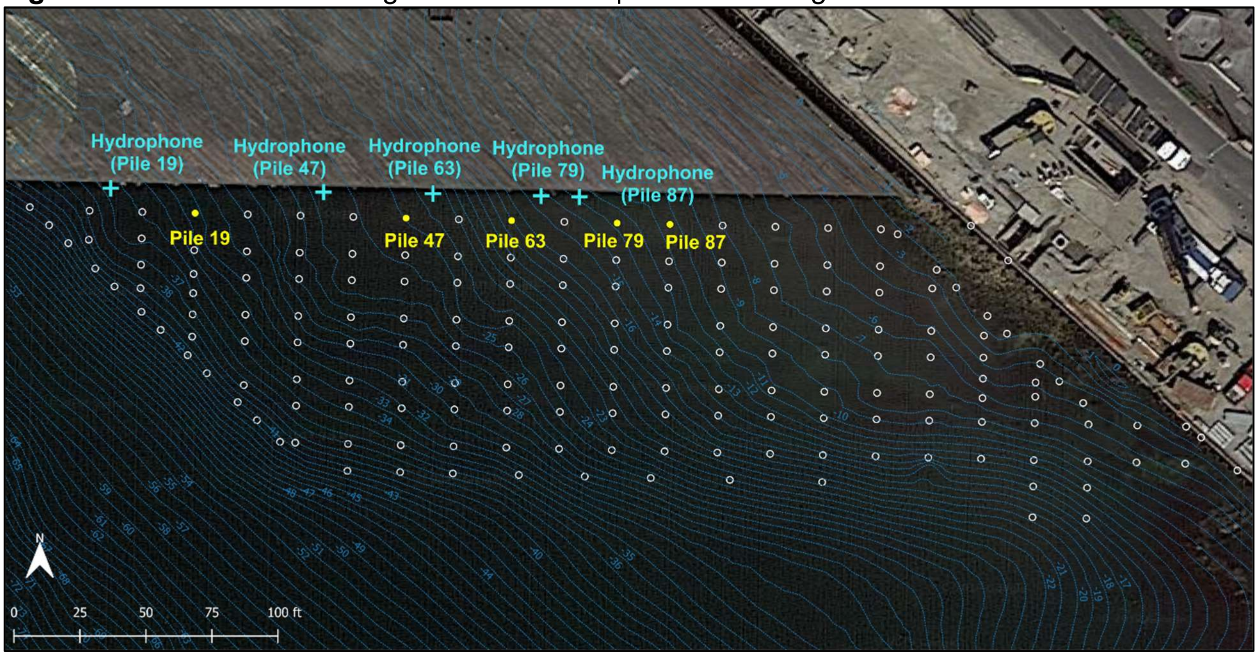
SEL values were calculated for each pile strike over the duration of the strike containing 90% of the acoustic energy using the following formula:

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

Where τ is the time interval containing 90% of the acoustic energy in each pile strike. cSEL values were calculated by combining the single strike SEL values for each pile. The resulting cSEL values from each pile driven on a particular day were then combined (logarithmically) to produce daily cSEL values.

The airborne and hydroacoustic measurement locations and the locations of the piles driven with the impact hammer are shown in Figure 7.5.

Figure 7.5 Pile and Monitoring Locations for Impact Pile Driving



The ranges of average underwater sound levels for each marine mammal hearing group measured during impact pile driving on September 13 and September 14, 2018 are provided in Table 7.4. The underwater sound levels measured over the duration of each pile drive, waveform and spectrogram of the pile strike which produced the highest peak sound pressure level, average unweighted underwater frequency spectrum, and average frequency spectrum for each hearing group from all pile strikes are provided in the Appendix.

Table 7.4 Average Underwater Sound Levels from Impact Pile Driving, dB re: 1 μPa

Metric	Hydrophone	Unweighted	Cetaceans			Pinnipeds	
			LF	MF	HF	Phocids	Otariids
Peak	Upper	176-193	176-193	176-193	176-193	176-193	176-193
	Lower	169-185	169-185	169-185	169-185	169-185	169-185
RMS	Upper	164-180	157-176	158-175	159-175	155-174	157-176
	Lower	158-174	152-169	151-168	152-174	149-167	150-168
SEL	Upper	155-169	145-161	150-163	150-163	145-160	145-161
	Lower	148-160	139-154	142-154	142-160	138-152	138-153

Note: Reported sound levels are normalized to 33 feet (10 meters) from piles using the practical spreading model.

Airborne sound levels measured during impact pile driving are summarized in Table 7.5. The average frequency spectrum from each pile is provided in the Appendix.

Table 7.5 Airborne Sound Levels from Impact Pile Driving, dB re: 20 μPa

Metric	Diesel Impact Hammer
RMS	102-104

Note: Reported sound levels are normalized to 50 feet (15 meters) from piles.

8.0 DISTANCES TO INJURY AND DISTURBANCE THRESHOLDS

The results of the acoustic monitoring and analysis were used in conjunction with background sound levels measured during Season 1 of the project to estimate the distances required for underwater sound levels to reach the marine mammal injury (Level A) and disturbance (Level B) thresholds and background sound levels.

In July 2016, NOAA issued updated technical guidance for determining the effects of underwater sound on marine mammals titled "Technical Guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammal Hearing". The Technical Guidance utilizes dual threshold criteria for injury from impulsive sounds. These criteria are peak sound pressure and cSEL values accumulated over a 24-hour period. The peak sound pressure criteria are unweighted and the cSEL values are frequency-weighted for each marine mammal hearing group. Injury criteria from non-impulsive sound (i.e. vibratory pile driving) include only the 24-hour cSEL criteria. Injury thresholds provided in the updated Technical Guidance are summarized in Table 8.1.

Table 8.1 Injury Thresholds, dB re: 1 μPa

Hearing Group	Impulsive		Non-Impulsive
	Peak (unweighted)	cSEL (weighted)	cSEL (weighted)
Low-frequency (LF) cetaceans	219	183	199
Mid-frequency (MF) cetaceans	230	185	198
High-frequency (HF) cetaceans	202	155	173
Phocid pinnipeds (PW) (underwater)	218	185	201
Otariid pinnipeds (OW) (underwater)	232	203	219

Source: Technical Guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammal Hearing, July 2016

Marine mammal disturbance thresholds (Level B) from underwater sound are based on RMS sound levels from previous guidance and are shown in Table 8.2.

Table 8.2 Disturbance Thresholds (RMS), dB re: 1 μPa

Marine Mammal	Pile Driving Disturbance Threshold	
	Vibratory	Impact
Cetaceans	120	160
Pinnipeds		

Source: National Marine Fisheries Service

Disturbance thresholds from airborne noise are the same for impact and vibratory pile driving and are based on RMS sound levels. The disturbance thresholds from airborne noise are provided in Table 8.3.

Table 8.3 Airborne Disturbance Threshold, RMS

Marine Mammal	Disturbance Threshold (Level B)
Harbor Seal	90
Other Pinnipeds	100

Distances required for underwater sound resulting from pile driving to reach the marine mammal thresholds and background sound levels were calculated using the "practical spreading model" currently used by NOAA. 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) reported in the "Technical Guidance for Assessment and Mitigation of the Hydroacoustic Effects of Pile Driving on Fish" dated November 2015, 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.

The formula provided above was also used to calculate the distances for airborne noise to reach the disturbance levels for harbor seals and other pinnipeds. In the case of airborne noise β is equal to 20, which is consistent information provided in the WSDOT document "Biological Assessment Preparation for Transportation Projects-Advanced Training Manual-Version 2015" for sound propagation from a point source over hard soil.

The estimated distances for underwater noise to reach the marine mammal thresholds and background sound levels are estimated using the highest average RMS and RMS_{90} sound levels from each marine mammal hearing group, highest weighted 24-hour cSEL for each marine mammal hearing group, and highest average unweighted peak sound levels measured during pile installation and by solving the practical spreading formula for D_2 resulting in the following:

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

The highest median sound levels were used to calculate the distances for airborne sound to reach disturbance thresholds for harbor seals and other pinnipeds.

8.1 Marine Mammal Disturbance and Injury Distances

The practical spreading model, the highest 24-hour cSEL values, and the loudest average peak, RMS and RMS_{90} sound levels recorded during pile driving were used to calculate the distances necessary for underwater sound to reach Level A and Level B thresholds. The resulting distances for vibratory pile driving are shown in Table 8.4 and impact pile driving distances are shown in Table 8.5.

Table 8.4 Distances to Marine Mammal Thresholds from Vibratory Pile Driving, Feet (Meters)

Hearing Group	Measured Sound Level		Marine Mammal Threshold		Distance to Threshold	
	cSEL	RMS	Level A	Level B	Level A	Level B
LF Cetaceans	187	153	199 cSEL	120 RMS	5.6 (1.7)	5,200 (1,585)
MF Cetaceans	190	157	198 cSEL		9.4 (2.9)	9,609 (2,929)
HF Cetaceans	190	158	173 cSEL		476 (145)	11,203 (3,415)
Pinnipeds (Phocids)	186	152	201 cSEL		3.4 (1.0)	4,460 (1,359)
Pinnipeds (Otariids)	187	153	219 cSEL		0.2 (0.07)	5,200 (1,585)

Table 8.5 Distances to Marine Mammal Thresholds from Impact Pile Driving, Feet (Meters)

Hearing Group	Measured Sound Level			Marine Mammal Threshold			Distance to Threshold		
				Level A		Level B	Level A		Level B
	Peak	cSEL	RMS_{90}	Peak	cSEL	RMS_{90}	Peak	cSEL	RMS_{90}
LF Cetaceans	193	191	176	219	183	160	0.6 (0.2)	105 (32)	383 (117)
MF Cetaceans	193	192	175	230	185		0.1 (0.03)	90 (28)	328 (100)
HF Cetaceans	193	192	175	202	155		8.2 (2.5)	9,644 (2,939)	328 (100)
Pinnipeds (Phocids)	193	189	174	218	185		0.7 (0.2)	59 (18)	281 (86)
Pinnipeds (Otariids)	193	190	176	232	203		0.1 (0.03)	4 (1)	383 (117)

Distances to Level A thresholds from vibratory pile driving are less than those anticipated in the project permits. However, the distances to Level A thresholds from impact pile driving for mid frequency cetaceans and high frequency cetaceans are farther than anticipated. The Level A threshold for mid frequency cetaceans was anticipated to be reached 33 feet (10 meters) from pile driving but results of hydroacoustic monitoring suggest the distance could be up to 90 feet (28 meters). The distance for high frequency cetaceans was anticipated to be 348 feet (106 meters), however measured sound levels estimate the distance to be 9,644 feet (2,939 meters).

As shown in Table 8.4, the distances to the Level B threshold from vibratory pile driving are less than the anticipated distance of 33.6 miles (54,117 meters). The distances from impact pile driving shown in Table 8.5 to reach the Level B threshold are also less than the anticipated 3,940 feet (1,201 meters).

Areas where underwater sound levels re expected to exceed the Level A and Level B thresholds are shown in Figure 8.1 through Figure 8.4.

Figure 8.1 Level A Thresholds from Vibratory Pile Driving

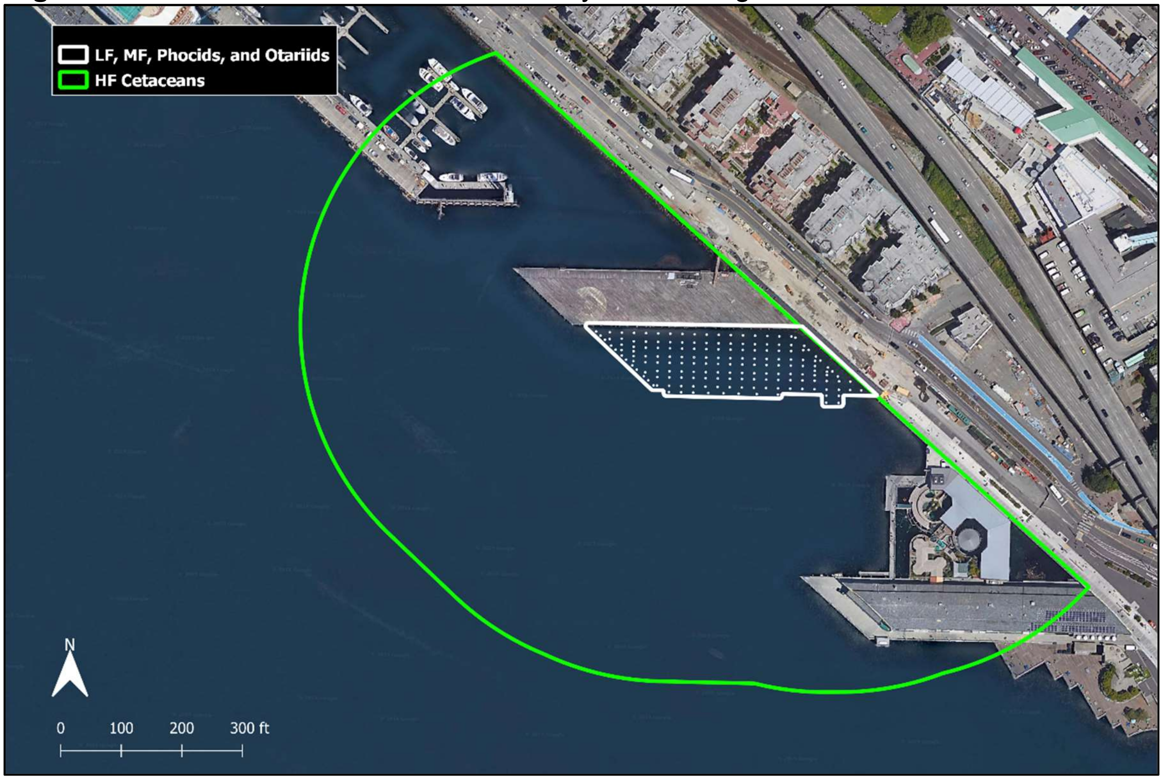


Figure 8.2 Level B Thresholds from Vibratory Pile Driving

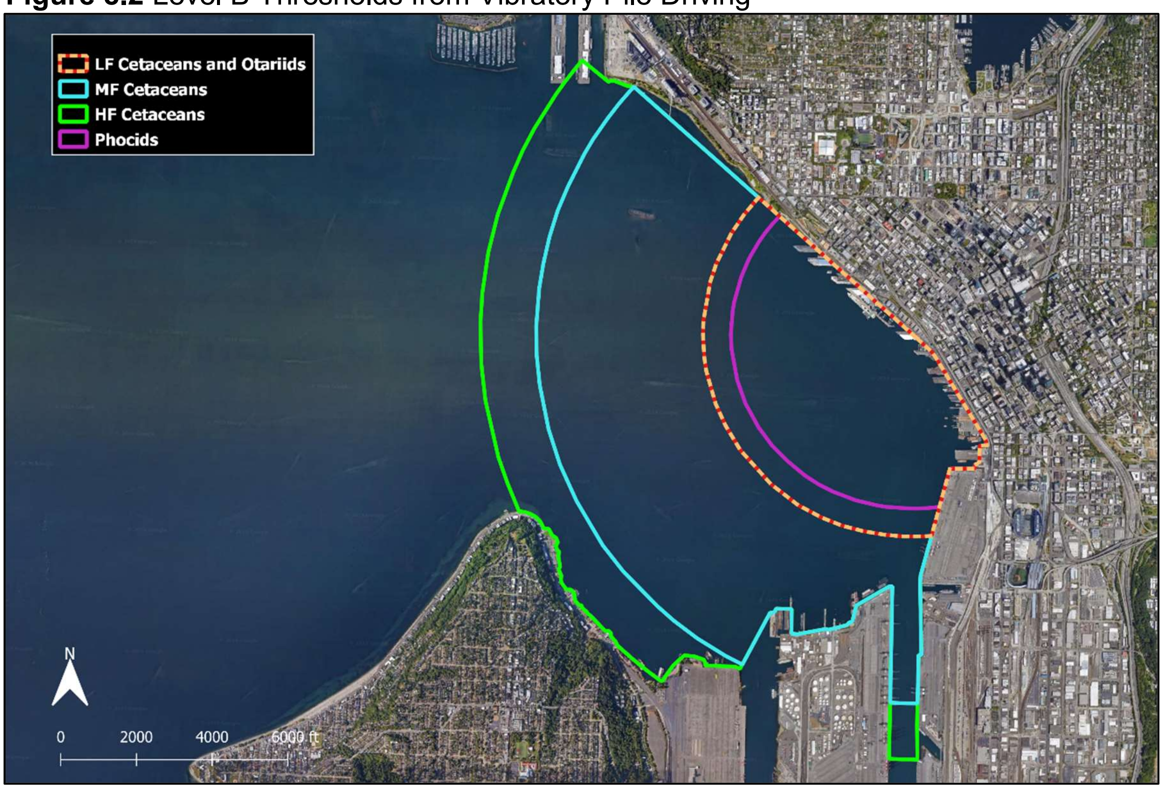


Figure 8.3 Level A Thresholds from Impact Pile Driving

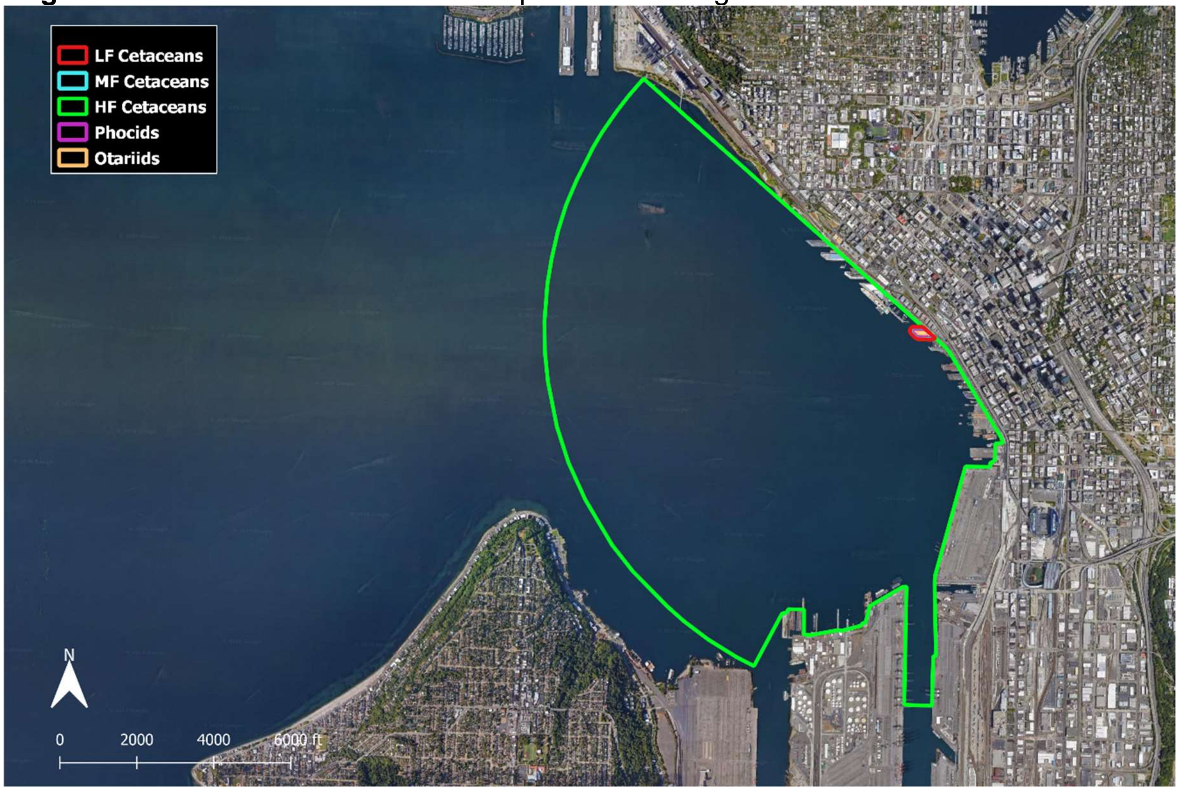
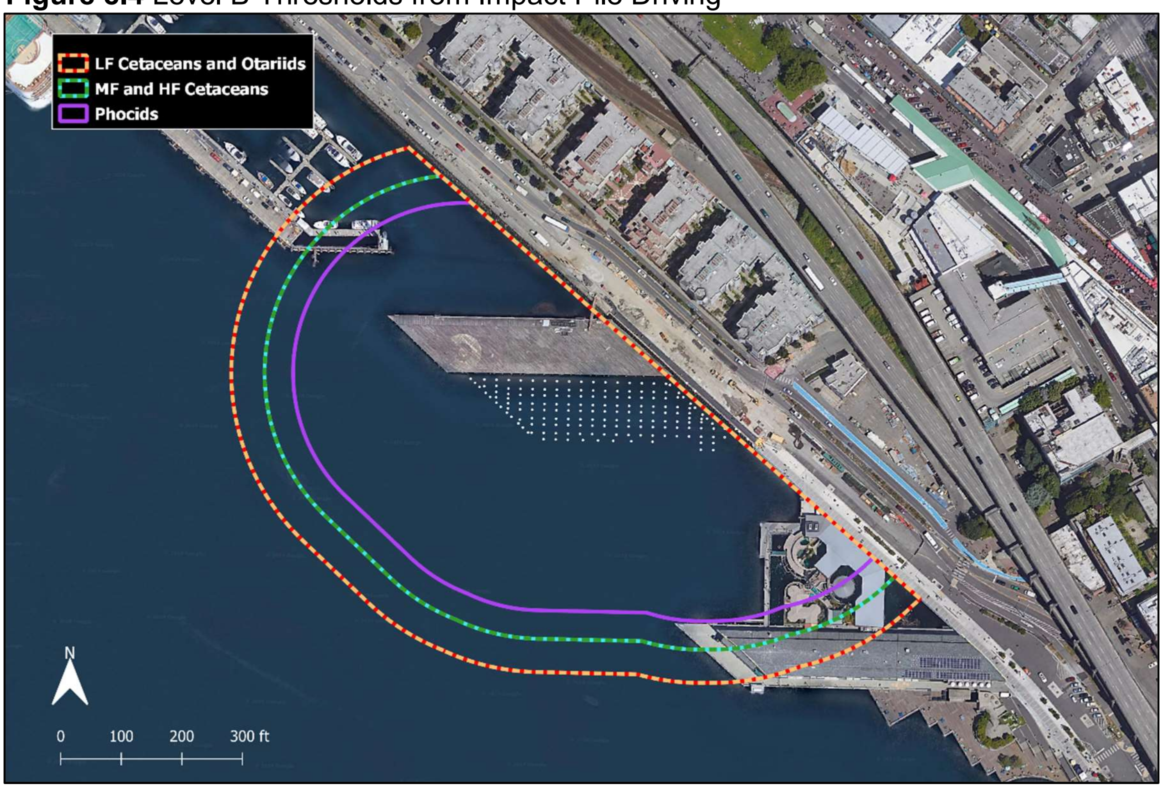


Figure 8.4 Level B Thresholds from Impact Pile Driving



The distances required for airborne sound levels from vibratory pile driving to reach the disturbance levels for harbor seals and other pinnipeds are shown in Table 8.6 and distances from impact pile driving are show in Table 8.7.

Table 8.6 Vibratory Distances to Pinniped Airborne Thresholds, Feet (Meters)

Species	Measured RMS Sound Level	Level B[1]	Distance, Feet (Meters)
Harbor Seal	100	90	158 (48)
Other Pinnipeds		100	50 (15)

1. Level A threshold not established

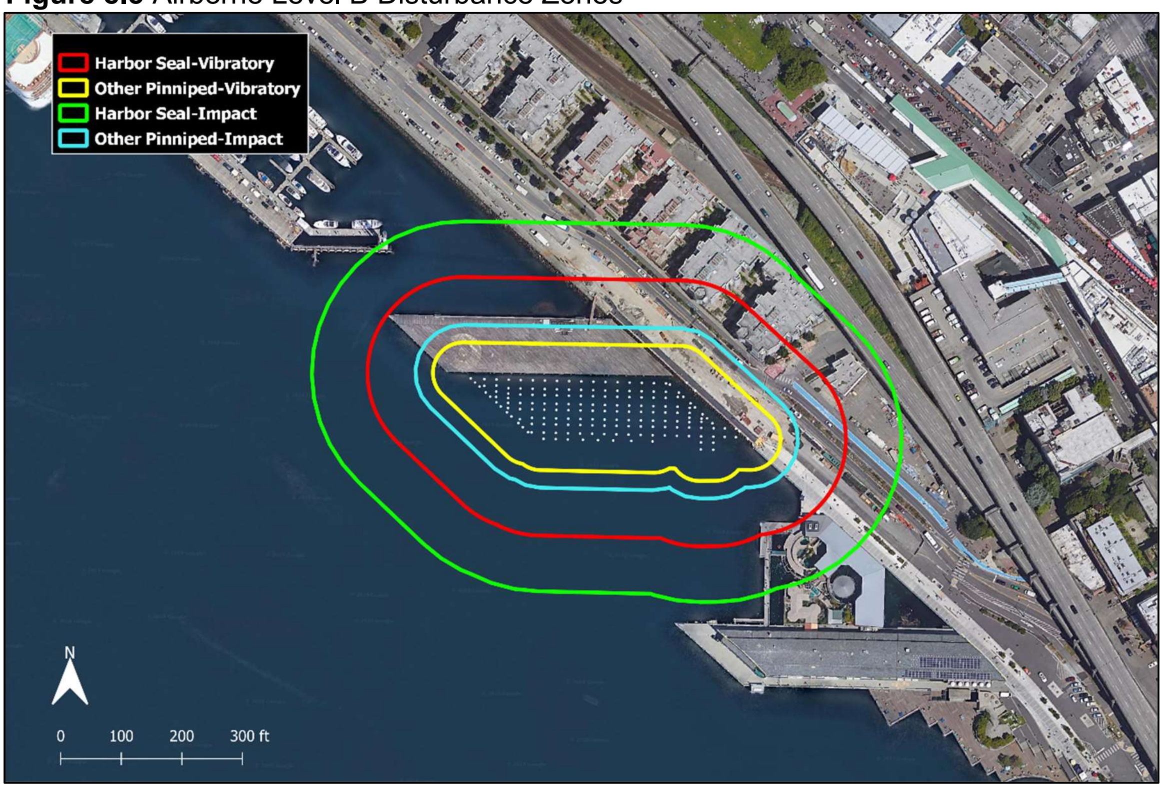
Table 8.7 Impact Distances to Pinniped Airborne Thresholds, Feet (Meters)

Species	Measured RMS Sound Level	Level B[1]	Distance, Feet (Meters)
Harbor Seal	104	90	250 (76)
Other Pinnipeds		100	79 (24)

1. Level A threshold not established

Areas where airborne sound levels are expected to exceed the disturbance thresholds for harbor seals and other pinnipeds are illustrated in Figure 8.5.

Figure 8.5 Airborne Level B Disturbance Zones



8.2 Distance to Background Sound Levels

Distances needed to reach background sound levels were calculated using the median daytime background sound levels measured for each marine mammal hearing group during Season 1 of the Project, as shown in Table 8.8.

Table 8.8 Distances to Background Sound Levels, Miles (Kilometers)

Hearing Group	Background Sound Level[1]	Highest Average RMS		Distance to Background	
		Vibratory	Impact	Vibratory	Impact
LF Cetaceans	118	153	176	1.3 (2.2)	46 (74)
MF Cetaceans	121	157	175	1.6 (2.5)	25 (40)
HF Cetaceans	121	158	175	1.8 (2.9)	25 (40)
Phocids	115	152	174	1.8 (2.9)	53 (86)
Otariids	115	153	176	2.1 (3.4)	73 (117)

1. The median 30-second RMS sound levels measured during season 1 were used to calculate the average background sound levels.

The calculated distances required for underwater sound produced by pile driving to reach background sound levels is up to 2.1 miles (3.4 kilometers) for vibratory pile driving and 73 miles (117 kilometers) for impact pile driving. Figures illustrating the areas where underwater sound levels are expected to exceed background sound levels are shown in Figure 8.6 and Figure 8.7.

Figure 8.6 Distances to Background from Vibratory Pile Driving

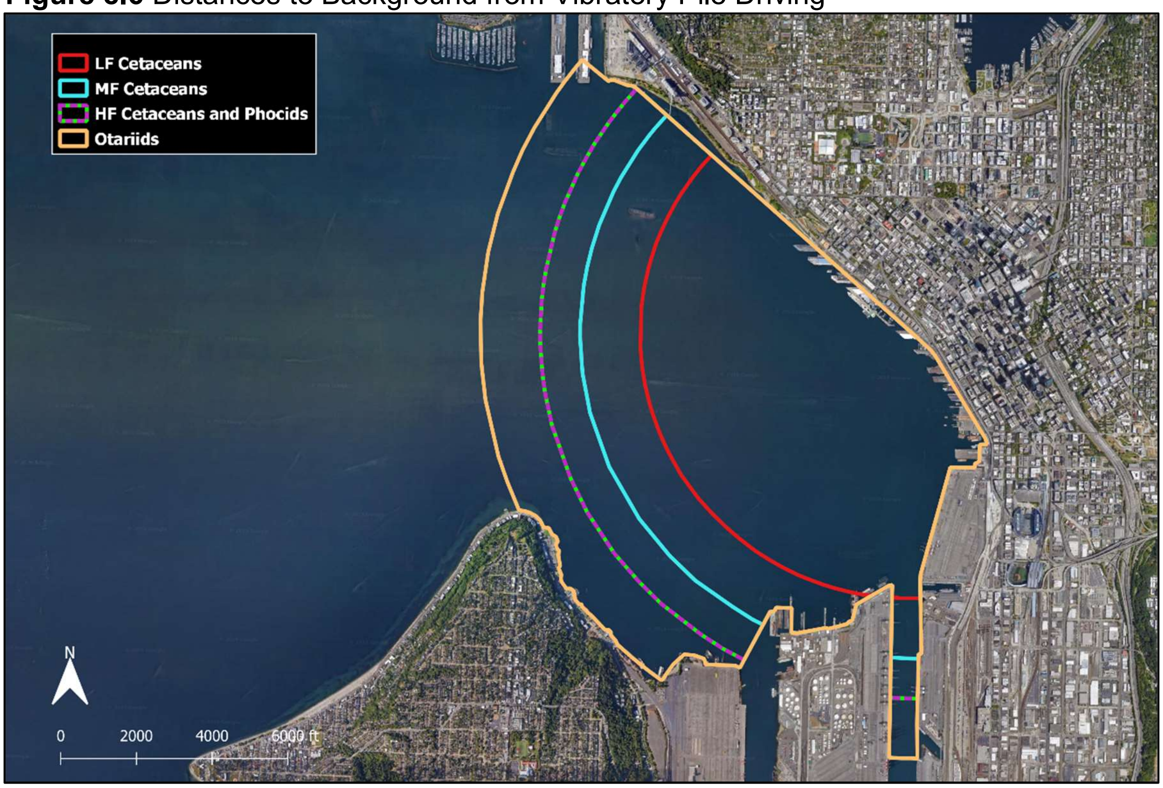


Figure 8.7 Distances to Background from Impact Pile Driving

8.3 Marine Mammal Monitoring

Monitors observed seven marine mammal species within the monitoring zone; however, these animals did not exhibit any changes in behavior associated with pile installation activities. Details of marine mammal monitoring are presented in a separate report entitled "Pier 62 Project Marine Mammal Monitoring Season 2 (2018-2019) Report."

9.0 REFERENCES

California Department of Transportation. "Hydroacoustic Effects of Pile Driving on Fish." November 2015.

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10.0 APPENDIX