Acoustic Monitoring Plan

TRIDENT SUPPORT FACILITIES
EXPLOSIVES HANDLING WHARF #1

NAVAL BASE KITSAP at BANGOR
SILVERDALE, WA

June 2012

DEPARTMENT OF THE NAVY

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1.0 INTRODUCTION

Naval Base Kitsap (NBK) at Bangor, Washington provides berthing and support services to U.S. Navy submarines and other fleet assets including the TRIDENT Fleet Ballistic Missile (TRIDENT) program. The Navy began a 2-year construction project (also called, the Pile Replacement Project) to conduct necessary repairs and maintenance on the Explosive Handling Wharf #1 (EHW-1) facility in August 2011. The wharf is a U-shaped concrete structure built in 1977 for ordnance handling operations in support of the Trident Submarine squadron, home ported at NBK at Bangor. The EHW-1's structural integrity is compromised due to deterioration of the wharf's piling sub-structure. The purpose of the project is to maintain the structure integrity of the wharf and ensure its continued functionality to support the operational requirements of the TRIDENT program.

The National Marine Fisheries Service (NMFS) issued an Incidental Harassment Authorization (IHA) under the Marine Mammal Protection Act (MMPA) for in-water repairs conducted in 2011. A second IHA will be issued for work occurring from July 16, 2012 through February 15, 2013. The 2011 IHA required airborne and underwater source level data collection during impact and vibratory pile installation, vibratory pile extraction, and pneumatic chipping (76 FR 30130). Source level and sound propagation data were collected for vibratory pile installation and removal in 2011. No impact pile installation was necessary in 2011 or is planned for the remainder of the project work; therefore, no source level data were or will be collected. In 2011, pneumatic chipping was not conducted; therefore no source level data were collected. However, pneumatic chipping is planned for the July 16, 2012 through February 15, 2013 work period; therefore acoustic monitoring of pneumatic chipping will be conducted.

This Acoustic Monitoring Plan provides a protocol for conducting airborne and hydroacoustic measurements of pneumatic chipping during concrete pile removal. This plan was developed to support the IHA for this project.

2.0 OBJECTIVES OF ACOUSTICAL MONITORING

Airborne and underwater acoustic measurements will be collected during pneumatic chipping operations to empirically verify the modeled behavioral disturbance zones. These zones are also referred to as buffer zones. The behavioral disturbance zones are defined by criteria established by NMFS for marine mammals. See definitions below.

- **Underwater Behavioral Disturbance Zone:** The behavioral disturbance zone includes the area within the 120 dBRMS re 1 µPa isopleth for marine mammals during pneumatic chipping.
- **Airborne Behavioral Disturbance Zone:** The airborne disturbance zone includes the area within the 100 dBRMS re 20 µPa (unweighted) for all pinnipeds except harbor seals, and 90 dBRMS re 20 µPa (unweighted) for harbor seals.

3.0 PROJECT AREA

EHW-1 (Figure 1) is located within the Hood Canal on NBK at Bangor. The entirety of NBK at Bangor, including the land areas and adjacent water areas in Hood Canal, is restricted from general public access (Figure 2). Two Waterfront Restricted Areas (WRAs) are associated with

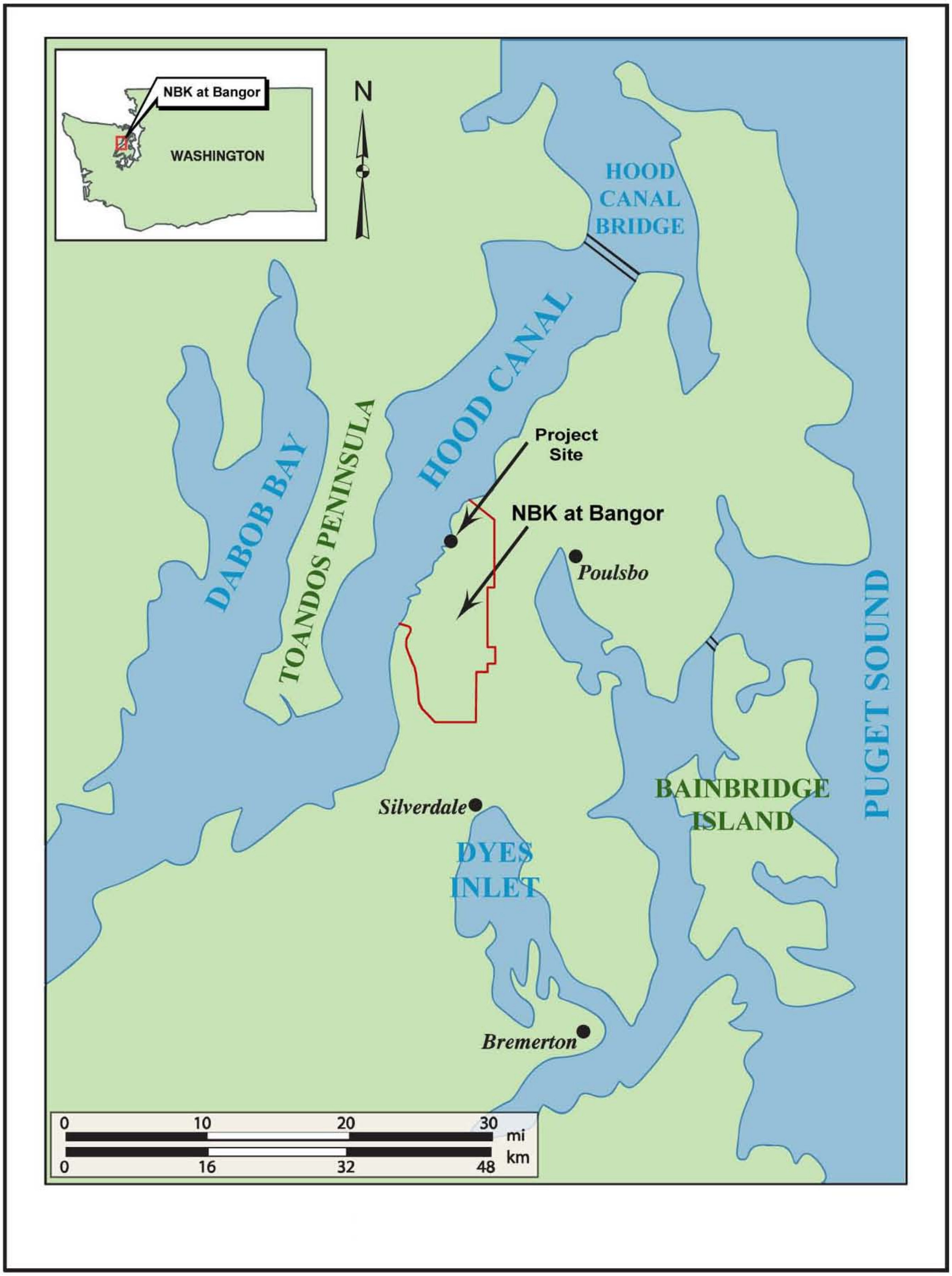

Figure 1. Vicinity Map

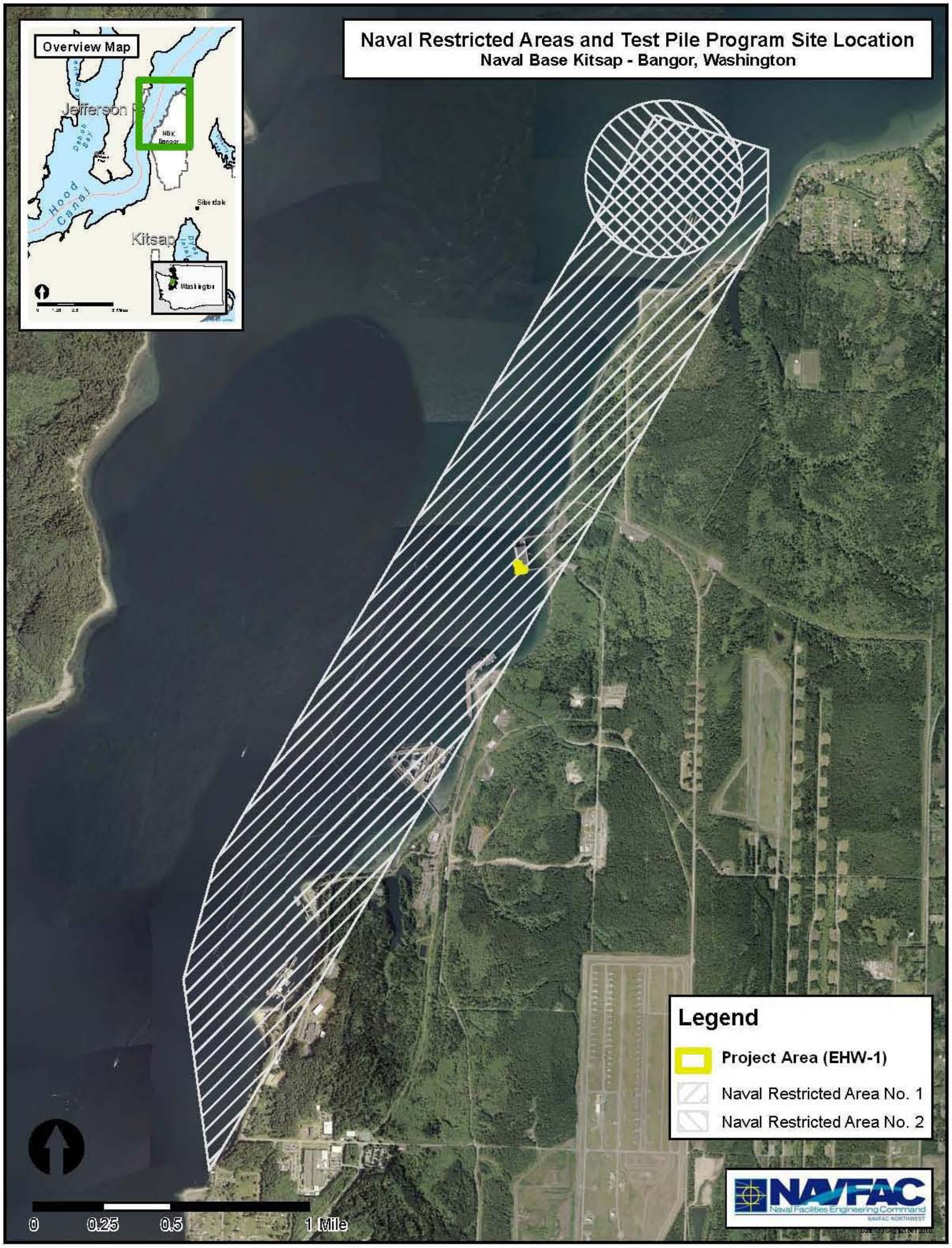

Figure 2. NBK at Bangor Vicinity Map and Waterfront Restricted Areas with Project Area Highlighted

NBK at Bangor: Naval Restricted Areas 1 and 2 (33 CFR 334.1220). Naval Restricted Area 1 covers the area north and south along Hood Canal encompassing the Bangor waterfront. The regulations associated with Naval Restricted Area 1 state that no person or vessel shall enter this area without permission from the Commander, Naval Submarine Base Bangor, or his/her authorized representative. Naval Restricted Area 2 encompasses the waters of Hood Canal within a circle of 1,000 yards diameter. The project area for the EHW-1 is located inside this WRA (Figure 2).

4.0 PNEUMATIC CHIPPING LOCATION

Ninety-six 24-inch hollow pre-cast concrete piles, located at the fragmentation barrier, walkway, Bent 8 outboard support, and Bents 9 and 10 will be removed with a pneumatic chipping hammer (Figure 3). At least five of these piles will be acoustically monitored during removal with a pneumatic chipping hammer.

5.0 ACOUSTIC MONITORING METHODS

SECURITY RESTRICTIONS:

Per security requirements, all vessels outside the WRA will remain outside the WRA for the duration of the monitoring period. Per security requirements, all vessels will be swept and cleared before being allowed to enter the WRA. All equipment will be inspected before being allowed to enter the WRA. Any near-field vessels must remain inside the WRA for the duration of the monitoring period. The vessel(s) will not be allowed to transit in/out of the WRA daily or weekly. In the event a vessel within the WRA needs replacement, the replacement vessel must be swept and cleared by security before entering the WRA.

All personnel associated with the acoustic monitoring will follow the requirements and commands of the Officer in Charge of security for the WRA.

ACOUSTIC MEASUREMENT LOCATIONS:

A hydrophone will be located at approximately 10 meters from the outer edge of each monitored pile. A microphone will be located to measure near-field airborne noise levels. Variation to these positions may occur due to logistical or security constraints, or based on the best professional judgment of the acoustics contractor in order to utilize the best positions to obtain the necessary data. Hydrophones, microphone, and recording systems will be checked daily, or for each deployment to ensure proper operation.

HYDROPHONES AND MICROPHONE:

Underwater hydrophones and airborne microphone will be used as outlined below. All sensors, signal conditioning equipment, and sampling equipment will be calibrated at the start of the monitoring period to National Institute of Standards and Technology (NIST) standards and will be re-checked at the start of each day.

A stationary 2-channel hydrophone recording system will be deployed to record a representative sample (subset of piles) during the monitoring period. A minimum of 5 concrete piles will be

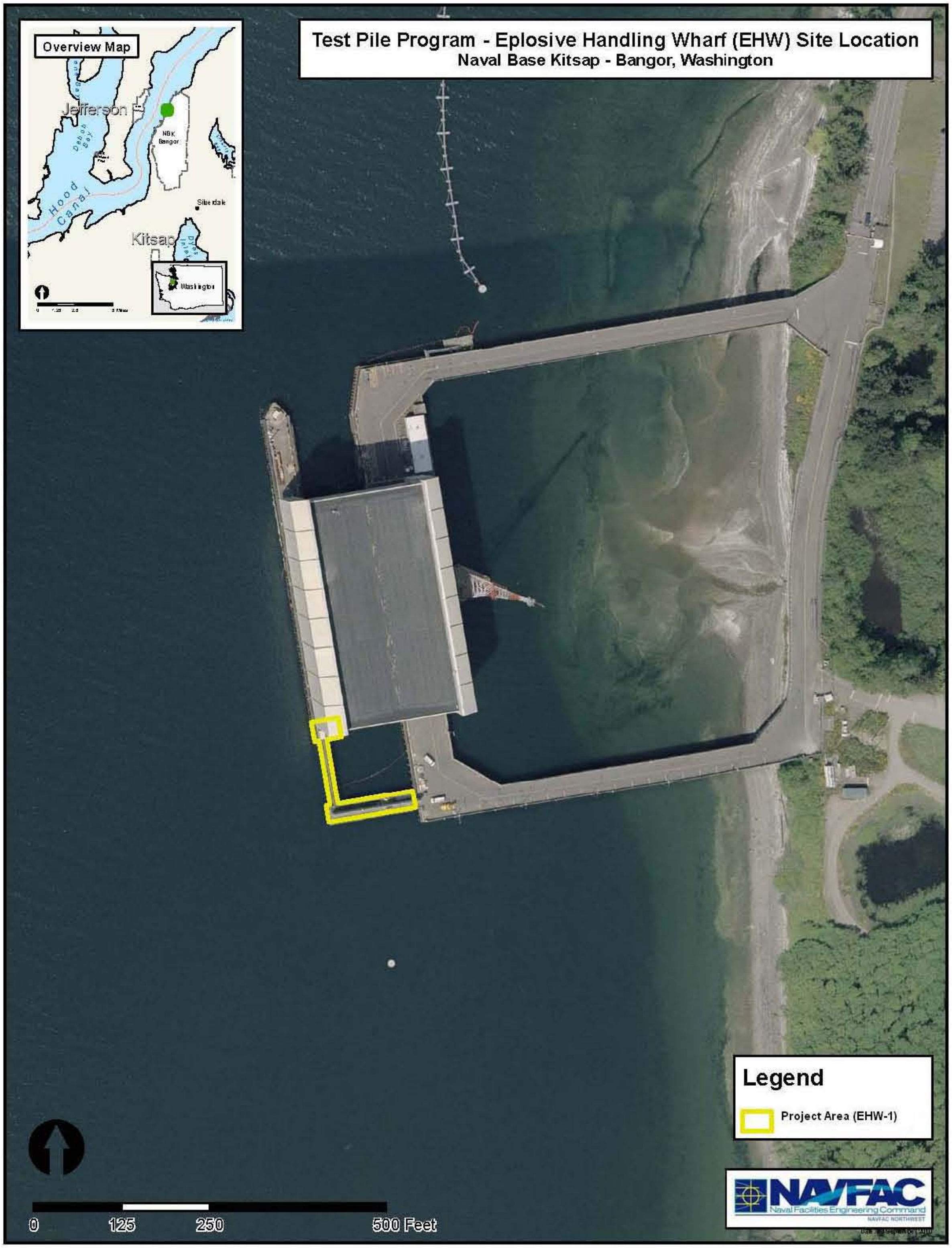

Figure 3. Project Area

monitored. The hydrophones will provide a continuous recording of the pile being chipped. The data will be analyzed after completion of the acoustic monitoring of pneumatic chipping.

a. Prior to monitoring, water depth measurements will be made to ensure that when taking tidal changes into consideration hydrophones will not drag on the bottom. One hydrophone will be placed at approximately mid-depth and the other at a position closer to the bottom (70-85% of the water depth) (see Appendix A, NMFS 2012 Guidance Document: Data Collection Methods to Characterize Impact and Vibratory Pile Driving Source Levels Relevant to Marine Mammals). Because the hydrophones may be supported from a floating platform (i.e., barge), the depth with respect to the bottom may vary due to tidal changes and current effects.

b. The hydrophone systems will be deployed so as to maintain a constant distance of approximately 10 meters from the pile.

c. The hydrophones, signal conditioning, and recording equipment will be configured to acquire maximum source levels without clipping recorded data. Hydrophone calibration will be checked at the beginning of each day of monitoring.

1. Appropriate measures will be taken to eliminate strumming of the hydroacoustic cable in the current and minimize flow noise over the hydrophones. There will be a direct line of acoustic transmission through the water column between the pile and the hydrophones in all cases, without any interposing structures, including other piles. At least one stationary land-based microphone will be deployed to record airborne sound levels produced during pneumatic chipping. The microphone will measure far-field airborne sounds. A sound level meter with microphone will be located in the near-field if logistical and security constraints permit to make near-field source level measurements. Near-field measurements will not be continuous and will be used to identify which sources of noise are making significant contributions to the overall noise levels measured at the shoreline microphones. Specific locations will be determined by ease of access (terrain restrictions and presence of a road) and security permission. The microphone will be calibrated at the beginning of each day of monitoring activity.

MEASURES TO MEET OBJECTIVES

1. Empirically verify the modeled behavioral disturbance zones.

a. Underwater and airborne acoustic monitoring will occur for 5 concrete piles during the duration of pneumatic chipping. If a representative sample has not been achieved after the 5 piles have been monitored, acoustic monitoring will continue until a representative acoustic sample has been collected.

b. Underwater and airborne sound pressure levels will be recorded continuously during pneumatic chipping. Data will be downloaded periodically (i.e., daily or on another appropriate schedule) and will be analyzed after the completion of the acoustic monitoring period for this project.

c. Underwater noise will be referenced to 1 micro Pascal, and airborne noise will be referenced to 20 micro Pascals.

d. All sensors will have a current calibration traceable to NIST standards. Calibration factors for all sensors will be logged.

e. Monitoring equipment will be set to a minimum frequency range of 10 Hz[1] to 20 kHz and a minimum sampling rate of 44 kHz. To facilitate further analysis of data, the underwater signal will be recorded as a text file (.txt) or other compatible data format (e.g., .xls or .csv). Recorded time-series may be recorded using commercial audio formats (e.g., .wav) and will not be compressed during recording.

f. Underwater acoustic measurements will be coordinated with the monitoring coordinator and construction contractor to be certain that the acousticians are aware of when pneumatic chipping will be initiated and when it is completed. This is especially important because work will occur underwater. Coordination will be with radios, cell phones, and/or flags for near-field measurements.

g. Another vessel proposed to deploy a 2-channel hydrophone array may be positioned to collect data on the far-field sound levels (the 120 dBRMS zone) for pneumatic chipping. This vessel will generally remain at this location while recording sound levels. If this additional vessel is used, data from this hydrophone array will be used to estimate spreading loss and extrapolate out to the 120 dB RMS isopleths in the event that this sound pressure level occurs beyond where this vessel is stationed.

h. Post-analysis of underwater sound level signals will include the following:

    i. RMS values (average, standard deviation/error, minimum, and maximum) for each recorded pile. The 10 second RMS averaged values will be used for determining the source value and extent of the 120 dB underwater isopleth.

    ii. Frequency spectra will be provided for each functional hearing group (low-frequency cetaceans, mid-frequency cetaceans, high frequency cetaceans, and pinnipeds as outlined in NMFS 2012 Guidance Document: Data Collection Methods to Characterize Impact and Vibratory Pile Driving Source Levels Relevant to Marine Mammals (Appendix A) for representative pneumatic chipping.

    iii. All underwater source levels will be standardized to a reference distance of 10 meters (33 feet).

i. Post-analysis of airborne noise will be presented in an unweighted format, and will include:

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[1] 10 Hz is slightly higher than the 7 Hz guidance provided by NMFS for low frequency cetaceans. This deviation is provided because there is a reasonable chance the equipment used will not allow capture and accurate analysis to 7 Hz. Since the dominant frequency for vibratory driving is around 25 Hz (Burgess and Blackwell 2003), the Navy expects frequencies below 10 Hz would not influence the overall sound levels.

i. The unweighted RMS values (average, minimum, and maximum) for each recorded pile. The average values will be used for determining the extent of the airborne isopleths relative to species specific criteria.

ii. Frequency spectra will be provided from 10 Hz to 20 kHz provided for representative pneumatic chipping.

iii. All airborne source levels will be standardized to a reference distance of approximately 15 meters (50 feet).

ADDITIONAL CONSIDERATIONS:

Timing and Consolidation of Testing Objectives:

The acoustic team and species monitoring teams will work cooperatively to identify and monitor the disturbance zone specified in this plan.

Baseline Environmental and Construction Equipment Data:

Prior to and during the pile driving activity, environmental data will be gathered, such as water depth, wave height, weather conditions, and other factors that could contribute to influencing the underwater sound levels (e.g., aircraft, boats). Start and stop time of each pneumatic chipping event will be recorded. Pneumatic chipping data will be compared to ambient data. Unweighted airborne and underwater ambient data was collected in 2011 from hydrophones placed on a raft near the Toandos peninsula. Data was collected continuously during daylight hours only. Ambient sound levels were determined by utilizing samples from periods where no pile driving/in-water construction activities was occurring. These data were processed in the same manner as the vibratory pile installation signals since they were both non-pulse sounds. Recording were made from 10 Hz to 20 kHz range using a standard sampling frequency of 44 kHz.

Additional ambient data will be recorded in 2012 during construction of an adjacent project (Explosive Handling Wharf-2). Data will be compared to data from 2011. Data collected in 2012 will utilize the methodology outlined and approved by NMFS in the EHW-2 Acoustic Monitoring Plan. Background data will be reported as the dB rms level that occurs at least 50% of the time (50^{th} percentile or 50% cumulative distribution function [CDF]).

The construction contractor will supply the acoustics specialist with the substrate composition, chipping hammer model and size, hammer energy settings, and any changes to those settings during chipping hammer operation.

Equipment:

Table 1 provides examples of the type of equipment that may be used to monitor underwater and airborne sound pressure levels. All applicable equipment will have NIST traceable calibration.

6.0 SIGNAL PROCESSING

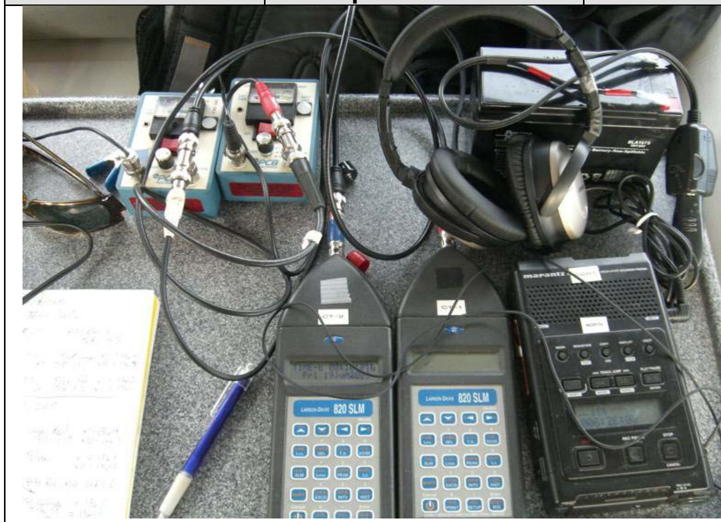
Post-analysis of the recorded time-series signals will include the following for each recorded pile: RMS value, mean and standard deviation/error of the RMS, duration of each chipping event measured, and a frequency spectrum for each species group for representative piles.

Table 1. Examples of Equipment Used in Acoustic Sound Monitoring

Item	Specifications	Description	Usage
Hydrophone with 35 to 100 feet of cable	Reson Model TC-4013 with Receiving Sensitivity-211dB ±3dB re 1V/µPa or Reson Model TC-4033 with –Sensitivity 203 dB re V/µPa	 TC-4013  TC-4033	Capture underwater sound pressures and convert to voltages that can be recorded/analyzed by other equipment.
Signal Conditioning Amplifier	PCB Model 422E13 charge converter Amplifier Gain- 0.1 mV/pC to 10 V/pC Transducer Sensitivity Range- 10^{-12} to 10^{3} C/MU		Adjust signals from hydrophone to levels compatible with recording equipment.
Multi-gain signal conditioner	PCB Model 480M122 battery-powered signal conditioning (multi-gain)		

Item	Specifications	Description		Usage
Portable Digital Audio Recorder (2-channel)	Sampling Rate- 44K Hz or greater		Several models available with similar specifications	Records audio signals received by hydrophone.
SLM Battery Power	9-volt batteries	9-volt small batteries (e.g., Duracell)		Provides power to Multi-gain signal conditioner (3 each) and SLM (1 each).
Digital Audio Recorder Battery power	12-volt gel-cell battery 2.5 to 25 amp-hour	12-volt portable battery		Provides power to digital audio recorders.
Digital Audio Recorder Battery power	2.5-volt batteries	Provides internal battery to digital audio recorders		Internal battery
Weather-proof enclosure	Pelican case to protect from water and weather	Pelican case approximately 20-inches L x 18 inches W, 8 inches D		Houses underwater data acquisition, storage and power equipment.
Microphone (free field type)	Range- 30 – 120 dBA Sensitivity- -29 dB ± 3 dB (0 dB = 1 V/Pa)	Connected to Sound Level Meter		Monitoring airborne sounds from pile driving activities (if not raining).
ANSI Type 1 Sound Level Meter or Laptop computer	Compatible with digital analyzer	Equipped with ½-inch diameter microphone described above		Measures received acoustic signals and outputs analog audio signal to digital audio recorder.

Item	Specifications	Description	Usage
Calibrator (pistonphone-type)	Accuracy- IEC 942 (1988) Class 1		Calibration check of hydrophone and microphone in the field. Includes hydrophone and microphone calibrator coupler.
Weighted line/chain marked in 5-foot increments to attach hydrophone and anchoring weights	-		Takes the strain off of the hydrophone cables preventing damage.
Various surface floats	Buoys and raft for each unattended measurement position		To keep the hydrophone at the appropriate position. Raft is attached to anchored buoy and equipped with hydrophone kit.

Item	Specifications	Description	Usage
			
2-channel system showing SLMs, Multi-gain amplifiers, 12-volt battery and headphones		Hydrophones used to measure underwater sounds	

7.0 ANALYSIS

Analysis of the data from the San Francisco-Oakland Bay Bridge Pile Driving Demonstration project indicated that 90 percent of the acoustic energy for most pile driving impulses occurred over a 50- to 100-millisecond period with most of the energy concentrated in the first 30 to 50 milliseconds (Illingworth and Rodkin, Inc. 2001). The RMS values for continuous sound sources (i.e., pneumatic chipping and ambient) will be calculated for sound levels measured in10-second durations over the duration of the event; the final RMS value for the event will be the average of all 10-second RMS sound levels. Units of underwater sound pressure levels will be dB re 1 -μPa.

8.0 REPORTING

A draft report will be submitted by the Navy to the NMFS within 90 work days of the completion of hydroacoustic monitoring. The results will be summarized in graphical form and include summary statistics and time histories of pneumatic chipping sound values for each pile measured. A final report will be prepared and submitted by the Navy to the NMFS within 30 work days following receipt of comments on the draft report from the regulatory agencies. The Navy will contact NMFS immediately should any unexpected circumstances occur during construction which require the consultation of the regulatory agencies for guidance.

The final report will include the following information for all monitored piles:

- Size and type of piles.
- The chipping hammer energy rating, make and model of the hammer used to extract the piles.
- Description of the sound monitoring equipment.
- Distance between hydrophones and pile.
- Depth of the hydrophones and depth of the water at hydrophone locations.
- Distance from the pile to the water's edge.
- Depth of water in which the pile was extracted.
- Duration of pneumatic chipping during each monitored day.
- Results of the hydroacoustic monitoring, including the frequency spectrum, ranges and means including standard deviation/error for RMS SPLs.
- The distance at which the RMS values reach the 120 dB rms threshold and background sound levels.
- Pneumatic chipping monitoring results, which will include the maximum and overall average RMS calculated for each monitored pile.
- Description of any observable marine mammal, fish, or bird behavior in the immediate area and, if possible, correlation to underwater sound levels occurring at that time.

- Comparison of modeled and field results.

9.0 REFERENCES

Illingworth & Rodkin, Inc. 2001. Final Data Report: Noise and Vibration Measurements Associated with the Pile Demonstration Project for the San Francisco-Oakland Bay Bridge East Span. August 2001.

Burgess, W.C., and S.B. Blackwell. 2003. Acoustic monitoring of barrier wall installation at the former Rhoˆne-Poulence Site, Tukwila, Washington. Prepared for RCI Environmental, Inc. Greeneridge Report 290-, revised 6 March 2003.

APPENDIX A

GUIDANCE DOCUMENT: DATA COLLECTION METHODS TO CHARACTERIZE IMPACT AND VIBRATORY PILE DRIVING SOURCE LEVELS RELEVANT TO MARINE MAMMALS

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UNITED STATES DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL MARINE FISHERIES SERVICE
Northwest Region
7600 Sand Point Way NE
Seattle, Washington 98115

Memorandum

To: Interested Parties

From: NMFS Northwest Region and Northwest Fisheries Science Center

Subject: Guidance Document: Data Collection Methods to Characterize Impact and Vibratory Pile Driving Source Levels Relevant to Marine Mammals

Date: January 31, 2012

Objectives: Provide guidance to characterize underwater pile driving source levels relevant to marine mammals.

Scope: This guidance is applicable to pile driving activities in the Northwest Region, specifically for use in marine mammal consultations and permit applications, pursuant to the Endangered Species Act (ESA) and the Marine Mammal Protection Act (MMPA). These measurements should take into account spectral, spatial, temporal and sample size considerations, as specified below. Equipment considerations and guidance on data processing are also provided.

Guidance:

Spectral considerations

For purposes of characterizing pile driving source levels relevant to marine mammals, analysis of collected data should eliminate frequencies below the range of functional hearing of marine mammals (described in Southall et al. 2007). The list below identifies common species that occur in inland waters of Washington State by functional hearing group.

Common marine mammal species that occur in inland waters of Washington State:

- Low-frequency cetaceans: humpback, gray and minke whales
- Mid-frequency cetaceans: killer whales (resident and transient)
- High-frequency cetaceans: harbor and Dall's porpoises
- Pinnipeds: Steller and California sea lions, harbor seals, and northern elephant seals

For pile driving, the majority of the acoustic energy is confined to frequencies below 2 kHz (Reinhall and Dahl 2011), whereas above 20 kHz there is very little acoustic energy from either impact or vibratory pile driving (as documented below in Appendix A), and between these two bounds there exists a small but largely negligible contribution. Therefore, 20 kHz provides a robust high-frequency limit (f-high) for measuring all pile driving source levels, whereas the low-frequency limit (f-low) should be defined by the estimated auditory bandwidth for each functional hearing group (Table 1).

There should be no attenuation in the band between f-low and f-high for the appropriate functional hearing groups listed in Table 1. The roll-off below f-low and above f-high should be as steep as possible and at a rate of at least -40 dB/decade (a decade is a factor of 10 in frequency) after f-low and f-high.

Table 1. F-low and f-high limits for characterizing underwater background sound relevant to marine mammals.

Functional hearing Group[1]	f-low[2]	f-high[3]
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

[1] See the above list of common species that occur in nearshore waters of Washington and Oregon, which identifies species to functional hearing groups. All genera represented in each functional hearing group are specified in Southall et al. 2007.
[2] F-low values of estimated auditory bandwidths in Southall et al. 2007.
[3] As documented in the Appendix A below.

Spatial considerations

A measurement range of 10 m from the pile driving activity is consistent with established practice, and there is certain value in continuing with this practice as results are readily comparable with past measurements. However, if the primary intent of this measurement is to serve as a close-range datum with which to estimate sound pressure at much longer ranges through use of propagation modeling, then the range for this close-range datum should be not less than 3 H, where H is water depth. This range will provide a more accurate estimate at longer ranges; physical reasons for this are discussed in Reinhall and Dahl (2011). The measurement depth should be 70-85% of H to provide the most consistent results (Appendix B).

Temporal considerations

Measurements should be collected during active pile driving. Measure the whole pile-driving event, but during data analysis only characterize the periods of maximum hammer energy. Maximum hammer energy is characterized by removing starts (ramp up of hammer energy) and stops (ramp down of hammer energy) from data being analyzed. Also, remove data collected during sound attenuation and transition periods associated with sound attenuation. For example, if a bubble curtain is used, remove data when bubbles are first turned on and after they become fully effective, as well as periods when bubbles are turned off and bubbles have not completely been removed from the water column. Bubbles can remain in the water column after the bubble curtain has been turned off at the source and therefore will interfere with source measurements up to ~one minute after the bubble curtain is turned off (Coleman 2011). Data collected during sound attenuation (i.e., when bubbles are fully effective) can be analyzed separately to determine the effectiveness of attenuation methods.

Sample size considerations

Characterize a representative number of pile driving events for each project. One whole pile driving event is characterized as one sample. Vibratory pile driving events should be considered separately from impact pile driving events. Where possible, it is beneficial to have repeat sampling for each of the following considerations: pile size (diameter) and type (e.g., wood, concrete, steel), which are likely to have greatest influence on source level (Carlson 2007). Other considerations also likely to affect source levels include bathymetry, substrate type, distance from shore, water depth, and hammer energy. Record and report these variables. Repeated sampling will help characterize variability.

Data processing

For each functional hearing group, measurements should be reported in overall SPL across the entire frequency band (referred to as "broad band SPL", and defined as the decibel equivalent of the rms pressure within the frequency band, referenced to 1 μPa). Different data processing is required to characterize source levels for vibratory pile driving than for impact driving. For vibratory pile driving, characterize overall dBrms levels by taking 10 sec averages across the whole event and averaging all the 10 sec periods. Averaging 10 sec periods will likely capture the variation in sound levels over the pile-driving event. For impact pile driving, characterize overall dBrms levels by integrating sound for each waveform across 90% of the acoustic energy in each wave (using the 5-95 percentiles to establish the 90% criterion) and averaging across all waves in the pile-driving event (i.e., as demonstrated in Figure 1 of Madsen et al. 2006).

Equipment considerations

The recording system must be capable of recording the minimum bandwidth required per above frequency considerations (Table 1). Receiving sensitivities should be sufficient to measure very high acoustic pressures. This device will have different receiving sensitivity than the device used for background sound monitoring (NMFS 2011). For close-range (~10 m) measurements, it can be expected that peak pressures can reach as high as 10^5 Pa, which is equivalent to 220 dB re: 1 μPa. Therefore, document that hydrophone sensitivities and associated electronic recording networks (e.g., amplifier gains, digital recording ranges) are able to measure this large signal without distortion.

Applicability to other areas

Pile size and type are probably the most important factors affecting sound levels from pile driving, whereas wetted depth (a typical surrogate for water depth) is not very predictive of sound levels (Carlson 2007). Therefore, when data cannot be collected and you must instead estimate a source level for use in consultation or permit application, the best surrogate will have the following characteristics in common with the proposed project: pile size and type (most important), as well as bottom substrate, water depth and hammer energy.

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NMFS. 2011. Guidance Document: Data Collection Methods to Characterize Underwater Background Sound Relevant to Marine Mammals in Coastal Nearshore Waters and Rivers of Washington and Oregon. Memorandum from NMFS Northwest Region and Northwest Fisheries Science Center to Interested Parties.

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

Acknowledgements

This guidance was developed collaboratively by the NMFS (Alison Agness, Shane Guan, and Drs. Marla Holt and Amy Scholik-Schlomer), Washington Department of Transportation (Marion Carey, Jim Laughlin and Rick Huey), University of Washington (Dr. Peter Dahl), and Beamreach (Dr. Scott Veirs).

Appendix A.

Dr. Peter H. Dahl, University of Washington

Fig. A1 shows the energy spectral density from both impact and vibratory pile driving, integrated over frequency in a cumulative manner and normalized to give a cumulative distribution function (CDF) over frequency. Such a CDF function asymptotes to 1 or 100%, and the plots indicate that the majority of the energy from both impact and vibratory pile driving is confined to frequencies less than about 2 kHz, as the CDF is approaching 1 at this frequency. The vibratory pile driving data are from the study conducted at the Port Townsend Ferry terminal in October 2010 (Stockham et al. 2011, Laughlin, 2010), and the impact pile driving data are from a re-evaluation of results from Reinhall and Dahl (2012); in this case a depth- averaged energy spectral density is used to compute the CDF. It is evident that for both impact and vibratory pile driving that an upper frequency of 20 kHz is entirely sufficient to adequately characterize the frequency distribution.

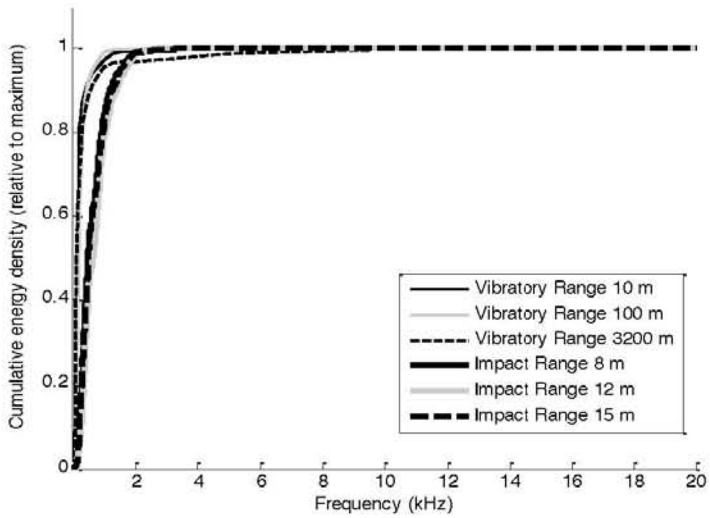

Fig. A1: Cumulative energy relative to maximum based on integration of a energy spectral density for vibratory pile driving from the Port Townsend experiment and impact pile driving from the Vashon Island experiment.

References

Reinhall, P.G., and P. H. Dahl. 2011. Underwater Mach wave radiation from impact pile driving: theory and observation. Journal of the Acoustical Society of America 130: 1209-1216.

Stockham, M.L., P.H. Dahl, and P.G. Reinhall. 2011 Underwater Sound Measurements During Vibratory Pile Driving at Port Townsend, WA.

Appendix B.

Dr. Peter H. Dahl, University of Washington

For purposes of obtaining a measure of pressure near the source of both impact and vibratory pile driving, deploy the hydrophone at a depth representing 0.70 H to 0.85 H, where H is the water depth. Close range measurements are typically made at nominal range of 10 m, however if the primary intent of this measurement is to estimate pressure at long range then the close-range measurement should be at ranges not less than 3 H.

Fig. B1 shows computed peak pressure from impact pile driving for several different combinations of hydrophone depth and hydrophone range. The actual values for peak pressure are consistent with measured results given in Reinhall and Dahl (2011). The combinations are scaled according to depth of hydrophone (D) divided by water depth (H), as shown in the legend, and by range of hydrophone from the pile divided by D as identified in the x-axis. Thus, for example, D/H = 1 represents a series of hypothetical measurements with the hydrophone on the bottom, and D/H = 0.5 represents similar set of measurements with hydrophone at mid-depth.

It is clear from the figure that pressures represented by D/H = 1 are always greater than D/H = 0.5, with this situation being in effect out to ranges of nearly 4 water depths. This is consistent with Reinhall and Dahl (2011) where it is shown that the maximum pressure occurs near the bottom for relatively close ranges on the scale of the water depth. Furthermore, a more representative average "peak pressure" is obtained by averaging from mid-water to the bottom. This is shown in Fig. B1 by the line consisting of symbols.

For the analyst who will make a measurement at just *one* depth, what is the depth that best represents this average? From Fig. B1, this depth is 0.85 times the water depth H. However, changing the water depth H will change this value to a small degree and simulations similar to that shown in Fig. B1 involving a range of expected pile driving water depths from 6 – 13 m suggest a guidance of 0.7 H to 0.85 H provides reasonably consistent values of peak pressure.

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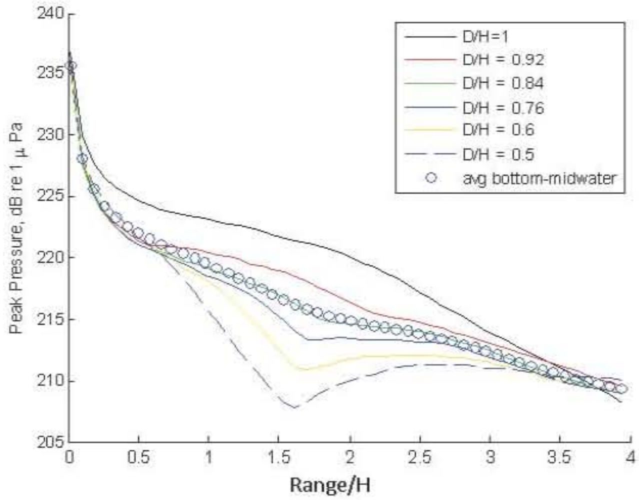

Fig. B1: Peak acoustic pressure as a function of range scaled by water depth (H), and as a function of measurement depth (D) scaled by H. The line of symbols represents an average from mid-water to bottom.

References

Reinhall, P.G., and P. H. Dahl. 2011. Underwater Mach wave radiation from impact pile driving: theory and observation. Journal of the Acoustical Society of America 130: 1209-1216.