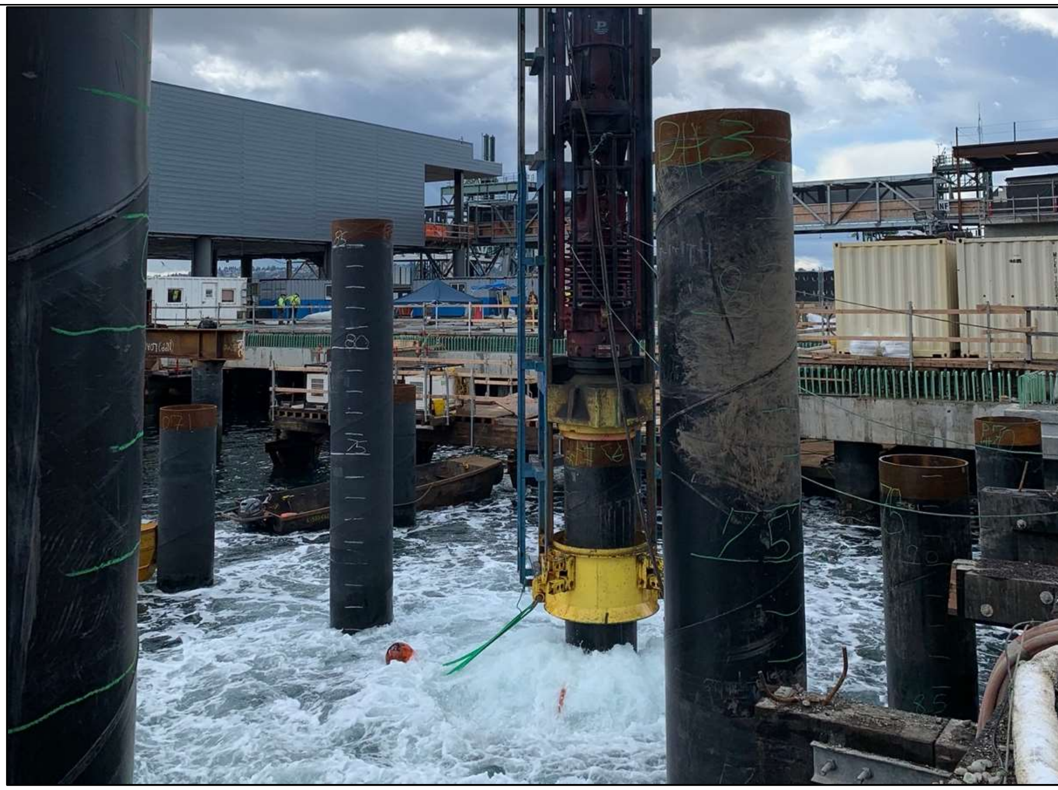

COLMAN DOCK SEASON 4
HYDROACOUSTIC MONITORING REPORT

January 28, 2021

Prepared For:

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1.0 EXECUTIVE SUMMARY

This Hydroacoustic Monitoring Report presents the results of underwater (hydroacoustic) and airborne sound level measurements made on October 21, 2020 during the installation of 36-inch steel pipe piles with a diesel impact hammer. This monitoring was conducted during Season 4 of the Seattle Multimodal Terminal at Colman Dock (Project).

Average unweighted underwater 90% RMS (RMS_{90}) sound levels measured approximately 33 feet (10 meters) from impact pile driving of 36-inch piles ranged between 168 and 174 dB re: 1 μPa and average peak sound levels ranged between 175 and 193 dB re: 1 μPa.

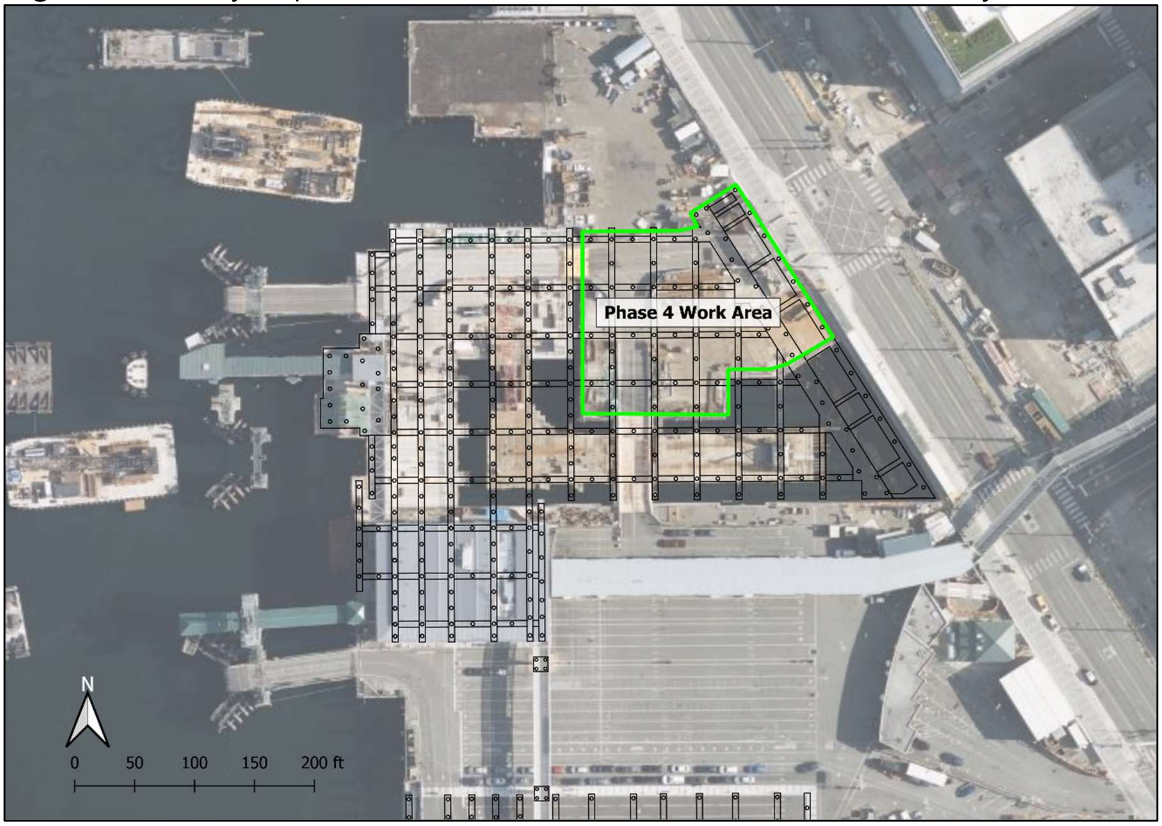
Based on the highest average peak and the daily cSEL levels measured by the far-field hydrophone, the distance required for sound to dissipate to below marine mammal injury thresholds (Level A) are estimated to be 2,459 feet (749 meters) for high-frequency cetaceans and up to 23 feet (7 meters) for all other marine mammals. RMS_{90} sound levels are estimated to dissipate to below the 160 dB marine mammal disturbance threshold (Level B) after 111 feet (34 meters).

2.0 INTRODUCTION

The Project Specifications and the Underwater Noise Monitoring Plan issued by the Washington State Department of Transportation (WSDOT), dated July 27, 2016 include requirements for hydroacoustic monitoring. These requirements include the number of piles to be monitored, monitoring equipment, signal processing requirements, measurement locations, analysis methodology, and information required to be reported to the Services. This Hydroacoustic Monitoring Report fulfills the Project's hydroacoustic monitoring and reporting requirements.

The Project is located west of Alaskan Way between Marion Avenue and Yesler Way in downtown Seattle, Washington (see Figure 2.1). Underwater and airborne sound level measurements were conducted on October 21, 2020.

Figure 2.1 Vicinity Map of Seattle Multimodal Terminal at Colman Dock Project



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:

- **A-Weighted Decibel (dBA)**

  The human ear has a unique response to sound pressure. It is less sensitive to those sounds falling outside the speech frequency range. Sound level meters and monitors utilize a filtering system to approximate human perception of sound. Measurements made utilizing this filtering system are referred to as "A weighted" and are called "dBA".

- **Equivalent Sound Level (L_{eq})**

  Equivalent Sound Level is the level of a constant sound having the same energy content as the actual time-varying level during a specified interval. The L_{eq} is used to characterize complex, fluctuating sound levels with a single number.

- **Maximum Sound Level (L_{max})**

  L_{max} is the maximum recorded root mean square (rms) A-weighted sound level for a given time interval or event. L_{max} can be defined for two time weightings, "slow" and "fast." "Slow" uses 1-second time constant, and "fast" uses a 125-millisecond time constant. For transient events of very short duration, L_{max} "fast" will be greater than L_{max} "slow." This report utilized L_{max} "fast".

- **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).

- **Percent Sound Level (L_n)**

  Percent Sound Level is the sound level that is exceeded n percent of the time; for example, L_{08} is the level exceeded 8% of the time. L_{25} is the sound level exceeded 25% of the time. This report utilizes the L_{90} and L_{95} descriptors.

- **Root Mean Square (RMS)**

  The RMS level is the square root of the average squared pressure over a given time period. In hydroacoustics, the RMS level has been used by the National Marine Fisheries Service (NMFS) in criteria for assessing sound pressure impact on 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.

4.0 HYDROACOUSTIC MONITORING AND REPORTING REQUIREMENTS

Requirements for the Project's hydroacoustic monitoring, signal processing, and reporting are included in the Project Specifications dated July 21, 2017; the Seattle Multimodal Terminal at Colman Dock-Phase 1 Underwater Noise Monitoring Plan authored by WSDOT dated July 27, 2016; and the Colman Dock Phase 4 Underwater Noise Monitoring Plan issued by The Greenbusch Group, Inc. dated June 25, 2020. Underwater sound level limits are not included in either the Project Specifications or the Underwater Noise Monitoring Plans authored by WSDOT and Greenbusch.

4.1 Project Specifications

Section 00 72 00 1-07.6(6) of the Project Specifications includes the following underwater noise monitoring requirements for the Contractor:

- The Contractor will comply with the provisions of the Underwater Noise Monitoring Plan authored by WSDOT. To comply with the WSDOT Underwater Noise Monitoring Plan, the Contractor will conduct hydroacoustic monitoring during construction to document the sound transmission during impact pile driving of steel piles.
- A representative subset of impact driven steel piles will be monitored at the start of each in-water work season, per the noise monitoring plan.
- Underwater sound levels will be continuously monitored for the entire duration of each pile being driven.
- The Contractor shall provide qualified staff and appropriate equipment to conduct impact driven steel pile hydroacoustic monitoring. Only staff with appropriate hydroacoustic expertise, as approved by the Contracting Agency, shall perform this monitoring.

4.2 WSDOT Underwater Noise Monitoring Plan

The Underwater Noise Monitoring Plan issued by WSDOT includes requirements regarding the number of piles to be monitored, hydroacoustic monitoring equipment, signal processing requirements, measurement locations, analysis methodology and information required to be reported to the Services.

The WSDOT Underwater Noise Monitoring Plan requires hydroacoustic monitoring locations to be 33 feet (10 meters) away from the pile at mid water depth and 3H, where H is the water depth of the pile being monitored. The 3H hydrophone should be at 80% of the water depth at the measurement location. Monitoring locations are required to have a clear acoustic line-of-sight between the pile and the hydrophones.

Sound levels measured at these locations must include the frequency spectrum, ranges, means, and L_{50} for peak, RMS_{90} and SEL_{90} sound pressure levels for each marine mammal functional hearing group as well as the broadband sound pressure levels. L_{50} levels reported in this document are the median sound levels from each pile drive. The estimated distance at which peak, RMS and cSEL values exceed the respective threshold values must also be reported.

Airborne sound level measurements are required to be made between 50 feet and 200 feet from impact pile driving. Notes are also required to be made to document any anomalous noise events such as boats and low flying aircraft that could influence the measurements and these events must be excluded from the measurement results. Ambient airborne sound levels must also be made for at least 15 minutes in the absence of construction activities to document background sound levels. The results of airborne sound monitoring must include the frequency spectrum, L_{max}, L_{eq}, and L_{90} for each pile including time history plots and an estimation of the received sound levels at the nearest residences.

4.3 Greenbusch Underwater Noise Monitoring Plan

The Colman Dock Phase 4 Underwater Noise Monitoring Plan authored by the Greenbusch Group, Inc. was prepared based on the requirements of the Project Specifications and the WSDOT Underwater Noise Monitoring Plan and provides details of how the hydroacoustic monitoring will be implemented. The Greenbusch Underwater Noise Monitoring Plan includes specific types of equipment that will be used during the monitoring, the resumes of hydroacoustic monitoring staff and a discussion of which piles will be monitored.

5.0 PILE AND PILE DRIVING EQUIPMENT INFORMATION

During Season 4, all steel pipe piles were initially driven with a vibratory hammer and then proofed with a diesel impact hammer. The piles were all 36-inch diameter steel pipe piles with wall thicknesses of 1-inch. Piles ranged in length from approximately 75-feet to 95-feet. The substrate is primarily composed of sand, shell hash, silt and includes some gravel and cobble.

All measured piles were driven with an APE D100-52 diesel impact hammer with an energy rating of 248,063 foot-pounds. The ram weighed 22,050 pounds with a stoke length of 11.25 feet. A cut sheet of the APE 100-52 diesel impact hammer can be found in the Appendix of this Report.

Table 5.1 provides a summary of the steel pipe piles driven with the impact pile driver during the measurements.

Table 5.1 Summary Pipe Piles, Feet (Meters)

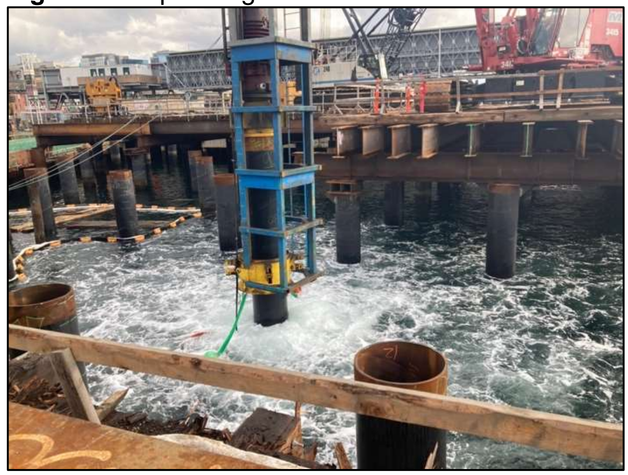
Pile ID	Date Driven	Sound Attenuation	Distance to Water's Edge	Water Depth	Embedment[1]	Number of Strikes[2]
West Side of North Trestle						
N9.5-NG	10/21/20	Bubble Curtain	170 (52)	31 (9.4)	66 (20.1)	104
N9-NG			155 (47)	30 (9.1)	77 (23.5)	221
N9-NF.7			162 (49)	31 (9.4)	69 (21.0)	83
N9-NF.4			170 (52)	31 (9.4)	69 (21.0)	71
N8-NF.5			135 (41)	25 (7.6)	79 (24.1)	273
East Side of North Trestle						
N7-NF.5	10/21/20	Bubble Curtain	106 (32)	26 (7.9)	75 (22.9)	166
N6-NG			65 (20)	18 (5.5)	58 (17.7)	205
N6-NF.5			75 (23)	24 (7.3)	67 (20.4)	191

1. Embedment depths obtained from pile logs.
2. Number of strikes included in analysis.

During hydroacoustic monitoring an unconfined bubble curtain was used during all impact pile driving. The unconfined bubble curtain consisted of five 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 unconfined bubble curtain are shown in Figure 5.1 and Figure 5.2. The system design calculations and drawings of the bubble curtain are provided in the Appendix.

Figure 5.1 Bubble Curtain

Figure 5.2 Operating Bubble Curtain



6.0 MEASUREMENT METHODOLOGY

6.1 Equipment

The hydroacoustic and airborne monitoring equipment used during Season 4 are identified in Table 6.1 and Table 6.2.

Table 6.1 Hydroacoustic Monitoring Equipment

Make and Model	Quantity	Description	Serial Number
Brüel & Kjaer Type 2250	1	Sound Level Analyzer	3006756
Reson TC-4013	2	Hydrophone	2513032
			0712213
Brüel & Kjaer Type 2647-A	2	Charge Converter (1 mV/pC)	2582112
			2638259
Brüel & Kjaer 1704-A-002	1	Signal Conditioner	101161
G.R.A.S. Type 42AC	1	Pistonphone	201835
Tascam DR-100MKIII	1	Digital Audio Recorder	1690316

Table 6.2 Airborne Monitoring Equipment

Make and Model	Quantity	Description	Serial Number
Svantek SV307	1	Sound Level Analyzer	78646
Svantek ST30	1	Microphone	82620
Larson Davis CAL200	1	Acoustic Calibrator	16826

Monitoring equipment was 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 during post-processing. Hydrophones were calibrated using the G.R.A.S. pistonphone and microphone was calibrated with the Larson Davis CAL200 acoustic calibrator.

Underwater sound levels were measured using two Reson TC-4013 hydrophones connected to the Brüel & Kjaer Type 2647-A charge converters and Brüel & Kjaer 1704-A-002 signal conditioner. The signal conditioner was connected to the Tascam DR-100KMIII digital audio recorder, which recorded the signals as WAV files at a sample rate of 48,000 samples per second for subsequent signal analysis. The Brüel & Kjaer Type 2250 allowed for real-time approximations of peak and cSEL sound levels while the measurements were being performed.

Airborne sound levels were measured using the Svantek SV307 sound level analyzer. The Svantek SV307 meets the requirements for a Type 1 sound level analyzer. The airborne equipment recorded a WAV file at a sample rate of 48,000 samples per second for subsequent signal analysis as well as 1-second logging of unweighted and A-weighted L_{eq}, L_{max}, L_{90}, and L_{95} sound levels. Spectral data were also recorded at 1-second intervals at 1/3 octave resolution.

Photographs of the monitoring equipment are provided in Figure 6.1 and Figure 6.2.

Figure 6.1 Hydroacoustic Monitoring Equipment

Figure 6.2 Airborne Monitoring Equipment

6.2 Measurement Locations

Two hydrophones were used to measure underwater sound produced by impact pile driving. One near-field hydrophone was located at mid water depth approximately 33 feet (10 meters) from the pile. A far-field hydrophone was positioned at mid water depth 3H from the pile, where H was the water depth at the pile. Whenever possible, the hydrophones were positioned with a clear acoustic line-of-sight between the hydrophones and pile.

Distances between the pile and microphone ranged between 55 feet (17 meters) and 95 feet (29 meters). The microphone was located approximately 7-feet above the dock and at least 5-feet from any acoustically reflective surfaces. A direct line-of-sight was maintained between the microphone and piles throughout the measurements.

The distances between the hydrophones and piles were verified using a laser distance measurement device. Water depth was measured at all monitoring locations prior to deploying the hydrophones. Hydrophones were secured to existing portions of Colman Dock.

In addition to water depth measurements, tidal information was obtained from NOAA Station #9447130 and was used to track tidal changes during construction. Table 6.3 presents the depths of the hydrophones, water depth at the measurement locations as well as distances between the hydrophones and piles. Figures illustrating the hydroacoustic measurement positions are presented in Section 7.1 and Section 7.2 of this Report.

Table 6.3 Hydrophone Location Summary, Feet (Meters)

Pile ID	Hydrophone	Depth at Measurement Location	Hydrophone Depth	Distance to Pile
West Side of North Trestle				
N9.5-NG	Near-Field	28 (8.5)	16 (4.9)	30 (9.1)
	Far-Field	20 (6.1)	10 (3.0)	75 (22.9)
N9-NG	Near-Field	28 (8.5)	12 (3.7)	30 (9.1)
	Far-Field	20 (6.1)	10 (3.0)	60 (18.3)
N9-NF.7	Near-Field	28 (8.5)	12 (3.7)	36 (11.0)
	Far-Field	20 (6.1)	10 (3.0)	60 (18.3)
N9-NF.4	Near-Field	28 (8.5)	12 (3.7)	46 (14.0)
	Far-Field	20 (6.1)	10 (3.0)	65 (19.8)
N8-NF.5	Near-Field	28 (8.5)	12 (3.7)	26 (7.9)
	Far-Field	20 (6.1)	10 (3.0)	40 (12.2)
East Side of North Trestle				
N7-NF.5	Near-Field	20 (6.1)	12 (3.7)	28 (8.5)
	Far-Field	28 (8.5)	12 (3.7)	45 (13.7)
N6-NG[1]	-	20 (6.1)	12 (3.7)	30 (9.1)
N6-NF.5	Near-Field	20 (6.1)	12 (3.7)	33 (10.1)
	Far-Field	20 (6.1)	10 (3.0)	45 (13.7)

1. There was insufficient time to finish relocating one of the hydrophones therefore, data is only reported from one hydrophone.

7.0 IMPACT PILE DRIVING ANALYSIS AND RESULTS

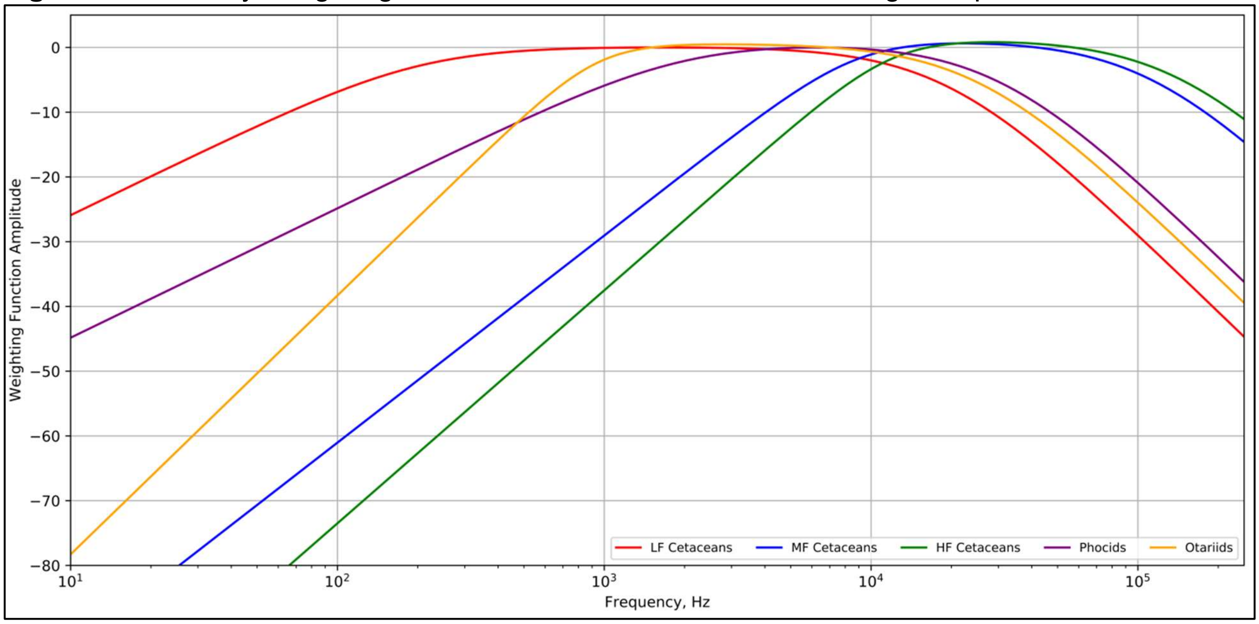
During post-processing, the hydroacoustic data were frequency-weighted for each of the marine mammal hearing groups defined in the NOAA technical guidance document titled "Technical Guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammal Hearing" dated April 2018. This Technical Guidance 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



Underwater noise data collected during impact pile driving were analyzed to determine the range, mean, L_{50} 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 WSDOT Underwater Noise Monitoring Plan. Standard deviation and L_{50} were calculated using decibel values and mean values were calculated using mean sound pressure levels. Periods when pile driving was not occurring under full power were excluded from this analysis. Reported sound levels from the near-field hydrophone have been normalized to 33 feet (10 meters) from the piles using the practical spreading model. For additional information on the practical spreading model please see Section 8.0 of this Report.

The RMS_{90} was established between the 5th percentile and 95th percentile for each recorded 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.

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 were combined (logarithmically) to produce daily cSEL values.

Airborne data were analyzed to determine the range and median of 1-second unweighted L_{eq} and L_{max} sound levels as well as A-weighted L_{eq}, L_{max}, L_{90}, and L_{95} sound levels. The 1/3 octave L_{eq} and L_{max} spectral data was also calculated. Periods when pile driving was not occurring are exclude from the analysis.

Details and results of the acoustic monitoring at the west and east sides of the North Trestle are discussed in Section 7.1 and Section 7.2.

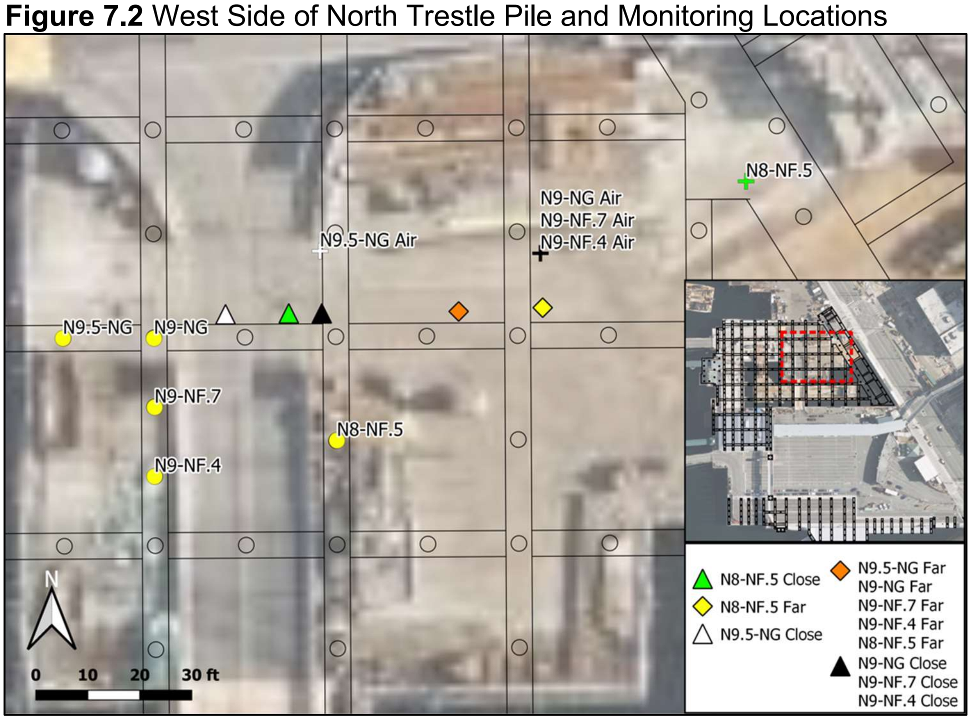
7.1 West Side of North Trestle

Acoustic measurements were made during impact pile driving of five 36-inch steel pipe piles near the west side of the North Trestle on October 21, 2020. During the measurements, the water temperature was approximately 55 degrees Fahrenheit. There was no precipitation during the measurements.

During the measurements, both hydrophones were suspended from portion of Colman Dock that had not been demolished. An unobstructed acoustical path was maintained between the hydrophones and piles during all measurements. The microphone was positioned approximately 7-feet above the existing dock with an unobstructed acoustical path to the piles. The locations of the hydrophones, microphone, and piles are shown in Figure 7.2.

Soft start procedures were followed before the drive of Pile N9.5-NG. All other piles were driven continuously and did not include soft starts.

Figure 7.2 West Side of North Trestle Pile and Monitoring Locations



Summaries of the airborne and underwater sound levels produced by impact pile driving at the west side of the North Trestle are shown in Table 7.2 through Table 7.11.

Table 7.2 N9.5-NG Underwater Sound Levels, dB re: 1 μPa

Frequency Range	Peak					RMS_{90}					SEL					cSEL
	Max	Min	SD	Mean	L_{50}	Max	Min	SD	Mean	L_{50}	Max	Min	SD	Mean	L_{50}	
Near-Field Hydrophone (measured 30 feet from pile, reported levels normalized to 33 feet)																
Unweighted	192	184	1.7	188	188	176	169	1.0	173	173	168	160	1.1	165	165	185
LF Cetacean	187	178	1.7	183	183	175	164	1.7	171	171	161	153	1.4	158	158	178
MF Cetacean	187	178	1.6	183	183	171	163	1.1	167	167	162	154	1.1	159	159	179
HF Cetacean	187	179	1.6	183	183	172	164	1.1	168	168	162	155	1.1	159	159	179
PW	184	175	1.8	180	180	169	160	1.5	165	165	158	150	1.3	154	154	174
OW	185	175	1.9	180	180	171	160	1.8	166	166	159	150	1.5	154	154	175
Far-Field Hydrophone (75 feet from pile)																
Unweighted	183	171	1.8	177	177	170	160	1.6	165	165	158	150	1.4	154	153	174
LF Cetacean	177	167	2.0	171	171	164	155	1.5	159	159	152	144	1.5	148	147	168
MF Cetacean	177	167	1.9	172	171	164	154	1.6	159	159	152	144	1.4	148	148	168
HF Cetacean	177	167	1.9	172	172	164	155	1.6	159	159	153	144	1.4	148	148	168
PW	173	164	2.0	169	169	160	152	1.6	156	156	149	140	1.6	145	145	165
OW	174	165	2.1	169	169	161	152	1.7	157	156	149	141	1.7	145	145	166

Table 7.3 N9.5-NG Airborne Sound Levels, dB re: 20 μPa[1]

Unweighted						A-Weighted											
L_{eq}			L_{max}			L_{eq}			L_{max}			L_{90}			L_{95}		
Min	Max	Med	Min	Max	Med	Min	Max	Med	Min	Max	Med	Min	Max	Med	Min	Max	Med
89	107	103	101	114	108	84	106	101	96	114	107	80	95	82	80	94	81

1. Sound levels measured 55 feet from pile. Reported sound levels have been normalized to 50 feet.

Table 7.4 N9-NG Underwater Sound Levels, dB re: 1 μPa

Frequency Range	Peak					RMS_{90}					SEL					cSEL
	Max	Min	SD	Mean	L_{50}	Max	Min	SD	Mean	L_{50}	Max	Min	SD	Mean	L_{50}	
Near-Field Hydrophone (measured 30 feet from pile, reported levels normalized to 33 feet)																
Unweighted	188	176	2.7	182	182	173	164	1.6	168	167	163	155	1.4	158	158	182
LF Cetacean	182	171	2.6	177	176	168	157	2.1	162	162	155	146	1.6	150	149	174
MF Cetacean	186	172	2.8	178	177	168	158	1.8	162	162	157	149	1.4	152	152	176
HF Cetacean	186	172	2.7	178	177	168	159	1.8	163	162	158	150	1.4	153	152	176
PW	184	169	3.0	175	174	165	155	2.0	160	159	154	144	1.6	148	148	172
OW	183	170	3.0	176	175	167	156	2.2	161	160	154	145	1.7	149	149	173
Far-Field Hydrophone (60 feet from pile)																
Unweighted	176	164	2.0	171	171	164	155	1.3	158	157	154	146	1.3	149	149	173
LF Cetacean	171	159	1.9	165	164	159	145	2.0	152	151	146	136	1.5	141	140	164
MF Cetacean	173	160	2.1	166	165	157	149	1.4	152	151	148	140	1.3	143	143	167
HF Cetacean	173	161	2.1	166	165	158	149	1.3	152	152	149	141	1.3	144	143	167
PW	169	156	2.1	163	162	155	143	1.9	148	147	144	134	1.6	139	138	162
OW	170	156	2.2	163	162	156	143	2.3	149	148	145	134	1.7	139	138	162

Table 7.5 N9-NG Airborne Sound Levels, dB re: 20 μPa[1]

Unweighted						A-Weighted											
L_{eq}			L_{max}			L_{eq}			L_{max}			L_{90}			L_{95}		
Min	Max	Med	Min	Max	Med	Min	Max	Med	Min	Max	Med	Min	Max	Med	Min	Max	Med
89	108	102	100	114	107	83	106	100	99	114	106	80	91	82	79	88	81

1. Sound levels measured 77 feet from pile. Reported sound levels have been normalized to 50 feet.

Table 7.6 N9-NF.7 Underwater Sound Levels, dB re: 1 μPa

Frequency Range	Peak					RMS_{90}					SEL					cSEL
	Max	Min	SD	Mean	L_{50}	Max	Min	SD	Mean	L_{50}	Max	Min	SD	Mean	L_{50}	
Near-Field Hydrophone (measured 36 feet from pile, reported levels normalized to 33 feet)																
Unweighted	195	184	2.0	190	190	177	170	1.3	173	173	166	161	1.0	164	164	183
LF Cetacean	188	180	2.2	184	184	174	168	1.4	171	171	161	155	1.2	158	157	177
MF Cetacean	188	180	2.0	185	184	173	165	1.5	169	169	160	155	1.0	158	158	177
HF Cetacean	188	180	2.0	185	185	173	166	1.5	169	169	161	156	1.0	159	158	178
PW	188	177	2.2	183	182	173	164	1.7	168	168	159	152	1.3	155	155	175
OW	189	176	2.4	184	183	174	164	1.9	169	169	160	152	1.6	156	156	176
Far-Field Hydrophone (60 feet from pile)																
Unweighted	182	173	2.0	178	178	171	159	2.5	164	164	158	151	1.4	154	154	174
LF Cetacean	176	167	1.9	172	172	165	156	1.9	161	161	151	145	1.5	148	148	168
MF Cetacean	175	166	1.9	172	172	164	153	2.4	158	158	152	145	1.3	148	148	167
HF Cetacean	176	166	1.9	172	172	165	153	2.4	159	158	152	145	1.4	149	149	168
PW	173	164	1.9	169	169	160	152	1.8	156	156	148	142	1.4	145	145	164
OW	174	164	2.2	170	170	161	153	1.9	157	157	148	142	1.6	145	145	165

Table 7.7 N9-NF.7 Airborne Sound Levels, dB re: 20 μPa[1]

Unweighted						A-Weighted											
L_{eq}			L_{max}			L_{eq}			L_{max}			L_{90}			L_{95}		
Min	Max	Med	Min	Max	Med	Min	Max	Med	Min	Max	Med	Min	Max	Med	Min	Max	Med
91	103	101	100	109	106	84	101	99	98	107	105	80	90	82	79	87	81

1. Sound levels measured 80 feet from pile. Reported sound levels have been normalized to 50 feet.

Table 7.8 N9-NF.4 Underwater Sound Levels, dB re: 1 μPa

Frequency Range	Peak					RMS_{90}					SEL					cSEL
	Max	Min	SD	Mean	L_{50}	Max	Min	SD	Mean	L_{50}	Max	Min	SD	Mean	L_{50}	
Near-Field Hydrophone (measured 46 feet from pile, reported levels normalized to 33 feet)																
Unweighted	192	183	2.4	188	188	173	169	0.8	171	171	164	160	0.7	162	162	181
LF Cetacean	187	176	2.9	183	183	172	165	1.7	169	169	158	153	1.1	156	156	174
MF Cetacean	188	177	2.8	183	183	168	163	1.0	166	166	158	155	0.7	156	156	175
HF Cetacean	188	178	2.7	183	183	169	164	0.9	166	166	158	155	0.7	157	157	175
PW	187	173	3.5	181	182	172	161	2.5	166	166	156	150	1.5	153	153	172
OW	188	174	3.7	183	183	174	161	3.0	168	168	158	149	2.0	154	154	173
Far-Field Hydrophone (65 feet from pile)																
Unweighted	180	172	1.8	176	176	166	158	1.9	161	160	155	150	1.0	152	152	171
LF Cetacean	176	166	1.9	171	171	163	156	1.4	158	158	150	144	1.2	146	146	165
MF Cetacean	176	166	1.9	171	170	161	152	2.0	156	155	149	144	1.0	146	146	165
HF Cetacean	176	166	1.9	171	171	161	153	2.0	156	155	150	144	1.0	147	146	165
PW	174	163	2.1	169	168	160	151	1.4	155	155	146	141	1.0	143	143	162
OW	174	164	2.2	169	169	161	153	1.5	156	156	147	142	1.1	144	144	162

Table 7.9 N9-NF.4 Airborne Sound Levels, dB re: 20 μPa[1]

Unweighted						A-Weighted											
L_{eq}			L_{max}			L_{eq}			L_{max}			L_{90}			L_{95}		
Min	Max	Med	Min	Max	Med	Min	Max	Med	Min	Max	Med	Min	Max	Med	Min	Max	Med
91	103	100	101	108	106	84	102	99	100	107	104	80	90	82	80	87	81

1. Sound levels measured 87 feet from pile. Reported sound levels have been normalized to 50 feet.

Table 7.10 N8-NF.5 Underwater Sound Levels, dB re: 1 μPa

Frequency Range	Peak					RMS_{90}					SEL					cSEL
	Max	Min	SD	Mean	L_{50}	Max	Min	SD	Mean	L_{50}	Max	Min	SD	Mean	L_{50}	
Near-Field Hydrophone (measured 26 feet from pile, reported levels normalized to 33 feet)																
Unweighted	193	173	3.2	184	183	173	161	1.6	169	169	164	153	1.3	160	160	184
LF Cetacean	187	166	3.1	178	177	170	153	2.5	164	163	156	142	2.0	151	151	176
MF Cetacean	188	166	3.1	179	179	170	154	2.1	164	164	158	146	1.5	154	154	178
HF Cetacean	188	167	3.0	180	179	170	155	2.0	165	164	158	147	1.5	154	154	179
PW	187	162	3.5	177	176	168	147	3.0	161	160	154	139	2.2	149	149	174
OW	187	161	3.5	177	176	168	145	3.2	162	161	154	137	2.4	149	149	174
Far-Field Hydrophone (40 feet from pile)																
Unweighted	182	166	2.8	175	175	168	157	1.1	164	163	158	149	1.1	155	155	179
LF Cetacean	173	158	2.9	168	168	160	146	2.8	153	153	148	137	2.4	143	143	168
MF Cetacean	176	160	2.3	170	170	161	150	1.3	157	157	152	142	1.1	148	148	173
HF Cetacean	177	161	2.2	170	170	162	151	1.2	158	158	153	143	1.1	149	149	173
PW	171	155	2.7	166	166	155	142	2.0	150	150	146	134	1.7	141	141	166
OW	171	154	2.9	166	166	155	141	2.6	149	149	145	133	2.3	140	140	165

Table 7.11 N8-NF.5 Airborne Sound Levels, dB re: 20 μPa[1]

Unweighted						A-Weighted											
L_{eq}			L_{max}			L_{eq}			L_{max}			L_{90}			L_{95}		
Min	**Max**	**Med**	**Min**	**Max**	**Med**	**Min**	**Max**	**Med**	**Min**	**Max**	**Med**	**Min**	**Max**	**Med**	**Min**	**Max**	**Med**
90	107	104	101	113	110	85	106	102	99	113	108	81	93	83	80	91	82

1. Sound levels measured 95 feet from pile. Reported sound levels have been normalized to 50 feet.

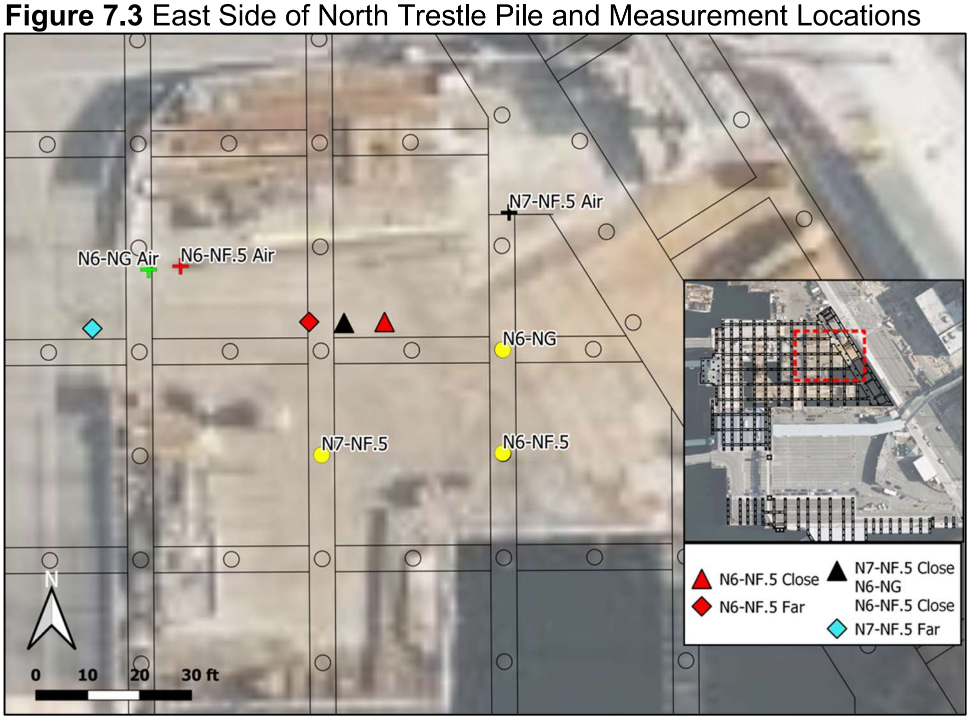
The underwater sound levels measured over the duration of each pile drive, the waveform of the of the pile strike which produced the absolute highest peak sound pressure level, and the average underwater frequency spectrum from all pile strikes are provided in the Appendix.

7.2 East Side of North Trestle

Three 36-inch steel pipe piles were measured during the afternoon of October 21, 2020 at the east side of the North Trestle. During the measurements, the water temperature was approximately 55 degrees Fahrenheit and no precipitation occurred during the measurements. The majority of the piles on the east side of the North Trestle were driven after the piles near the west side of the North Trestle.

Both hydrophones were secured to portions of Colman Dock that had not been demolished and an unobstructed acoustical path between the hydrophones and piles was maintained during all pile driving. There was insufficient time to finish relocating the hydrophones prior to the drive of N6-NG and only one hydrophone was able to collect data. The microphone was positioned north of the piles approximately 7-feet above the dock with a direct line-of-sight to the piles. The locations of the microphone, hydrophones, and piles are shown in Figure 7.3.

Figure 7.3 East Side of North Trestle Pile and Measurement Locations



Sound levels measured during the installation of piles near the east side of the North Trestle are shown in Table 7.12 through Table 7.17.

Table 7.12 N7-NF.5 Underwater Sound Levels, dB re: 1 μPa

Frequency Range	Peak					RMS_{90}					SEL					cSEL
	Max	Min	SD	Mean	L_{50}	Max	Min	SD	Mean	L_{50}	Max	Min	SD	Mean	L_{50}	
Near-Field Hydrophone (measured 28 feet from pile, reported levels normalized to 33 feet)																
Unweighted	184	168	2.7	179	179	171	160	1.8	167	167	162	151	1.5	158	158	180
LF Cetacean	176	158	2.9	170	170	165	145	3.8	159	158	151	137	2.6	147	147	169
MF Cetacean	179	163	2.4	173	173	165	154	2.0	161	161	156	145	1.6	151	151	174
HF Cetacean	179	164	2.3	173	173	166	155	2.0	161	161	156	145	1.6	152	152	174
PW	177	158	3.0	168	168	159	145	2.4	154	154	148	137	1.9	144	144	166
OW	176	156	3.6	168	167	159	143	3.0	152	152	147	134	2.3	142	142	165
Far-Field Hydrophone (45 feet from pile)																
Unweighted	188	169	4.1	179	177	171	160	1.4	167	167	162	151	1.4	158	158	180
LF Cetacean	181	162	4.6	173	171	166	148	4.0	158	156	152	139	3.1	146	145	169
MF Cetacean	182	166	3.7	174	173	165	154	1.6	161	161	156	145	1.5	152	152	174
HF Cetacean	182	167	3.6	174	173	166	154	1.6	162	161	156	145	1.5	152	152	175
PW	181	160	4.7	172	171	163	146	3.2	156	155	152	137	2.8	146	145	169
OW	182	160	5.1	173	171	167	145	4.6	157	154	152	135	3.6	146	144	169

Table 7.13 N7-NF.5 Airborne Sound Levels, dB re: 20 μPa[1]

Unweighted						A-Weighted											
L_{eq}			L_{max}			L_{eq}			L_{max}			L_{90}			L_{95}		
Min	Max	Med	Min	Max	Med	Min	Max	Med	Min	Max	Med	Min	Max	Med	Min	Max	Med
88	104	102	101	109	107	84	102	100	98	108	106	76	90	80	76	87	80

1. Sound levels measured 60 feet from pile. Reported sound levels have been normalized to 50 feet.

Table 7.14 N6-NG Underwater Sound Levels, dB re: 1 μPa[1]

Frequency Range	Peak					RMS_{90}					SEL					cSEL
	Max	Min	SD	Mean	L_{50}	Max	Min	SD	Mean	L_{50}	Max	Min	SD	Mean	L_{50}	
Near-Field Hydrophone (measured 30 feet from pile, reported levels normalized to 33 feet)																
Unweighted	178	173	1.2	175	175	173	167	1.3	170	170	162	158	1.1	160	160	183
LF Cetacean	167	155	2.6	160	159	153	149	1.1	151	151	144	140	1.1	142	141	165
MF Cetacean	171	166	1.1	169	168	166	161	1.2	163	163	156	151	1.1	153	153	177
HF Cetacean	172	167	1.1	169	169	167	161	1.2	164	164	157	152	1.1	154	154	177
PW	168	157	2.3	161	160	156	151	1.2	153	153	147	142	1.2	144	144	167
OW	168	155	3.1	159	158	154	148	1.3	151	150	145	139	1.3	141	141	165

1. There was insufficient time between pile drives to finish relocating one of the hydrophones. Therefore, data is only reported from one hydrophone.

Table 7.15 N6-NG Airborne Sound Levels, dB re: 20 μPa[1]

Unweighted						A-Weighted											
L_{eq}			L_{max}			L_{eq}			L_{max}			L_{90}			L_{95}		
Min	Max	Med	Min	Max	Med	Min	Max	Med	Min	Max	Med	Min	Max	Med	Min	Max	Med
92	104	101	103	110	106	86	101	98	100	107	104	83	96	85	83	94	84

2. Sound levels measured 70 feet from pile. Reported sound levels have been normalized to 50 feet.

Table 7.16 N6-NF.5 Underwater Sound Levels, dB re: 1 μPa

Frequency Range	Peak					RMS_{90}					SEL					cSEL
	Max	Min	SD	Mean	L_{50}	Max	Min	SD	Mean	L_{50}	Max	Min	SD	Mean	L_{50}	
Near-Field Hydrophone (measured 33 feet from pile)																
Unweighted	202	184	3.5	193	192	183	168	2.6	174	173	168	158	2.0	164	163	187
LF Cetacean	195	179	3.3	188	187	180	167	2.5	174	173	163	152	2.3	158	158	181
MF Cetacean	196	179	3.4	188	188	178	163	2.9	169	169	163	153	2.1	158	158	181
HF Cetacean	196	179	3.3	188	188	178	163	2.7	169	169	163	153	2.1	158	158	181
PW	195	177	3.5	188	187	179	164	2.9	172	172	163	150	2.5	157	157	180
OW	196	178	3.5	189	188	180	166	2.8	174	174	164	151	2.5	158	158	181
Far-Field Hydrophone (45 feet from pile)																
Unweighted	190	175	3.3	185	185	173	161	2.4	168	168	163	151	2.4	159	159	182
LF Cetacean	186	169	3.6	180	180	171	156	3.0	166	166	155	143	2.6	152	152	175
MF Cetacean	185	169	3.5	180	180	166	155	2.4	163	163	157	145	2.4	153	153	176
HF Cetacean	186	170	3.5	180	180	167	155	2.4	163	163	157	146	2.4	153	154	176
PW	185	167	3.9	179	179	169	152	4.0	163	162	154	142	2.8	150	150	173
OW	186	167	4.0	180	181	171	154	3.7	166	166	155	142	3.0	151	151	174

Table 7.17 N6-NF.5 Airborne Sound Levels, dB re: 20 μPa[1]

Unweighted						A-Weighted											
L_{eq}			L_{max}			L_{eq}			L_{max}			L_{90}			L_{95}		
Min	Max	Med	Min	Max	Med	Min	Max	Med	Min	Max	Med	Min	Max	Med	Min	Max	Med
90	102	100	101	107	105	86	100	98	98	106	104	81	90	82	80	89	82

1. Sound levels measured 71 feet from pile. Reported sound levels have been normalized to 50 feet.

The underwater sound levels measured over the duration of each pile drive, the waveform of the of the pile strike which produced the absolute highest peak sound pressure level, and the average underwater frequency spectrum from all pile strikes are provided in the Appendix.

8.0 DISTANCE TO MARINE MAMMAL DISTURBANCE AND INJURY THRESHOLDS

Data collected during impact pile driving was used to estimate the distance required for underwater sound levels to reach the disturbance and injury thresholds for fish and marine mammals.

The distances 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 distances required for underwater noise to reach the disturbance and injury thresholds for fish and marine mammals are estimated by solving the practical spreading formula for D_2 resulting in the following:

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

To estimate the distances required for underwater noise to reach the disturbance and injury thresholds sound levels measured by the far-field hydrophone were normalized to their average measurement distance of 60 feet (18 meters) to allow for comparison of measured sound levels. After calculating the far-field sound levels at 60 feet (18 meters), the highest median peak, RMS_{90} and daily cSEL values were used to calculate the distances required for sound to reach marine mammal thresholds. The far-field hydrophone provides a more accurate estimate of sound levels at greater distances, as described in the National Marine Fisheries Service Guidance Document titled "Data Collection Methods to Characterize Impact and Vibratory Pile Driving Source Levels Relevant to Marine Mammals", dated January 31, 2012.

8.1 Marine Mammal Threshold Distances

The results of the acoustic monitoring and analysis were used to estimate the distances required for underwater sound levels to reach the marine mammal injury (Level A) and disturbance (Level B) thresholds.

In April 2018, 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, such as impact pile driving. 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 thresholds from impulsive sounds are in Table 8.1.

Table 8.1 Injury Thresholds, dB re: 1 μPa

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

Source: Technical Guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammal Hearing, April 2018

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	Impact Pile Driving Disturbance Threshold
Cetaceans	160
Pinnipeds	

Source: National Marine Fisheries Service

The practical spreading model, the 24-hour cSEL values, and the loudest average peak, 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 impact pile driving distances are shown in Table 8.3.

Table 8.3 Distances to Marine Mammal Thresholds from Impact Pile Driving, Feet (Meters)

<table>
<tr><th rowspan="3">Hearing Group</th><th colspan="3" rowspan="2">Measured Sound Level</th><th colspan="3">Marine Mammal Threshold</th><th colspan="3">Distance to Threshold</th></tr>
<tr><th colspan="2">Level A</th><th>Level B</th><th colspan="2">Level A</th><th>Level B</th></tr>
<tr><th>Peak[1]</th><th>cSEL</th><th>RMS_{90}</th><th>Peak</th><th>cSEL</th><th>RMS_{90}</th><th>Peak</th><th>cSEL</th><th>RMS_{90}</th></tr>
<tr><td>LF Cetaceans</td><td>183</td><td>177</td><td>164</td><td>219</td><td>183</td><td rowspan="5">160</td><td>0.24 (0.07)</td><td>23 (7.1)</td><td>111 (34)</td></tr>
<tr><td>MF Cetaceans</td><td>183</td><td>179</td><td>161</td><td>230</td><td>185</td><td>0.04 (0.01)</td><td>22 (6.8)</td><td>70 (21)</td></tr>
<tr><td>HF Cetaceans</td><td>183</td><td>179</td><td>161</td><td>202</td><td>155</td><td>3.25 (0.99)</td><td>2,459 (749)</td><td>70 (21)</td></tr>
<tr><td>Pinnipeds (Phocids)</td><td>183</td><td>175</td><td>160</td><td>218</td><td>185</td><td>0.28 (0.08)</td><td>12 (3.7)</td><td>60 (18)</td></tr>
<tr><td>Pinnipeds (Otariids)</td><td>183</td><td>175</td><td>164</td><td>232</td><td>203</td><td>0.03 (0.01)</td><td>0.9 (0.3)</td><td>111 (34)</td></tr>
</table>

1. All peak values shown in this table are unweighted peak levels.

As shown in Table 8.3, the estimated distances required for sound produced by impact pile driving to reach the 160 dB marine mammal disturbance threshold is up to 111 feet (34 meters) from the pile. Approximately 2,459 feet (749 meters) may be required for sound to dissipate to below the Level A injury thresholds for high-frequency cetaceans, 23 feet (7 meters) for other cetaceans, and 12 feet (3.7 meters) for pinnipeds. Figure 8.1 illustrates the areas where underwater sound levels are expected to exceed the Level A and Level B thresholds for marine mammals. Descriptions of observed marine mammal behavior can be found in the marine mammal monitoring report.

Figure 8.1 Marine Mammal Disturbance and Injury Zones

8.2 Fish Threshold Distances

In 2008, The Fisheries Hydroacoustic Working Group, the Federal Highway Administration and Federal Agencies, including the National Marine Fisheries Service (NMFS), agreed upon dual sound level threshold criteria for the onset of injury to fish. These thresholds include peak sound pressure levels and cSEL levels for fish weighing more than 2 grams and fish weighing less than 2 grams. These thresholds as well as the threshold for "effective quiet" are shown in Table 8.4.

Table 8.4 Threshold Levels for Fish, dB re: 1 μPa

Effect	Metric	Fish Mass	Threshold
Physical Injury	Peak	N/A	206
	Daily cSEL	< 2 grams	183
		≥ 2 grams	187
Effective Quiet	Single Strike SEL	N/A	150

The distances for underwater sound levels to reach the threshold values listed in Table 8.4 were calculated using the practical spreading model and the highest mean peak and single strike SEL unweighted sound levels as well as the daily cSEL level measured by the far-field hydrophone. The resulting distances are provided in Table 8.5.

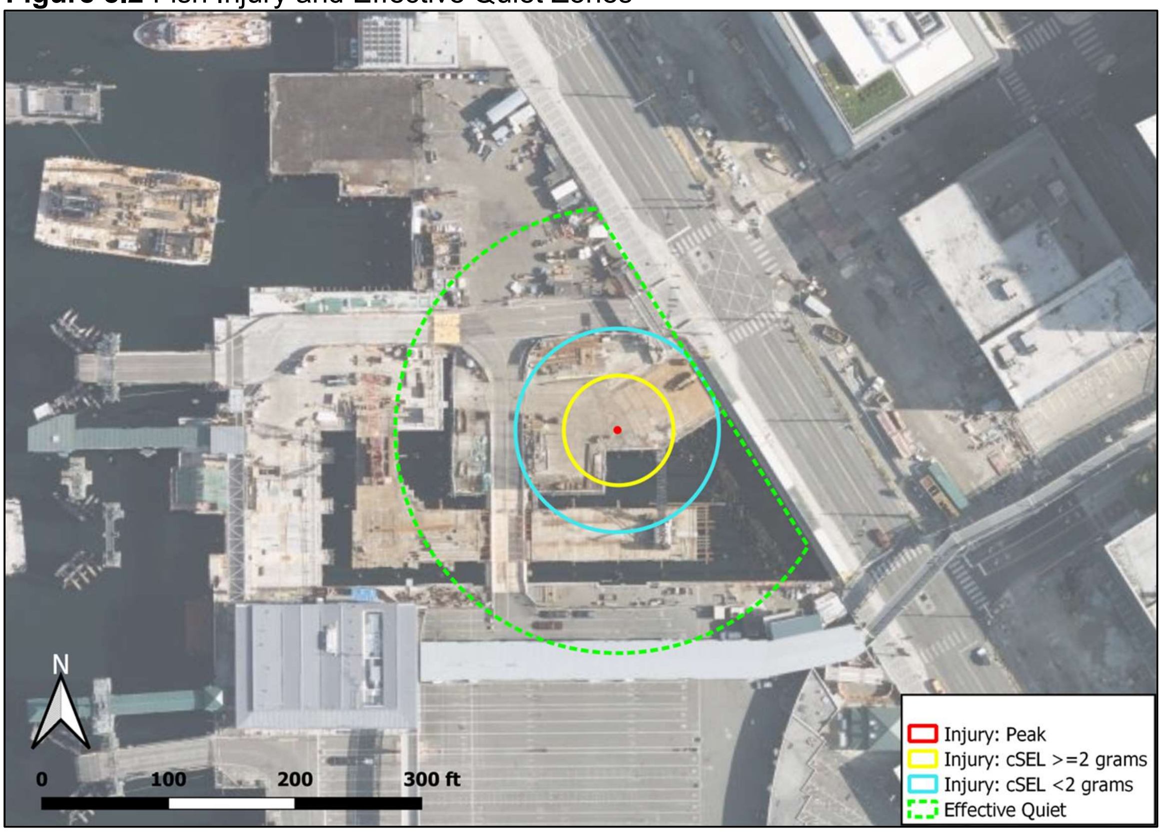
Table 8.5 Distances to Fish Thresholds, Feet (Meters)

Effect	Metric	Measured Sound Level	Fish Mass	Threshold	Distance
Physical Injury	Peak	183[1]	N/A	206	**1.8 (0.5)**
	Daily cSEL	185	< 2 grams	183	**80 (24.5)**
			≥ 2 grams	187	**43 (13.2)**
Effective Quiet	Single Strike SEL	157[1]	N/A	150	**176 (53.6)**

1. The highest mean peak and singe strike SEL sound levels were measured during impact pile driving of Pile N6-NF.5.

Figure 8.2 illustrates the areas where underwater sound levels are expected to exceed the injury and effective quiet thresholds for fish.

Figure 8.2 Fish Injury and Effective Quiet Zones



9.0 PREDICTED AIRBORNE SOUND LEVELS AT NEARBY PROPERTIES

Airborne sound levels measured during Season 4 were used to predict sound levels at nearby residential properties.

Sound levels were predicted using a 3-D computer noise model. The computer noise model uses the acoustic modeling software Cadna/A. Cadna/A utilizes the CADNA (Control of Accuracy and Debugging for Numerical Applications) computation engine developed by the Pierre et Marie Curie University in Paris. The model accounts for the effects of distance, topography, and surface reflections on sound levels produced by impact pile driving.

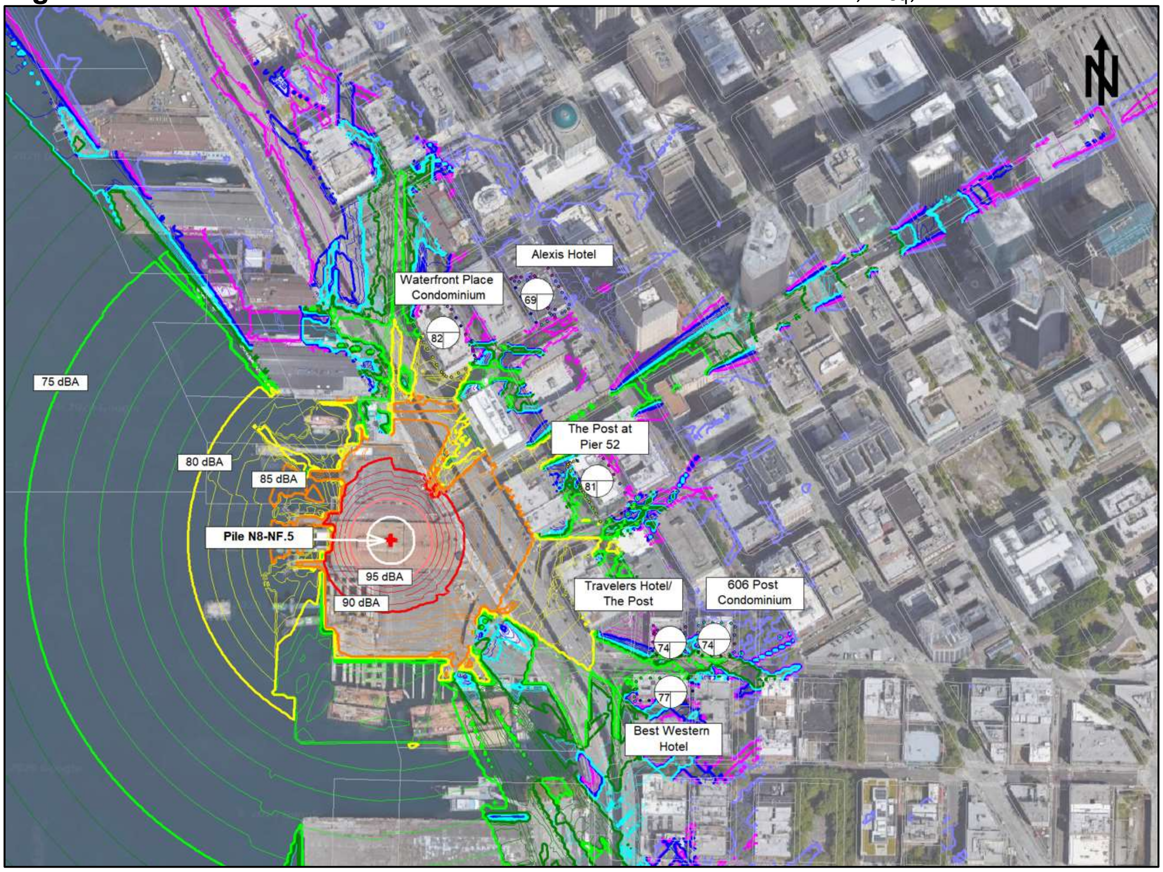
The computer noise model was generated based on pile locations determined from project drawings and sound levels measured during Season 4. Elevation contours and locations and heights of nearby buildings were based on Geographic Information System (GIS) data downloaded from the Seattle Department of Construction and Inspections website.

Predicted sound levels at nearby residential properties are shown in Table 9.1. Sound contours predicted 5-feet (1.5 meters) above grade from pile N8-NF.5 which typically produced the loudest predicted sound levels at nearby properties are shown in Figure 9.1. Predicted sound levels shown in Table 9.1 are the loudest sound levels calculated at the building facades, which may be at different elevations than the sound level contours shown in Figure 9.1.

Table 9.1 Predicted Airborne Sound Levels at Nearby Residential Properties

Property	Predicted 1-Second L_{eq} at Nearby Residential Use Properties, dBA							
	N9.5-NG	N9-NG	N9-NF.7	N9-NF.4	N8-NF.5	N7-NF.5	N6-NG	N6-NF.5
The Post at Pier 52	80	79	78	77	80	80	78	77
Waterfront Place	81	80	79	79	82	81	79	78
Alexis Hotel	73	72	71	71	68	65	63	62
Best Western Plus Pioneer Square Hotel	75	75	73	74	77	76	74	74
606 Post Condominium	72	71	70	70	73	72	70	70
Travelers Hotel the Post Condominium	72	72	70	68	74	73	71	71

Figure 9.1 Predicted Airborne Sound Levels 5-Feet Above Grade, L_{eq}, dBA



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