Mukilteo Multimodal Project – Phase 2
UNDERWATER NOISE MONITORING PLAN

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INTRODUCTION

The Washington State Ferries (WSF) proposes to construct the new Mukilteo Multimodal ferry terminal in Phase II and completely remove the existing berthing structures at the existing Mukilteo Ferry Terminal. Construction activities will consist of earthwork, retaining wall construction, soil contamination remediation, surveying, installing signals at two intersections, roadway construction, utility work, the construction of berthing structures, an overhead walkway and a terminal building. The work includes permanent landscaping and architectural elements, constructing all four of the planned toll booths, constructing seven of the planned holding lanes, constructing a transit station, the installation of the supervisor's office, and a fishing pier.

The two types of piles proposed for this project that will be driven with an impact hammer include 30-inch diameter steel pipe as part of the trestle, dolphins, and part of the terminal building and a 24-inch steel pipe pile used to support a temporary pier access, construct wingwalls, and construct the public fishing pier.

The steel pipe pile will be driven with a vibratory hammer, and then proofed with an impact hammer.

No un-attenuated pile strikes will be allowed during the installation of the steel pipe piles.

PROJECT AREA

The new Mukilteo Multimodal Terminal will be located east of the existing Mukilteo terminal. See vicinity maps shown in Figure 1 and Figure 2.

Figure 1. Vicinity map of Mukilteo Multimodal Terminal Project.

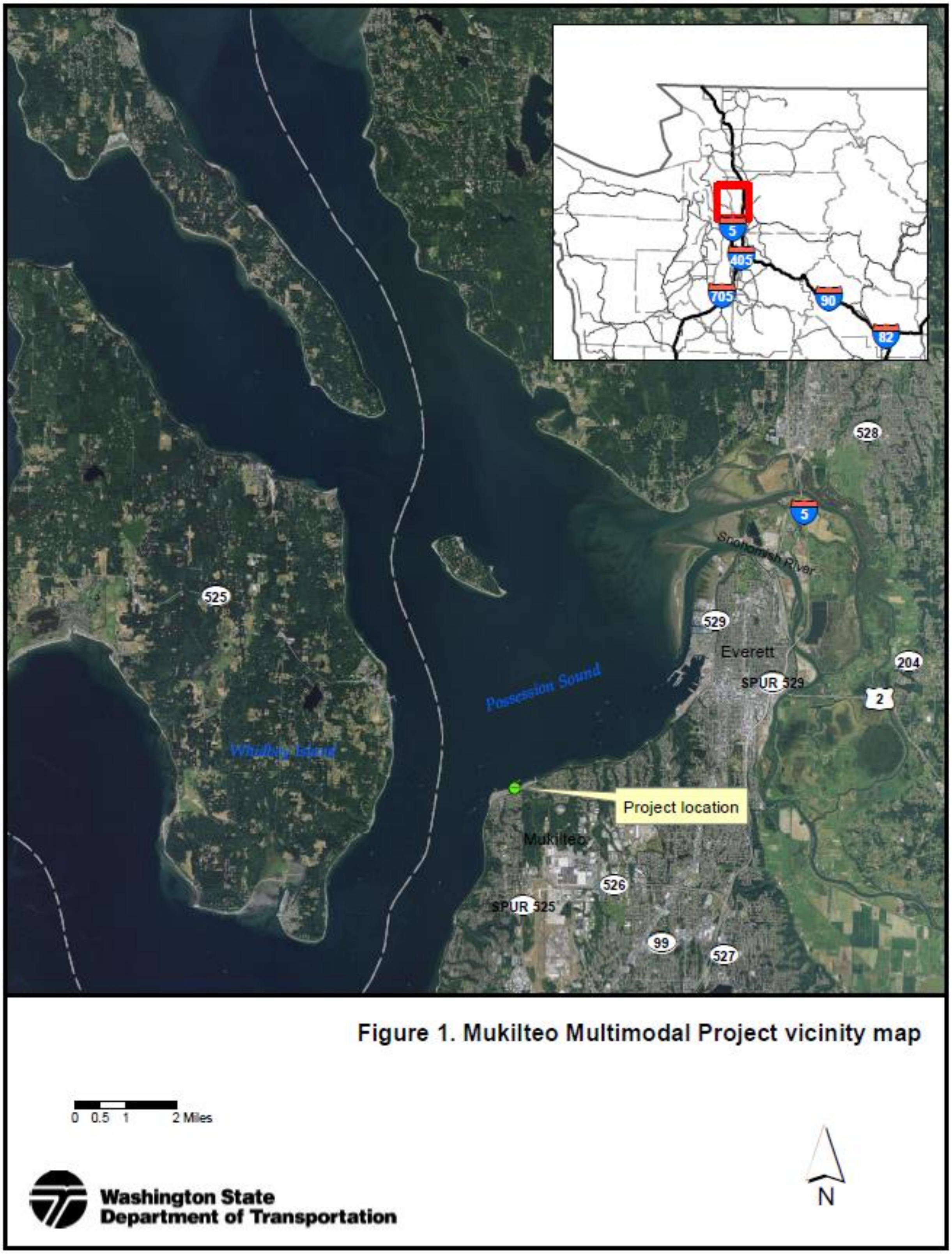
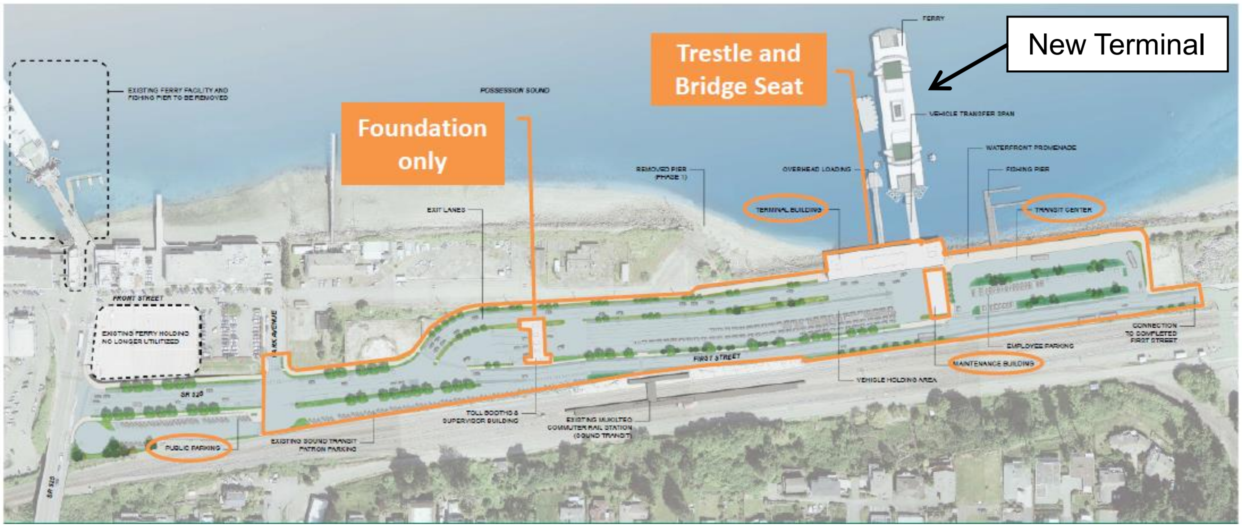


Figure 2. Location of new Mukilteo Multimodal Terminal.



PERMIT/ESA CONDITIONS

Please refer to the USFWS and NMFS Biological Opinion for permit and ESA conditions for this project.

PILE INSTALLATION LOCATION

Figure 3 indicates the location of the Mukilteo Multimodal Phase 2 piles to be installed. There will be two 24-inch diameter pipe piles and three 30-inch diameter pipe piles.

Figure 3. Approximate location of piles to be impact driven for the Seattle Trestle Test Pile Project (yellow) and the approximate location of the hydrophones (stars).

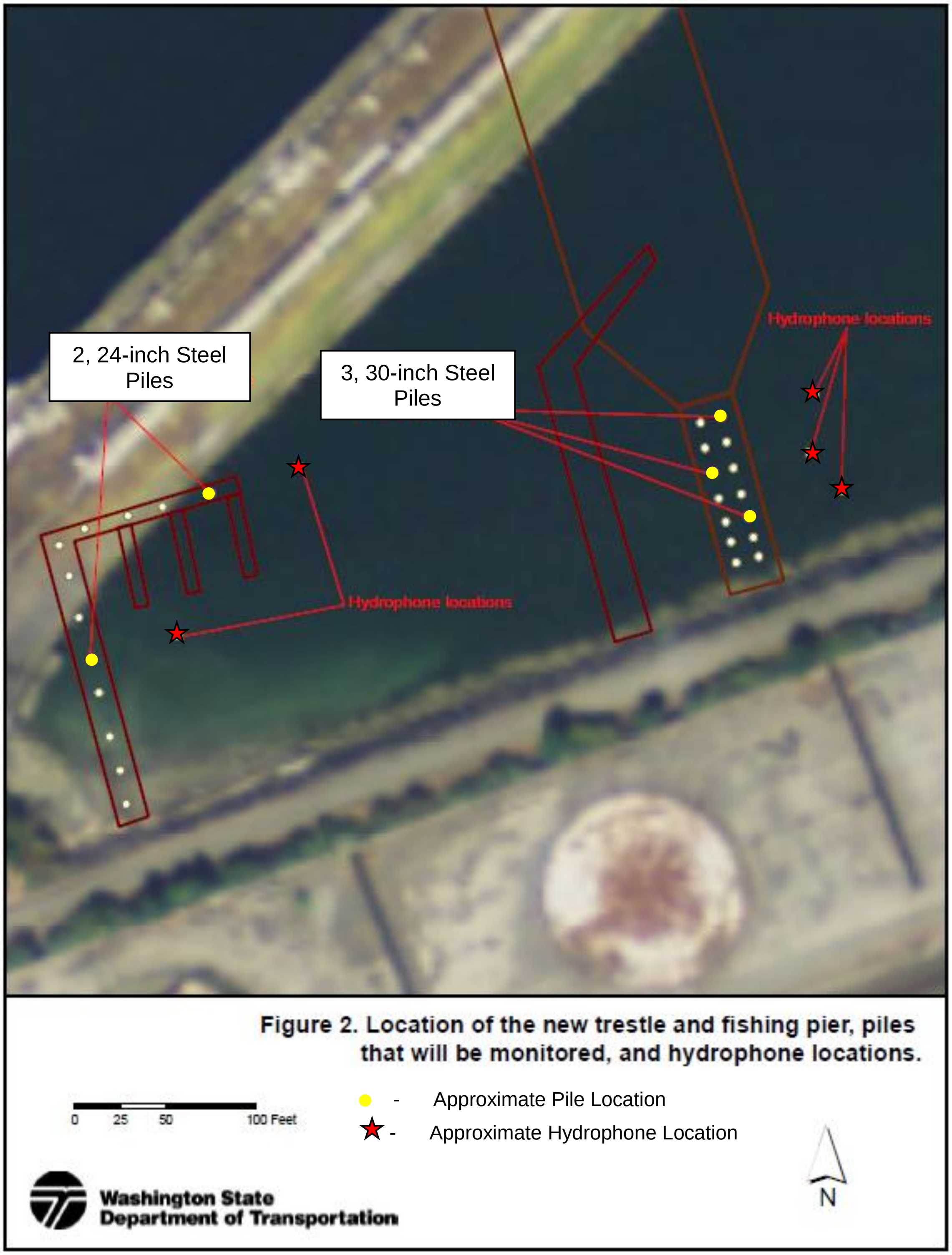


Figure 2. Location of the new trestle and fishing pier, piles that will be monitored, and hydrophone locations.

PILE INSTALLATION

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Hydroacoustic monitoring will be conducted for two 24-inch steel piles and three 30-inch steel piles during impact driving. Hydroacoustic monitoring of the piles during impact driving will include:

- Monitoring 5 steel piles at 10 meters range and if appropriate at 3H range where H is the water depth at the pile including two of the 24-inch steel piles and three of the 30-inch steel piles.
- Airborne monitoring of the impact driving of the piles.

Figure 3 indicates the location of the piles to be monitored and the approximate hydrophone locations for each pile being monitored. All hydrophones will be placed at least 1 m (3.3 feet) below the surface. One hydrophone will be placed at a distance of 10 meters from the hydrophone being monitored at mid-water depth. If appropriate a second hydrophone will be placed at a distance of 3H where H is the water depth at the pile being monitored and at a depth of 0.8 percent of the water depth at 3H. Hydrophones will be located with a clear acoustic line-of-sight between the pile and the hydrophone.

Table 1 lists the piles to be installed, the approximate water depth, and the number and size of piles that will be installed. Table 2 lists the equipment specifications that will be used during monitoring.

Table 1
Water Depth and Number Piles to be Monitored

Structure	Approximate Water Depth (ft)	Number and Size of Piles
Trestle and Terminal building	18	(3) 30-inch steel piles
Temporary Access Pier	18	(2) 24-inch steel piles

Table 2

Equipment for underwater sound monitoring (hydrophone, signal amplifier, and calibrator). All have current National Institute of Standards and Technology (NIST) traceable calibration.

Item	Specifications	Minimum Quantity	Usage
Hydrophone	Receiving Sensitivity- -211dB re 1V/µPa	1	Capture underwater sound pressures near the source and convert to voltages that can be recorded/analyzed by other equipment.

Item	Specifications	Minimum Quantity	Usage
Signal Conditioning Amplifier	Amplifier Gain- 0.1 mV/pC to 10 V/pC Transducer Sensitivity Range- 10-12 to 103 C/MU	1	Adjust signals from hydrophone to levels compatible with recording equipment.
Calibrator (pistonphone-type)	Accuracy- IEC 942 (1988) Class 1	1	Calibration check of hydrophone in the field.
Digital Signal Analyzer	Sampling Rate- 48kHz or greater	1	Analyzes and transfers digital data to laptop hard drive.
Laptop computer or Digital Audio Recorder	Compatible with digital signal analyzer	1	Record digital data on hard drive or digital tape.
Real Time and Post-analysis software	-	1	Monitor real-time signal and post-analysis of sound signals.
Airborne Noise Meter (free field type 1)	Range- 30 – 120 dBA Sensitivity- -29 dB ± 3 dB (0 dB = 1 V/Pa)	1	Monitor airborne sound levels for possible human impacts (if not raining)

To facilitate further analysis of data full bandwidth, time-series underwater signal shall be recorded as a text file (.txt) or wave file (.wav) or similar format. Recorded data shall not use data compression algorithms or technologies (e.g. MP3, compressed .wav, etc.).

METHODOLOGY

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Up to two hydrophones will be placed, one at midwater depth at a distance of 10 meters and if applicable a second at a distance of 3H, where H is the water depth at the pile and a depth of 0.8 of the water depth at 3H from each pile being monitored. A weighted tape measure will be used to determine the depth of the water. The hydrophones will be attached to a nylon cord. The nylon cord will be attached to an anchor that will keep the line the appropriate distance from each pile. The nylon cord or chain will be attached to a float or tied to a static line at the surface. The distances will be measured by a tape measure, where possible, or a range-finder. The acoustic path (line of sight) between the pile and the hydrophones will be unobstructed in all cases.

The hydrophone calibration will be checked at the beginning of each day of monitoring activity. The monitoring software (RTPro, v7.1) is used in combination with the Pistonphone calibrator to determine the correction factor for each hydrophone. The hydrophone correction factor must be less than 0.2 dB to be acceptable. Prior to the initiation of pile driving, the hydrophone will be placed at the appropriate distance and depth as described above.

The onsite inspector/contractor will inform the acoustics specialist when pile driving is about to start to ensure that the monitoring equipment is operational. Underwater sound levels will be continuously monitored during the entire duration of each pile being driven with a minimum one-third octave band frequency resolution. The wideband instantaneous absolute peak pressure and Sound Exposure Level (SEL) values of each strike and an estimate of the daily cumulative SEL should be monitored in real time during construction to ensure that the project does not exceed its authorized take level. Peak and RMS pressures will be reported in dB (re:1 μPa). SEL will be reported in dB (re: 1 $\mu Pa^2 \cdot sec$).

Prior to, and during, the pile driving activity, environmental data will be gathered, such as water depth and tidal level, wave height, and other factors that could contribute to influencing the underwater sound levels (e.g. aircraft, boats, etc.). Start and stop time of each pile driving event will be logged.

The contractor will provide the following information, in writing, to the noise specialist conducting the hydroacoustic monitoring for inclusion in the final monitoring report: a description of the substrate composition, approximate depth of significant substrate layers, hammer model and size, pile cap or cushion type, hammer energy settings and any changes to those settings during the piles being monitored, depth pile driven, blows per foot for the piles monitored, and total number of strikes to drive each pile that is monitored.

Ambient airborne noise levels will be monitored for a minimum of 15-minutes in the absence of construction activities to determine background airborne sound levels (if not raining). Type 1 sound level meters will be programmed to make 1-second measurements every 1 seconds and record the L_{max}, L_{eq} and L_{95}, thus capturing all, of the individual pile strikes.

Airborne noise measurements will be made at a distance between 50 feet and 200 feet from the pile depending on the availability of suitable location to place the meter. Notes will be made regarding any anomalous noise events such as boats and low flying commercial aircraft. These events will be noted on the data sheets but excluded from the results.

Sound Attenuation Monitoring

None of the monitored piles will be tested with the sound attenuation off (or absence) to test its effectiveness[1].

SIGNAL PROCESSING

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Post-analysis of the underwater pile driving sounds will include:

- Number of pile strikes per pile and per day.
- For each recorded strike (or each strike from a subset), determine the following:
  - The peak pressure, defined as the maximum absolute value of the instantaneous pressure (overpressure or underpressure).

[1] Note: There may be circumstances where the U.S. Fish and Wildlife Service determines that unattenuated pile driving (striking the pile with the bubble curtain turned off) would pose a significant risk of injury to marbled murrelets. In those situations, the Service may request that unattenuated pile driving does not occur and that hydroacoustic monitoring be conducted to determine the extent at which certain thresholds are met instead. This will need to be determined on a case by case basis for projects that may affect marbled murrelets.

- The root mean squared sound pressure across 90% of the strikes energy ($RMS_{90\%}$).
- Sound exposure level, measured across 90% of the accumulated sound energy ($SEL_{90\%}$). Calculation methodology is provided in Appendix A.
- Both broadband and marine mammal functional hearing group analysis.

- Maximum, mean, and range of the peak pressure with attenuation.
- Maximum, mean, range, and Cumulative Distribution Function (CDF) of the $RMS_{90\%}$, with attenuation where the CDF is used to report the percentage of $RMS_{90\%}$ values above the thresholds.
- Maximum, mean, and range of the $SEL_{90\%}$, with attenuation.
- Cumulative SEL (cSEL) across all of the pile strikes. If SEL was calculated for all strikes, cSEL is estimated as indicated in Appendix A. If SEL was calculated for a subset of strikes, cSEL is estimated as follows: cSEL = SEL_{mean} + 10*log(total # strikes).
- A frequency spectrum between a minimum of 20 and 20 kHz for up to eight successive strikes with similar sound levels.

ANALYSIS

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Analysis of the data from the San Francisco-Oakland Bay Bridge Pile Installation Demonstration project (PIDP) 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, 2001). The RMS values computed for this project will be computed over the duration between where 5% and 95% of the energy of the pulse occurs. The SEL energy plot will assist in interpretation of the single strike waveform. The single strike SEL associated with the highest absolute peak strike along with the total number of strikes per pile and per day will be used to calculate the cumulative SEL for each pile and each 24-hour period.

In addition a waveform analysis of the individual absolute peak pile strikes will be performed to determine any changes to the waveform with the bubble curtain. Units of underwater sound pressure levels will be dB (re:1 μPa) and units of SEL will be re:1 $\mu Pa^2 \cdot sec$. In addition to a full broadband analysis the data will be analyzed for each marine mammal functional hearing group (Southall et al., 2007).

Analysis of the airborne noise levels will be a plot of the L_{max}, L_{eq} and L_{95} over the duration of each pile driving event.

REPORTING

Preliminary results for the daily monitoring activities, if required, will be submitted/reported to the primary point of contact[2] at each of the Services within 24 hours after monitoring concludes for the day. In addition a final draft report including data collected and summarized from all monitoring locations will be submitted to the Services within 90 days of the completion of hydroacoustic

[2] The primary point of contact is the biologist that conducted the Section 7 consultation for the Service(s). In the event that the consulting biologist is not available, communication regarding monitoring results and reports should be addressed to the manager of the consultation branch or division with a reference to the consultation title.

monitoring. The results will be summarized in graphical form and include summary statistics and time histories of impact sound values for each pile. A final report will be prepared and submitted to the Services within 30 days following receipt of comments on the draft report from the Services. The report shall include:

1. Size and type of piles.
2. A detailed description of the bubble curtain, including design specifications if applicable.
3. The impact hammer energy rating used to drive the piles, make and model of the hammer.
4. A description of the sound monitoring equipment.
5. The distance between hydrophones and piles.
6. The depth of the hydrophones and depth of water at hydrophone locations.
7. The distance from the pile to the water’s edge.
8. The depth of water in which the pile was driven.
9. The physical characteristics of the bottom substrate into which the piles were driven.
10. The total number of strikes to drive each pile and for all piles driven during a 24-hour period.
11. The underwater wideband background sound pressure level reported as the 50% CDF.
12. The results of the hydroacoustic monitoring, as described under Signal Processing including an analysis of the marine mammal functional hearing groups. An example table is provided in Appendix C for reporting the results of the monitoring.
13. The results of the airborne monitoring, including the frequency spectrum, the Lmax, L_{eq} nd L_{90} for each pile strike for each pile including time history plots, and an estimation of the received levels at the nearest residences
14. The distance at which peak, cSEL, and RMS values exceed the respective threshold values.
15. A description of any observable fish, marine mammal, or bird behavior in the immediate area will and, if possible, correlation to underwater sound levels occurring at that time.

REFERENCES

Illingworth and Rodkin, Inc. 2001. Noise and Vibration Measurements Associated with the Pile Installation Demonstration Project for the San Francisco-Oakland Bay Bridge East Span, Final Data Report, Task Order 2, Contract No. 43A0063.

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

APPENDIX A

Calculation of Cumulative SEL

An estimation of individual SEL values can be calculated for each pile strike by calculating the following integral, where T is T_{90}, the period containing 90% of the cumulative energy of the pulse (eq. 1).

$$SEL = 10\log\left(\int_0^T \frac{p^2(t)}{p_0^{\ 2}} dt \right) \quad dB \qquad \text{(eq. 1)}$$

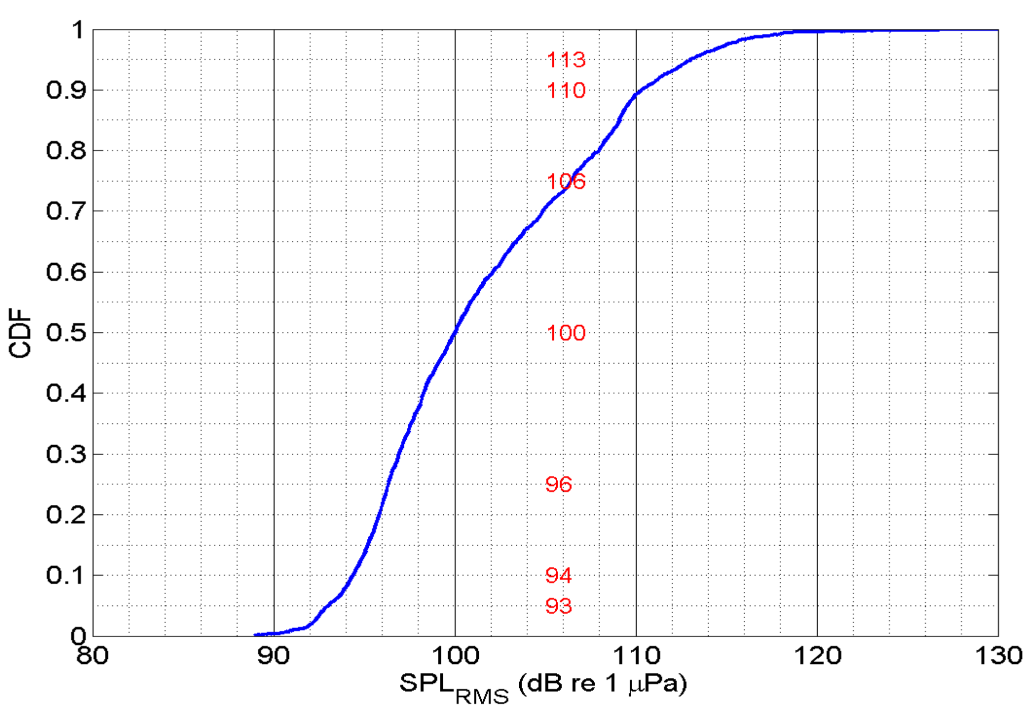
Calculating a cumulative SEL from individual SEL values cannot be accomplished simply by adding each SEL decibel level arithmetically. Because these values are logarithms they must first be converted to antilogs and then accumulated. Note, first, that if the single strike SEL is very close to a constant value (within 1 dB), then cumulative SEL = single strike SEL + 10 times log base 10 of the number of strikes N, i.e, $10Log_{10}(N)$. However if the single strike SEL varies over the sequence of strikes, then a linear sum of the energies for all the different strikes needs to be computed. This is done as follows: divide each SEL decibel level by 10 and then take the antilog. This will convert the decibels to linear units (or $uPa^2 \bullet s$). Next compute the sum of the linear units and convert this sum back into dB by taking $10Log_{10}$ of the value. This will be the cumulative SEL for all of the pile strikes.

APPENDIX B

Calculation of a Cumulative Distribution Function and Plot for Background Sound Level Analysis

Data from three full 24-hour underwater measurement cycles (minimum) are used to calculate a 30-second Root Mean Square (RMS) value for each 30-second period for the entire dataset. The RMS should be calculated for both the full frequency range recorded as well as a separate dataset which has been passed through a high pass filter thus eliminating those frequencies below 1000 Hz. These datasets are then grouped into 24-hour periods. To determine if the data is approximately log-normal in distribution, each 24-hour period is plotted as a Probability Density Function (PDF). Each 24-hour period can be plotted on the same PDF plot. The plots should be approximately log normal in distribution and thus can be used in the further analysis. Each day of data should have an approximately Gaussian sigmoid shape, the differences between them and the ideal might be hard to spot, but the sigmoid from day to day will show noticeable variation. Data which does not approximate a log normal distribution should be excluded from further analysis.

The Cumulative Distribution Function (CDF) plot is obtained by plotting the normalized cumulative sum vs. the bin location. You can also get the PDF from plotting the normalized bin count vs. the bin location. The normalized bin count is obtained by dividing the count column by (number of data points multiplied by the space between 2 consecutive bins). This provides the integral of the PDF equal to 1. For instructions on creating a histogram in Microsoft Excel, see: http://www.vertex42.com/ExcelArticles/mc/Histogram.html



APPENDIX C

Table 1. Example table for required information for reporting the results of hydroacoustic monitoring of pile driving.

Date and Time	Pile ID	Hammer Impact or Vibratory	# Strikes or Vibratory Seconds	Distance to Pile from Hydrophone (m)	Water Depth (m)		Peak (dB)			SEL$_{90\%}$ (dB)				RMS$_{90\%}$ (dB)			Notes
					At Pile	At H-phone	Max	Min	Mean	Max	Min	Mean	cSEL$_{90\%}$	Max	Min	Mean	