APPENDIX E: UNDERWATER NOISE ASSESSMENT

Georgia-Pacific Antioch Terminal Breasting Dolphin Replacement Project

UNDERWATER NOISE ASSESSMENT

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I. INTRODUCTION

Georgia–Pacific proposes to drive thirteen (13) piles in the San Joaquin River to replace a portion of their terminal in Antioch, CA. This report is an assessment of potential sound levels generated by planned pile driving activities for the Georgia-Pacific Antioch Terminal Breasting Dolphin Replacement Project. The project proposes to install three (3) 24-inch steel pipe piles, three (3) 30-inch steel pipe piles, two (2) 42-inch steel pipe piles, one (1) 48-inch steel pipe pile, and four (4) 72-inch steel pipe piles as part of the new structure.

Pile driving will be conducted with both a vibratory hammer and a diesel impact hammer. It is estimated that each pile will require approximately 15 minutes of vibratory driving and 100 to 700 blows with an impact hammer to drive the piles to final tip elevation.

This report includes the prediction of underwater sound levels. Calculations are based on the results of measurements for similar projects. Predicted underwater sound levels are compared against interim thresholds that have been accepted by the Federal Highway Administration (FHWA), California Department of Transportation (Caltrans), and the National Oceanic and Atmospheric Administration (NOAA) National Marine Fisheries Service (NMFS). These thresholds are discussed in this report.

Pile driving will produce underwater noise in and around the project area. Most of the pile driving activities would be in water about 30 feet deep, and would be in the vicinity of the existing docks. It is difficult to predict underwater sound levels from pile driving activities without actual measurements of similar piles in the area. However, it is possible to estimate the sound level based on the results of measurements that have been previously performed for similar projects in different areas. In this analysis, available underwater sound data for projects involving the installation of similar types of piles were reviewed. The sound levels for proposed pile driving activities were estimated using these data combined with an understanding of how and where these activities would occur. These predictions are essentially a best estimate based on empirical data and engineering judgment, but by their very nature contain a degree of uncertainty. The duration of driving for each pile installation and number of piles strikes were also estimated as part of the noise prediction process, based on available data from similar projects and engineering estimates.

II. UNDERWATER SOUNDS FROM PILE DRIVING

Fundamentals of Underwater Noise

Sound is typically described by the pitch and loudness. Pitch is the height or depth of a tone or sound, depending on the relative rapidity (frequency) of the vibrations by which it is produced. Loudness is intensity of sound waves combined with the reception characteristics of the auditory system. Intensity may be compared with the height of an ocean wave in that it is a measure of the amplitude of the sound wave.

In addition to the concepts of pitch and loudness, there are several noise measurement scales which are used to describe sound. A decibel (dB) is a unit of measurement describing the amplitude of sound, equal to 20 times the logarithm to the base 10 of the ratio of the pressure of the sound measured to the reference pressure. For underwater sounds, a reference pressure of 1 micropascal (µPa) is commonly used to describe sounds in terms of decibels. Therefore, 0 dB on the decibel scale would be a measure of sound pressure of 1 µPa. Sound levels in decibels are calculated on a logarithmic basis. An increase of 10 decibels represents a ten-fold increase in acoustic energy, while 20 decibels is 100 times more intense, 30 decibels is 1,000 times more intense, etc.

When a pile driving hammer strikes a pile a pulse is created that propagates through the pile and radiates sound into the water, the ground substrate, and the air. Sound pressure pulse as a function of time is referred to as the waveform. In terms of acoustics, these sounds are described by the peak pressure, the root-mean-square pressure (RMS), and the sound exposure level (SEL). The peak pressure is the highest absolute value of the measured waveform, and can be a negative or positive pressure peak. For pile driving pulses, RMS level is determined by analyzing the waveform and computing the average of the squared pressures over the time that comprise that portion of the waveform containing the vast majority of the sound energy.[1] The pulse RMS has been approximated in the field for pile driving sounds by measuring the signal with a precision sound level meter set to the "impulse" RMS setting and is typically used to assess impacts to marine mammals. Another measure of the pressure waveform that can be used to describe the pulse is the sound energy itself. The total sound energy in the pulse is referred to in many ways, such as the "total energy flux".[2] The "total energy flux" is equivalent to the unweighted SEL for a plane wave propagating in a free field, a common unit of sound energy used in airborne acoustics to describe short-duration events referred to as dB re: 1µPa2-sec. Peak pressures and RMS sound pressure levels are expressed in dB re: 1µPa. The total sound energy in an impulse accumulates over the duration of that pulse. Figure 1 illustrates the descriptors used to describe the acoustical characteristics of an underwater pile driving pulse. Table 1 includes the definitions of terms commonly used to describe underwater sounds.

The variation of instantaneous pressure over the duration of a sound event is referred to as the waveform. Studying the waveforms can provide an indication of rise time; however, rise time differences are not clearly apparent for pile driving sounds due to the numerous rapid fluctuations that are characteristic to this type of impulse. A plot showing the accumulation of sound energy over the duration of the pulse (or at least the portion where much of the energy accumulates) illustrates the differences in source strength and rise time. An example of the characteristics of a typical pile driving pulse is shown in Figure 1.

[1] Richardson, Greene, Malone & Thomson, *Marine Mammals and Noise*, Academic Press, 1995 and Greene, personal communication.

[2] Finerran, et. al., *Temporary Shift in Masked Hearing Thresholds in Odontocetes after Exposure to Single Underwater Impulses from a Seismic Watergun*, Journal of the Acoustical Society of America, June 2002.

Table 1 - Definitions of Underwater Acoustical Terms

Term	Definition
Decibel, dB	A unit describing, the amplitude of sound, equal to 20 times the logarithm to the base 10 of the ratio of the pressure of the sound measured to the reference pressure. The reference pressure for air is 20 micropascals (µPa) and 1 µPa for underwater.
Equivalent Noise Level, L_{eq}	The average noise level during the measurement period.
L_{01}, L_{10}, L_{50}, L_{90}	The sound levels that are exceeded 1%, 10%, 50%, and 90% of the time during the measurement period.
Peak Sound Pressure, unweighted (dB)	Peak sound pressure level based on the largest absolute value of the instantaneous sound pressure. This pressure is expressed in this report as a decibel (referenced to a pressure of 1 µPa) but can also be expressed in units of pressure, such as µPa or PSI.
RMS Sound Pressure Level, (NMFS Criterion)	The average of the squared pressures over the time that comprise that portion of the waveform containing 90 percent of the sound energy for one pile driving impulse.[3]
Sound Exposure Level (SEL), dB re: 1 μPa^2 sec	Proportionally equivalent to the time integral of the pressure squared and is described in this report in terms of dB re: 1 μPa^2 sec over the duration of the impulse. Similar to the unweighted Sound Exposure Level (SEL) standardized in airborne acoustics to study noise from single events.
Cumulative SEL	Measure of the total energy received through a pile-driving event (here defined as pile driving over one day
Waveforms, µPa over time	A graphical plot illustrating the time history of positive and negative sound pressure of individual pile strikes shown as a plot of µPa over time (i.e., seconds)
Frequency Spectra, dB over frequency range	A graphical plot illustrating the distribution of sound pressure vs. frequency for a waveform, dimension in RMS pressure and defined frequency bandwidth

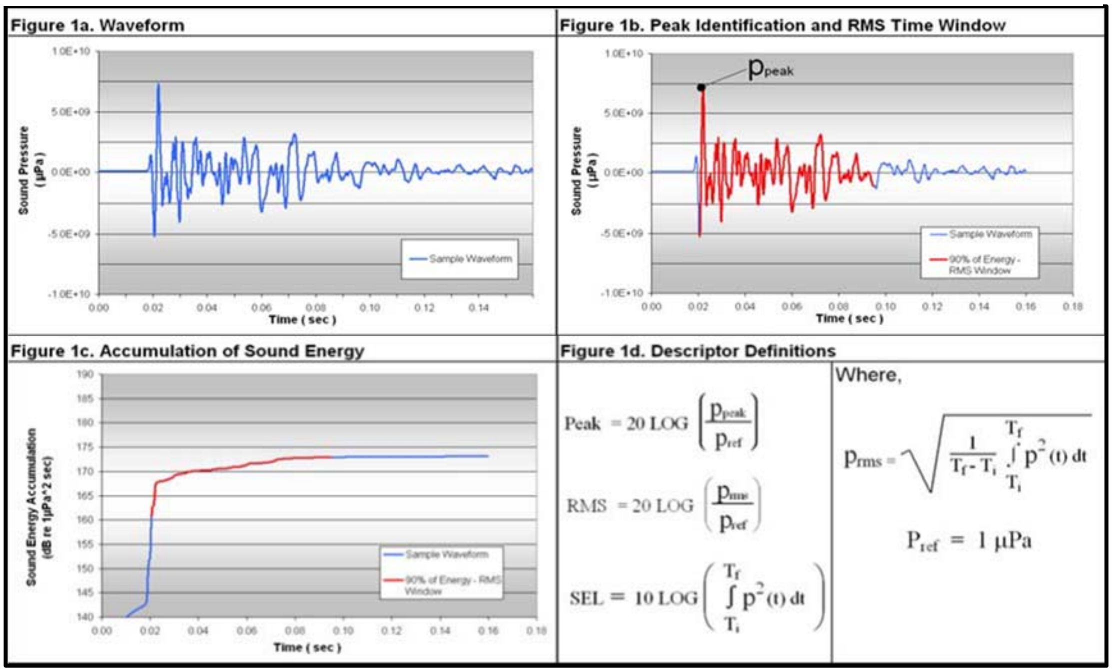
SEL is an acoustic metric that provides an indication of the amount of acoustical energy contained in a sound event. For pile driving, the typical event can be one pile driving pulse or many pulses such as pile driving for one pile or for one day of driving multiple piles. Typically, SEL is measured for a single strike and a cumulative condition. The cumulative SEL associated with the driving of a pile can be estimated using the single strike SEL value and the number of pile strikes through the following equation:

$$SEL_{CUMULATIVE} = SEL_{SINGLE\ STRIKE} + 10 \log (\#\ of\ pile\ strikes)$$

For example, if a single strike SEL for a pile is 165 dB and it takes 1,000 strikes to drive the pile, the cumulative SEL is 195 dBA (165 dB + 30 dB = 195 dB), where 10 * Log10(1000) = 30.

[3] The underwater sound measurement results obtained during the Pile Installation Demonstration Project indicated that most pile driving impulses occurred over a 50 to 100 millisecond (msec) period. Most of the energy was contained in the first 30 to 50 msec. Analysis of that underwater acoustic data for various pile strikes at various distances demonstrated that the acoustic signal measured using the standard “impulse exponential-time-weighting” (35-msec rise time) correlated to the RMS (impulse) level measured over the duration of the impulse.

Figure 1 - Characteristics of a Pile Driving Pulse



III. UNDERWATER SOUND THRESHOLDS

Underwater sound effects to fish and marine mammals are discussed below. In this report, peak pressures and RMS sound pressure levels are expressed in decibels re: 1 µPa. Sound exposure levels are expressed as dB re: 1µPa2-sec.

Fish

A Fisheries Hydroacoustic Workgroup (FHWG) that consisted of transportation officials, resources agencies, the marine construction industry (including Ports), and other experts was formed in 2003 to address the underwater sound issues associated with marine construction. The first order of business was to document all that was clearly known about the effects of sound on fish, which was reported in "The Effects of Sound on Fish."[4] This report recommended preliminary guidance to protect fish. A graph showing the relationship between the SEL from a single pile strike and injurious effects to fish based on size (i.e., mass) was presented. Fish with a mass of about 0.03 grams were expected to have no injury for a received SEL of a pile strike below 194 dB and suffer 50% mortality at about 197 dB. The report also described possible effects to the auditory system (i.e., auditory tissue damage and hearing loss), based on a received dose of sound. The recommendations were frequency dependent, based on the hearing thresholds of fish or most sensitive auditory bandwidths. For salmonids, hearing effects would be expected at or near the thresholds for injury based on the single strike SEL. A further investigation into the effects of pile

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[4] Hastings, M and A. Popper. 2005. The Effects of Sound on Fish. Prepared for the California Department of Transportation. January 28 (revised August 23).

driving sounds on fish was also recommended.

Caltrans commissioned a subsequent report to provide additional explanation of, and a practical means to apply, injury criteria recommended in "The Effects of Sound on Fish." This report is entitled "Interim Criteria for Injury of Fish Exposed to Pile Driving Operations: A White Paper," (White Paper).[5] The White Paper recommended a dual criterion for evaluating the potential for injury to fish from pile driving operations. The dual approach considered that a single pile strike with high enough amplitude, as measured by zero to peak (either negative or positive pressure) could cause injury. A peak pressure threshold for a single strike was recommended at 208 dB. In 2007, Carlson et al provided an update to the White Paper in a memo titled "Update on Recommendation for Revised Interim Sound Exposure Criteria for Fish during Pile Driving Activities."[6] In this memo, they propose criteria for each of three different effects on fish: 1) hearing loss due to temporary threshold shift, 2) damage to auditory tissues, and 3) damage to non-auditory tissues. These criteria vary due to the mass of the fish and if the fish is a hearing specialist or hearing generalist. In preparing this update, Dr. Mardi Hastings summarized information from some current studies in a report titled "Calculation of SEL for Govoni et al. (2003, 2007) and Popper et al. (2007) Studies."

On June 12, 2008, NMFS; U.S. Fish and Wildlife Service (USFWS); California, Oregon, and Washington Departments of Transportation; California Department of Fish and Game; and the U.S. Federal Highway Administration generally agreed in principal to interim criteria to protect fish from pile driving activities, as shown in Table 2. Note that the peak pressure criterion of 206 dB was adopted (rather than 208 dB), as well as accumulated SEL criteria for fish smaller than 2 grams. NMFS interpretation of the interim criteria is described by Woodbury and Stadler (2009).[7]

Table 2 - Adopted Impact Pile Driving Acoustic Criteria for Fish

Interim Criteria for Injury	Agreement in Principle
Peak	206 dB for all sizes of fish
Cumulative SEL	187 dB for fish size of two grams or greater. 183 dB for fish size of less than two grams.
Behavior effects threshold for all sizes of fish is 150 dB RMS	

The primary difference between the adopted criteria and previous recommendations is that the single strike SEL was replaced with a cumulative SEL over a day of pile driving. NMFS does not consider sound that produces an SEL per strike of less than 150 dB to accumulate and cause injury.

[5] Popper, A., Carlson, T., Hawkins, A., Southall, B. and Gentry, R. 2006. Interim Criteria for Injury of Fish Exposed to Pile Driving Operations: A White Paper. May 14.

[6] Carlson, T, Hastings, M and Popper, A. 2007. Memo to Suzanne Theiss, California Department of Transportation, Subject: Update on Recommendations for Revised Interim Sound Exposure Criteria for Fish during Pile Driving Activities. December 21.

[7] Stadler, J. and Woodbury, D. 2009. Assessing the effects to fishes from pile driving: Application of new hydroacoustic criteria. Proceedings of inter-noise 2009, Ottawa, Canada. August 23-26.

The adopted criteria listed in Table 2 are for pulse-type sounds (e.g., pile driving) and does not address sound from vibratory driving of piles; there are no acoustic thresholds that apply to the lower amplitude noise produced by vibratory pile driving. In fact, the acoustic thresholds developed for fish only apply to impact pile driving.

The Bureau of Ocean Energy Management, (BOEM—formerly Minerals Management Service), Caltrans, and National Cooperation of Highway Research Programs (NCHRP 25–28)/Transportation Research Board (TRB) have funded studies to identify the onset of injury to fish from impact pile driving. One of the goals of these studies was to provide quantitative data to define the levels of impulsive sound that could result in the onset of barotrauma injury to fish.[8] Laboratory simulation of pulse-type pile driving sounds enabled careful study of the barotrauma effects to Chinook salmon. The neutrally buoyant juvenile fish were exposed to impulsive sounds and subsequently evaluated for barotrauma injuries. Significant barotrauma injuries were not observed in fish exposed to 960 pulses at 180 dB SEL per pulse or 1,920 pulses at 177 dB per pulse. In both exposures, the resulting accumulated SEL was 210 dB SEL. Results of these studies are under review. At this time, the criteria in Table 2 are used by NMFS to judge impacts to fish. Potential behavior impacts that might occur above 150 dB RMS are not used to restrict pile driving.

IV. UNDERWATER SOUND GENERATING ACTIVITIES

Project Related Noise Sources

The primary sound generating activities associated with this project would be vibratory driving followed by impact driving of the steel shell piles. Preliminary indications are that an APE 400 vibratory hammer and a Delmag D160 diesel impact hammer would be required to drive the 42-inch, 48-inch, and the 72-inch piles. The 24-inch and the 30-inch walkway piles will be installed using an ICE 44 vibratory hammer and a Delmag D62 diesel impact hammer. The driving periods are not likely to be continuous. The required pile embedment and estimated number of pile strikes per pile is shown in Table 3.

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8 Halvorsen MB, Casper BM, Woodley CM, Carlson TJ, Popper AN (2012) Threshold for Onset of Injury in Chinook Salmon from Exposure to Impulsive Pile Driving Sounds. PLoS ONE 7(6): e38968. oi:10.1371/journal.pone.0038968

Table 3 - Piles Associated with New Terminal Construction Activities

Location	Quantity	Diameter (inches)	Pile Embedment Depth (feet)	Estimated Number of Pile Strikes
Breasting Dolphin Piles	4	72	65	700
Mooring Piles	2	42	51	420
	1	48	56	520
Walkway Piles	1	24	38	160
	2	24	48	360
	3	30	35	100

For vibratory installation it is estimated that the piles will be driven 30 feet; which would take approximately 15 minutes for each pile. For impact pile driving, pile installation is estimated to require 20 blows per foot until the pile reaches its required depth. A full pile driving event was assumed to require 100 to 700 pile strikes. The project would install one (1) pile per day for the 72-inch piles and up to two (2) piles per day for all other piles. In terms of underwater sound effects on fish, the highest cumulative sound levels would occur under any scenario where a 72-inch pile is impact driven in one day.

Impact pile driving produces pulsed-type sounds, while vibratory driving will produce more continuous-type sounds. The distinction between these two general sound types is important because they have differing potential to cause physical effects, particularly with regard to hearing. Pulsed sounds, such as impact pile driving, explosions, or seismic air guns, are brief, distinct acoustic events that occur either as an isolated event (e.g., explosion) or repeated in some succession (e.g., impact pile driving). Pulsed sounds are all characterized by discrete acoustic events that include a relatively rapid rise in pressure from ambient conditions to a maximum pressure value followed by a decay period that may include a period of diminishing, oscillating maximal and minimal pressures. Pulsed sounds are typically high amplitude events that have the potential to cause hearing injury. Continuous or non-pulsed sounds can be tonal or broadband. These sounds include vessels, aircraft, machinery operations such as vibratory pile driving or drilling, and active sonar systems. This project will have both pulsed and continuous type sounds from pile installation.

Discussion of Underwater Sound Generation from Pile Driving

A review of underwater sound measurements for similar projects was undertaken to estimate the near-source sound levels for vibratory and impact pile driving. Sounds from similar-sized steel shell piles have been measured in water for several projects. Measurements conducted for the Richmond Inner Harbor Project, Richmond San Rafael Bridge Seismic Retrofit, Trinidad Pier Replacement, Amorco Wharf Construction Project, the US Navy Test Pile Program and the US Navy Explosive Handling Wharf Project (EHW) are most representative due to the similar pile size and depth of water at the site. The projects included installation of 24-inch, 36-inch, 48-inch, and

72-inch diameter steel pipe piles. It is estimated that the noise levels for the 30-inch piles will be similar to the 36-inch piles and 42-inch piles will be the same as the 48-inch piles. Table 4 shows the acoustical measurements that were made during the installation of these piles.[9,10,11,12,13]

Table 4 - Underwater Sound Levels at 10 Meters Based on Similar Projects

Pile Driving Scenario	Peak Pressure (dB re:1µPa)	RMS Sound Pressure Level (dB re:1µPa)	SEL (dB re: $1µPa^2sec$)	Data Source
24-in. Diameter Impact Pile Driving	205	189	178	Amorco Wharf Construction
30-in. Diameter Impact Pile Driving (similar to 36 in)	208	190	177	U.S. Navy Kitsap Bangor
42 & 48-in. Diameter Impact Pile Driving	209	192	180	U.S. Navy Kitsap Bangor
72-in. Diameter Impact Pile Driving	214	199	189	Richmond San Rafael Bridge

Prediction of Underwater Sound from Project Pile Driving

Estimated noise impacts are discussed specifically for each type of pile driving. The near source sound levels were used to predict underwater sound levels at various distances from the pile being driven. These levels represent unattenuated conditions (i.e., no air bubble curtain or other means of reducing underwater sound levels). Based on past projects it is estimated that sound levels can be reduced up to 10 dB using a properly deployed attenuation device.

Sound from pile installation (i.e., impact driving) would transmit or propagate from the construction area. Transmission loss (TL) is the decrease in acoustic pressure as the sound pressure wave propagates away from the source. TL parameters vary with frequency, temperature, sea conditions, current, source and receiver depth, water depth, water chemistry, and bottom composition and topography. NMFS has developed an underwater acoustic calculator that uses practical spreading to predict sound levels at various distances from the source. The formula for transmission loss is TL = X log10 (R/10), where X is the calculated drop off rate and R is the distance from the source assuming the near source levels are at 10 meters. This TL model, based on the default practical spreading loss assumption, was used to predict underwater sound levels generated by pile installation from this project. For this analysis a TL of 18 to 20 Log(R/10) (i.e.,

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[9] Illingworth & Rodkin. 2012. Naval Base Kitsap at Bangor Test Pile Program: Acoustic Monitoring Report. Prepared by Illingworth & Rodkin, Inc. for U.S. Navy.

[10] Illingworth & Rodkin, Inc. 2013. Naval Base Kitsap at Bangor Trident Support Facilities Explosive Handling Wharf (EHW-2) Project - Acoustic Monitoring Report , BANGOR, WASHINGTON. 23 April 2013, Revised 15 May 2013. Prepared by Illingworth & Rodkin, Inc. for U.S. Navy. Available at http://www.nmfs.noaa.gov/pr/pdfs/permits/navy_kitsap_ehw2_acoustics2013.pdf, accessed October 15, 2014.

[11] Illingworth & Rodkin. 2009. Trinidad Pier Replacement. Prepared by Illingworth & Rodkin, Inc.

[12] Illingworth & Rodkin. 2003. Letter to Michael Cheney reporting results of underwater sound measurements. Prepared by Illingworth & Rodkin, Inc. for Castrol Oil.

[13] Illingworth & Rodkin. 2005. Letter to Sharon Lim (Tesoro) reporting results of underwater sound measurements. Prepared by Illingworth & Rodkin, Inc. for Tesoro.

18 dB loss per ten-fold increase in distance) was used for vibratory pile driving and a 17 Log TL(R/10) function was used for impact driving. These TL values were measured based on the drop off rate for EHW measurements in relatively deep water across the Hood Canal. This rate of transmission loss was much less than that measured by Blackwell in the Knik Arm of 22 to 29 dB per 10-fold increase in distance.[14] However, NMFS recommends a default practical spreading loss of 15 dB per ten-fold increase in distance when reliable data not available. Measurements conducted during pile driving for the project could further refine the rate of sound propagation or TL.

Impact Pile Driving

Peak sound pressure levels, average RMS sound pressure levels, and SELs from impact driving were predicted using the near source levels for impact pile driving and the practical loss sound propagation assumptions described above. Table 5 shows the extent of sound levels for the NMFS marine mammal and fish criteria.

Reducing sounds from impact pile driving using air bubble curtains is common. Caltrans reports a large range in sound reduction from almost no reduction to 30 dB as a result of use of these curtains. During the EHW project (i.e., the source of impact pile driving levels for this assessment) the reduction from an air bubble curtain was between 8 and 14 dB. Therefore, this assessment assumes that underwater sounds could be reduced at least 10 dB with the use of a properly designed and deployed air bubble curtain attenuation system.

Accumulated SEL levels associated with impact pile driving will vary daily, depending on the amount of pile driving. Table 6 shows the estimated accumulated SEL levels at 10 meters and the estimated distances to the accumulated 187 dB and 183 dB SEL level with and without an attenuation system. Reduction in the SEL level requires a properly designed and deployed air bubble curtain system.

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[14] Blackwell, S.B., 2005. Underwater Sound Measurements of Pile-Driving Sounds during the Port MacKenzie Dock Modifications, 13-16 August 2004. Greeneridge Sciences Report 328-1.March 2005.

Table 5 - Modeled Extent of Sound Pressure Levels from Unattenuated and Attenuated Impact Driving of One Pile

Modeling Scenario	Distance to Marine Mammal Acoustic Criteria in Meters			Distance to Fish Acoustic Criteria in Meters			Distance to Behavioral Zone
	RMS (dB re: 1uPa)			Peak (dB re: 1uPa)	Cumulative SEL[15] (dB re:1uPa-sec2)		RMS (db re:1uPa)
	Level B Harassment	Level A Injury					
	160	180	190	206	187	183	150
72-inch Piles (Pile ID: BD 1-4) Estimated 700 Pile Strikes per Pile							
Modeled Unattenuated	1,970[16]	130	35	30	620	1,065[16]	7,630[16]
Assuming a 10 dB Reduction with Attenuation	510	35	<10	<10	160	275	1,970[16]
48-inch Pile (Pile ID: MD 3) Estimated 520 Pile Strikes							
Modeled Unattenuated	765[16]	50	15	15	155	265	2,955[16]
Assuming a 10 dB Reduction with Attenuation	200	15	<10	<10	40	70	765[16]
42-inch Piles (Pile ID: MD 1&2) Estimated 420 Pile Strikes per Pile							
Modeled Unattenuated	765[16]	50	15	15	135	235	2,955[16]
Assuming a 10 dB Reduction with Attenuation	200	15	<10	<10	35	60	765[16]
30-inch Piles (Pile ID: WB 3-5) Estimated 100 Pile Strikes per Pile							
Modeled Unattenuated	580	40	<10	15	40	70	2,255[16]
Assuming a 10 dB Reduction with Attenuation	150	<10	<10	<10	10	20	580
24-inch Piles (Pile ID: WB 2&6) Estimated 360 Pile Strikes per Pile							
Modeled Unattenuated	510	35	<10	<10	95	160	1,970[16]
Assuming a 10 dB Reduction with Attenuation	130	<10	<10	<10	25	40	510
24-inch Pile (Pile ID: WB 1) Estimated 160 Pile Strikes							
Modeled Unattenuated	510	35	<10	<10	60	100	1,970[16]
Assuming a 10 dB Reduction with Attenuation	130	<10	<10	<10	15	25	510

[15] Base on the driving of one pile. SEL criteria apply to impact pile driving events that occur during one day. See Table 6 for predicted accumulated SEL for various daily pile driving scenarios.

[16] Distance to underwater noise thresholds is partially constrained by river topography

Table 6 - Cumulative SEL levels at 10 meters and Distances to the 187 dB and 183 dB Cumulative SEL Criterion for Pile Driving

Modeling Scenario	Total Strikes	Attenuation	Cumulative SEL (dB) at 10 Meters	Distance to 187 dB Cumulative SEL (Meters)	Distance to 183 dB Cumulative SEL (Meters)
One 72-inch pile	700	Unattenuated	217	62016	1065[17]
		Attenuated	207	160	275
MD1 (42-inch) & WB1 (24-inch)	580	Unattenuated	207	145	245
		Attenuated	197	40	65
MD2 (42-inch) & WB2 (24-inch)	780	Unattenuated	208	170	290
		Attenuated	198	45	75
BD1 (72-inch) & WB3 (30-inch)	800	Unattenuated	217	585	1005[17]
		Attenuated	207	150	260
WB4 (30-inch) & WB5 (30-inch)	200	Unattenuated	200	60	100
		Attenuated	190	15	25
WB6 (24-inch) & MD3 (48-inch)	880	Unattenuated	209	180	315
		Attenuated	198	50	80
WB5 (30-inch) & WB6 (24-inch)	460	Unattenuated	204	95	165
		Attenuated	194	25	40

[17] Distance to underwater noise thresholds is partially constrained by river topography

V. CONCLUSION

The levels generated during impact driving of all unattenuated piles except the 24-inch piles will exceed the adopted 206 dB peak criteria for injury to fish. The levels generated during impact pile driving of all attenuated piles will not exceed the 206 dB peak criteria. The cumulative SEL will exceed the 187 dB criteria with and without an attenuation system on all piles.

The worst case scenario for impact driving is driving a single 72-inch pile. It is estimated that the 206 dB peak level for an unattenuated 72-inch pile is at 30 meters. The cumulative SEL will exceed the 187 dB criteria out to a distance of approximately 620 meters unattenuated and 160 meters attenuated.

Vibratory pile installation results in much lower amplitude sound levels. The use of vibratory hammers for pile driving in San Francisco Bay is allowed without restrictions on the size of piles or time of year work is performed according to the program level “Not Likely to Adversely

Affect" (NLAA) consultation from the U.S. Army Corps of Engineers (Corps) in 2006. The NLAA consultation was developed jointly between the Corps, USFWS, and NMFS, and was approved by the USFWS on December 6, 2006, and by NMFS on December 21, 2007. The NLAA consultation concluded that use of a vibratory hammer, regardless of pile size, is not likely to exceed underwater sounds level thresholds established by NMFS for impacts to fish. While the application of the NLAA consultation to actions undertaken by non-governmental entities is up to the discretion of the Corps and NMFS, the measures included in that consultation are useful as guidance, and the Action's use of a vibratory hammer is consistent with the NLAA standards.