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Appendix Z: Underwater Acoustic Assessment

Coastal Virginia Offshore Wind Commercial Project

Dominion Energy®

Submitted by:
Dominion Energy Services, Inc.
707 E. Main Street,
Richmond, VA 23219

Prepared by:
Tetra Tech, Inc.
4101 Cox Road, Suite 120
Glen Allen, VA 23060

Submitted To:
Bureau of Ocean Energy Management
45600 Woodland Road
Sterling, VA 20166

CONSTRUCTION AND OPERATIONS PLAN

Coastal Virginia Offshore Wind Commercial Project

Appendix Z Underwater Acoustic Assessment

Prepared for:

Dominion Energy

707 East Main Street
Richmond, VA 23219

Prepared by:

TETRA TECH

Tetra Tech, Inc.
4101 Cox Road, Suite 120
Glen Allen, VA 23060

www.tetratech.com

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APPENDIX Z UNDERWATER ACOUSTIC ASSESSMENT
REVISION LOG

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APPENDIX Z UNDERWATER ACOUSTIC ASSESSMENT

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ACRONYMS AND ABBREVIATIONS

BOEM	Bureau of Ocean Energy Management
dB	decibel
dB re 1 µPa	decibels referenced at one micropascal
dB re 1 $\mu Pa^2 \cdot s$	decibels referenced at one squared micropascal-second
dBSea	Software for the prediction of underwater noise in a variety of environments
dB/km	decibels per kilometer
DP	dynamic positioning
DSPT	Direct Steerable Pipe Tunneling
DSTBM	direct steerable tunnel boring machine
ft	foot
HF	high-frequency
Hz	Hertz
kHz	kilohertz
kJ	kilojoule
km	kilometers
kN	kilonewton
Lease Area	BOEM-designated Renewable Energy Lease Area OCS-A 0483
LF	low-frequency
Lpk	peak sound pressure
m	meter
m/s	meters per second
MF	mid-frequency
MMPA	Marine Mammal Protection Act
NGDC	National Geophysical Data Center
nm	nautical mile
NOAA	National Oceanic and Atmospheric Administration
NOAA Fisheries	National Oceanic and Atmospheric Administration's National Marine Fisheries Service
OSS	offshore substation
Project	Coastal Virginia Offshore Wind Commercial Project
Offshore Project Area	The area where the Project facilities are physically located
PTS	permanent threshold shift
PW	Phocids in Underwater
rms	root-mean-square
SEL	sound exposure level
SEL_{cum}	cumulative sound exposure level
SPL	sound pressure level
Tetra Tech	Tetra Tech, Inc.
TTS	temporary threshold shift
USFWS	U.S. Fish and Wildlife Service
UTM	Universal Transverse Mercator
WTG	wind turbine generator
µPa	micropascal
λ	wavelength

Z.1 INTRODUCTION

The Virginia Electric and Power Company, doing business as Dominion Energy Virginia (hereinafter referred to as Dominion Energy), is proposing to construct, own, and operate the Coastal Virginia Offshore Wind Commercial Project (hereinafter referred to as the Project). The Project will be located in the Commercial Lease of Submerged Lands for Renewable Energy Development on the Outer Continental Shelf Offshore Virginia (Lease Number OCS-A-0483) (Lease Area), which was awarded through the Bureau of Ocean Energy Management (BOEM) competitive renewable energy lease auction of the Virginia Wind Energy Area offshore of Virginia in 2013. The Lease Area covers approximately 112,799 acres (45,658 hectares) and is approximately 27 statute miles (23.5 nautical miles [nm], 43.5 kilometers [km]) off the Virginia Beach coastline (Figure Z-1).

The Offshore Project Components, including the Wind Turbine Generators (WTGs), Offshore Substations (OSSs), and Inter-Array Cables, will be located in federal waters within the Lease Area, while the Offshore Export Cable Route Corridor will traverse both federal and state territorial waters of Virginia. During construction, the Project will additionally involve temporary construction laydown area(s) and construction port(s). The operation stage of the Project will include an onshore operations and maintenance facility with an associated Operations and Maintenance Port.

This Underwater Acoustic Assessment report has been prepared in support of the Project Construction and Operations Plan. As discussed in the Construction and Operations Plan, construction and operation of the Project have the potential to cause acoustic harassment to marine species, in particular, marine mammals, sea turtles, and fish populations. This report presents the acoustic modeling methodologies, as applied, to estimate the expected underwater noise levels generated during construction and operation of the proposed Project. The objective of this modeling study was to predict the ranges to acoustic thresholds that could result in injury (Level A Take) or behavioral disruption (Level B Take) of marine mammals, sea turtles, and fish during construction and operation of the Project. Primary noise-generating activities have been identified during construction as impact and vibratory pile-driving during WTG and OSS installation. Noise generated during other activities that has been evaluated including cofferdam installation and goal post installation. Up to nine cofferdams may be installed using vibratory pile driving and one cofferdam was modeled as representative to the proximity of the nine candidate locations. Goal post installation is associated with nearshore trenchless installation and will require the use of impact pile driving. Lastly, noise associated with vessel activity related to cable laying and WTG operation is also qualitatively discussed. During the decommissioning stage of the Project, all activities are anticipated to be similar to or less than those described for construction; therefore, impacts from decommissioning are not addressed specifically in this report

The revised Underwater Acoustic Assessment and modeling analysis reflects feedback received during recent consultations with the National Oceanic and Atmospheric Administration's (NOAA's) National Marine Fisheries Service (NOAA Fisheries) and BOEM, where further detail was requested regarding pile driving sound source development and sound propagation modeling. Additional assumptions and information pertaining to pile driving sound source development and sound propagation modeling have been provided as Attachments Z-1, Z-2, and Z-3 in this revised Underwater Acoustic Assessment.

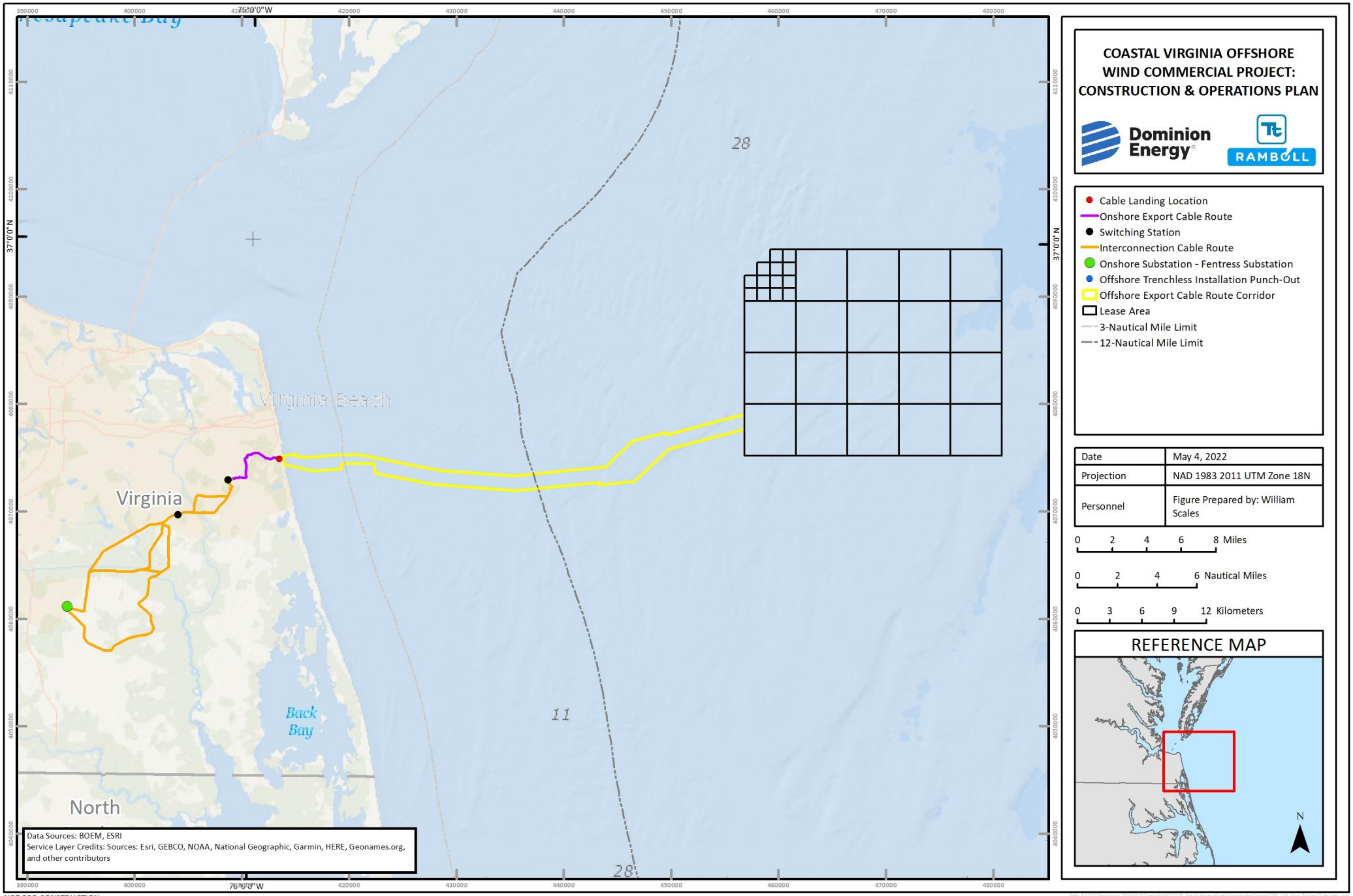

Figure Z-1. Offshore Project Area

Z.1.1 Acoustic Concepts and Terminology

This section outlines some of the relevant concepts in acoustics to help the non-specialist reader best understand the modeling assessment and results presented in this report. Sound is the result of mechanical vibration waves traveling through a fluid medium such as air or water. These vibration waves generate a time-varying pressure disturbance that oscillates above and below the ambient pressure.

It is important to note that underwater sound levels are not equivalent to in-air sound levels, with which most readers would be more familiar. An underwater sound pressure level (SPL or L_p) of 150 decibels (dB) referenced to 1 micropascal (re 1 µPa) is not equivalent to an in-air sound pressure level of 150 dB re 20 µPa due to the differences in density and speed of sound between water and air, and the different reference pressures that are used to calculate the dB levels, i.e., 1 µPa for water and 20 µPa for air. Underwater sound levels can be presented either as overall broadband levels or as frequency-dependent levels showing the frequency content of a source. Broadband values present the total average acoustic energy level of a source within a given frequency bandwidth, which is usually the band that contains most of the signal's energy. Sometimes it is preferable to refer to frequency-based sound levels (one-third octave band levels or octave band levels) to characterize spectral content of a sound source and/or identify narrowband sources.

The sound level estimates presented in this modeling study are expressed in terms of several metrics and apply the use of exposure durations to allow for interpretation relative to potential biological impacts on marine life. NOAA Fisheries issued a Technical Guidance that provides acoustical thresholds and defines the threshold metrics (NOAA Fisheries 2018). The ISO 18405 Underwater Acoustics – Terminology (ISO 2017) provided a dictionary of underwater bioacoustics for standardized terminology. Table Z-1 provides a summary of the relevant metrics from both NOAA Fisheries (2018) and ISO (2017) that are used within this report.

Table Z-1. Summary of Acoustic Terminology

Metric	NOAA Fisheries (2018)	ISO (2017)		Reference Value
		Main Text	Equations and Tables	
Sound Pressure Level	SPL	SPL	L_p	dB re 1 µPa
Peak Sound Pressure Level	PK	Lpk	$L_{p,pk}$	dB re 1 µPa
Cumulative Sound Exposure Level	SEL_{cum} a/	SEL	L_E	dB re 1 $µPa^2 \cdot s$

Note:
a/ NOAA Fisheries (2018) describes the SEL_{cum} metric over an accumulation period of 24-hour period. Following the ISO standard, this will be identified as SEL in the text and L_E will be used in tables and equations of this report with the accumulation period identified.

This report follows the ISO (2017) standard terminology and symbols for the sound metrics unless stated otherwise. Below are descriptions of the relevant metrics and concepts that should help frame the discussion of acoustics in this document. The majority of the information in the following sections provides further insight into how data and modeling results have been presented in accordance with regulatory reporting requirements and established criteria.

Peak sound pressure (Lpk or $L_{p,pk}$; dB re 1 µPa) is the maximum noise level over a given event and is calculated using the maximum variation of the pressure from positive to zero within the wave. The peak level is commonly used as a descriptor for impulsive sound sources. At high intensities, the Lpk can be a valid criterion for assessing whether a sound is potentially injurious; however, since it does not take into account the pulse duration or bandwidth of a signal, it is not a good indicator of loudness or potential for masking effects. The Lpk can be calculated using the formula below where *t* is the length of time. Impulses are characterized by a relatively rapid rise from ambient pressure to a maximal pressure value followed by a decay period that may include a period of diminishing, oscillating maximal and minimal pressures.

$$L_{p,pk} = 10\,log_{10}\left[\frac{max\left(\left|p^2(t)\right|\right)}{p_0^2}\right]\; dB \qquad (1)$$

Sound pressure level (SPL or L_p; dB re 1 µPa) is the root-mean-square (rms) pressure level in a stated frequency band over a specified time window. It is important to note that SPL always refers to an rms pressure level and therefore not instantaneous pressure. The SPL is calculated by taking the square root of the average of the square of the pressure waveform over the duration of the time period. The SPL is also known as the quadratic mean and is a statistical measure of the magnitude of a varying quantity. Given a measurement of the time of varying sound pressure p(t) from a given noise source, the SPL is computed according to the following formula where p(t) is the instantaneous pulse pressure as a function of time, measured over the pulse duration $0 \leq t \leq T$.

$$L_P = 10\,log_{10}\left(\frac{1}{T}\int_T p^2(t)dt/p_0^2\right)\; dB \qquad (2)$$

Sound exposure level (SEL or $L_{E;}$ dB re 1 µPa²·s) is similar to the SPL but further specifies the sound pressure over a specified time interval or event, for a specified frequency range. The SEL for a single event is computed from the time-integral of the squared pressure over the full event duration (T_{100}):

$$L_E = \; 10\,log_{10}\left(\int_{T_{100}} p^2(t)dt/T_0 p_0^2\right)\; dB \qquad (3)$$

where T_0 is a reference time interval of 1 second. The SEL represents the total acoustic energy received at a given location. Unless otherwise stated, sound exposure levels for impulsive noise sources (i.e., impact hammer pile-driving) presented in this report refer to a single pulse. In addition, SEL can be calculated as a cumulative metric over periods with multiple acoustic events. In the case of impulsive sources like impact piling, SEL describes the summation of energy for the entire impulse normalized to 1 second and can be expanded to represent the summation of energy from multiple pulses. For non-impulsive sources like vibratory pile driving the SEL accounts for the duration of the vibratory pile driving event. The latter is written SEL_{cum} denoting that it represents the cumulative sound exposure. The sound exposure level is often used in the assessment of marine mammal and fish injury/physiological impacts over a 24-hour time period. The SEL (dB re 1 µPa²·s) can be computed by summing (in linear units) the SEL of the N individual events:

$$L_{E,N} = \; 10\,log_{10}\left(\sum_{i=1}^{N} 10^{\frac{SEL_i}{10}}\right)\; dB \qquad (4)$$

Z.1.1.1 Sound Propagation in Shallow Waters

Seawater Absorption

Absorption in the underwater environment involves a process of conversion of acoustic energy into heat and thereby represents a true loss of acoustic energy to the water. The primary causes of absorption have been attributed to several processes, including viscosity, thermal conductivity, and chemical reactions involving ions in the seawater. The absorption of sound energy by water contributes to the attenuation (or reduction) in sound linearly with range and is given by an attenuation coefficient in units of decibels per kilometer (dB/km). This absorption coefficient is computed from empirical equations and increases with the square of frequency.

For example, for typical open-ocean values (temperature of 50 degrees Fahrenheit (°F) [10 degrees Celsius (°C)], pH of 8.0, and a salinity of 35 practical salinity units), the equations presented by Francois and Garrison (1982a and 1982b) yield the following values for seawater absorption: 0.001 dB/km at 100 Hertz (Hz), 0.06 dB/km at 1 kilohertz (kHz), 0.96 dB/km at 10 kHz, and 33.6 dB/km at 100 kHz. Thus, low frequencies are favored for long-range propagation. Seawater absorption was accounted for in the acoustic modeling according to the Fisher and Simmons (1977) calculation methodology. Site-specific sound speed profile information was input, resulting in a site-specific sound attenuation rate.

Scattering and Reflection

Scattering of sound from the surface and bottom boundaries and from other objects is difficult to quantify and is site-specific but is extremely important in characterizing and understanding the received sound field. Reflection, refraction, and diffraction from gas bubbles and other inhomogeneities in the propagating medium serve to scatter sound and will affect propagation loss and occur even in relatively calm waters. If boundaries are present, whether they are "real" like the surface of the sea or "internal" like changes in the physical characteristics of the water, they affect sound propagation. The acoustic intensity received depends on the losses due to the path length as well as the amount of energy reflected from each interface. Multiple reflections may occur as the sound reflects alternately from the bottom and the sea surface resulting in constructive and/or destructive interference patterns. Reflections occurring between the sea floor and surface are accounted for in the Project acoustic modeling analysis. The model is described further in Section Z.4.1, Sound Propagation Model.

Changes in direction of the sound due to changes of sound velocity are known as refraction. The speed of sound is not constant with depth and range but depends on the temperature, pressure, and salinity. Of the three factors, the greatest impact on sound velocity is temperature. The change in the direction of the sound wave with changes in velocity can produce many complex sound paths. When there is a negative temperature gradient, sound speed decreases with depth, and sound rays bend sharply downward. This condition is common near the surface of the sea. At some horizontal distance from the sound source, beyond where the rays bend downward, is a region in which sound intensity is negligible, which is called a shadow zone. Refraction may also produce sound channels that can trap the sound and allow a signal to travel great distances with minimal loss in energy; for example, the underwater channels are known as the Sound Fixing and Ranging channel, sometimes called the deep sound channel, which allows marine mammal communications to travel great distances.

Since the inhomogeneities in water are very small compared to the wavelength of the signal, this attenuation effect will mostly contribute when the signals encounter changes in bathymetries and propagate through the sea floor and the subsurface. For variable bathymetries, the calculation complexity increases as individual portions of the signal are scattered differently. However, if the acoustic wavelength is much greater than the scale of the seabed non-uniformities, as is most often the case for low-frequency sounds, then the effect of scattering on propagation loss becomes somewhat less important than other factors. Also, scattering loss occurring at the surface due to wave action will increase at higher sea states. For reflection from the sea surface, it is assumed that the surface is smooth. While a rough sea surface would increase scattering (and hence transmission loss) at higher frequencies, the scale of surface roughness is insufficient to have a significant effect on sound propagation in the near field relative to the source.

Seabed Absorption

Seabed sediment characteristics influence propagation loss in shallow water due to the repeated reflections and scattering at the water/seafloor interface. For underwater acoustic analysis, shallow water is typically defined as water depths less than 656 feet (ft; 200 meters [m]). Depending on the sediment properties, sound may be absorbed or reflected. For example, fine-grained silt and clay absorb sound efficiently, while sand, gravel, and bedrock are more reflective. To model these effects, the most important parameters to consider are the sediment density, sound speed, and acoustic attenuation.

The acoustic properties of different sediment types display a much greater range of variation than the acoustic properties of seawater. A good understanding of these properties and their spatial variation is useful for accurate modeling. Oftentimes it is challenging to obtain site-specific data characterizing the seafloor; however, geotechnical studies performed by Dominion Energy presented in the Marine Site Investigation report (MSIR) submitted for the Coastal Virginia Offshore Wind Commercial Project were used in the modeling analysis up to a depth of approximately 285 ft (87 m). Further details pertaining to sediment characteristics are provided in Section Z.4.2.2, Sediment Characteristics and in Attachment Z-1, Underwater Sound Propagation Modeling Methodology.

Cut-off Frequency

Sound propagation in shallow water is essentially a normal mode where a sound wave moves sinusoidally and has its own frequency and the sound channel is an acoustic waveguide. Each mode is a standing wave in the vertical direction that propagates in the horizontal direction at a frequency-dependent speed. Each mode has a cutoff frequency, below which no sound propagation is possible. The cutoff frequency is determined based on the type of bottom material and water column depth. This limiting frequency can also be calculated if the speed of sound in the sediment ($C_{sediment}$) is known (Au and Hastings 2008) and seasonal temperature variation of the speed of sound of the seawater (C_{water}) is known using the following equation:

$$f_c = \frac{C_{water}}{4h} / \sqrt{1 - (C_{water})^2 / (C_{sediment})^2} \tag{5}$$

Where:
f_c = critical frequency
C_{water} = speed of sound of water
$C_{sediment}$ = speed of sound in sediment
h = water depth in the direction of sound propagation

The speed of sound in sediment is higher than in water. In water, it is approximated at 1,500 meters/second (m/s). Values for speed of sound in sediment will range from 1,605 m/s in sand-silt sediment to 1,750 m/s in predominantly sandy areas. Sound traveling in shallower regions of the Offshore Project Area will be subject to a higher cutoff frequency and a greater attenuation rate than sound propagating in deeper regions.

Figure Z-2 graphically presents the cut-off frequency for different bottom material types (represented as separate lines on the figure) plotted as a function of water depth (x-axis) and cut-off frequency (y-axis). As shown, at an approximate water depth of 138 ft (42 m) and a sea bottom consisting of predominantly sand, which represents the deeper region of the Lease Area, the cut-off frequency would be expected to occur at approximately 0.03 kHz. Greater low-frequency attenuation rates would occur at shallower locations within the Lease Area. For the Project acoustic modeling analysis, the concept of cut-off frequency is incorporated into the modeling calculations through the characterization of sediment properties within the seabed.

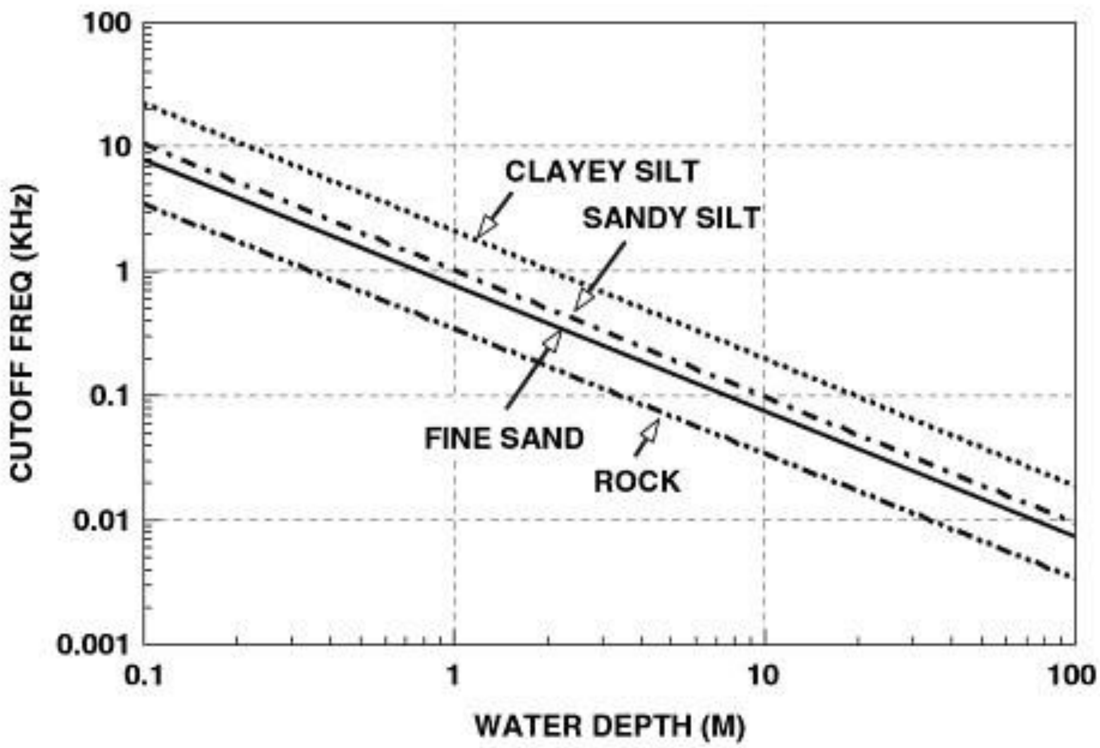

Figure Z-2. Cut-off Frequencies for Different Bottom Materials (Au and Hastings 2008)

Z.2 REGULATORY CRITERIA AND SCIENTIFIC GUIDELINES

Z.2.1 Underwater Acoustic Criteria

The Marine Mammal Protection Act (MMPA) of 1972 provides for the protection of all marine mammals. The MMPA prohibits, with certain exceptions, the “take” of marine mammals. The term “take,” as defined in Section 3 (16 U.S.C. § 1362 (13)) of the MMPA, means “to harass, hunt, capture, or kill, or attempt to harass, hunt, capture, or kill any marine mammal”. NOAA Fisheries has jurisdiction for overseeing the MMPA regulations as they pertain to most marine mammals; however, the U.S. Fish and Wildlife Service (USFWS) has jurisdiction over a select group of marine mammals including manatees, otters, walruses, and polar bears. Since manatees are present within the Offshore Project Area, the USFWS’s jurisdiction over manatees is pertinent to the Project; however, manatee presence offshore is considered rare. Generally, NOAA Fisheries is responsible for issuing take permits under MMPA, upon a request, for authorization of incidental but not intentional “taking” of small numbers of marine mammals by U.S. citizens or agencies who engage in a specified activity (other than commercial fishing) within a specified geographical region. The USFWS issues take permits for manatees, but criteria evaluating potential acoustic impacts to manatees has not yet been developed by the agency. “Harassment” was further defined in the 1994 amendments to the MMPA, with the designation of two levels of harassment: Level A and Level B. By definition, Level A harassment is any act of pursuit, torment, or annoyance that has the potential to injure a marine mammal or marine mammal stock, while Level B harassment is any act of pursuit, torment, or annoyance which has the potential to disturb a marine mammal or marine mammal stock in the wild by causing disruption of behavioral patterns, including, but not limited to, migration, breathing, nursing, breeding, feeding, or sheltering. NOAA Fisheries defines the threshold level for Level B harassment at 160 dB SPL for impulsive sound, averaged over the duration of the signal and at 120 dB SPL for non-impulsive sound, with no relevant acceptable distance specified.

NOAA Fisheries provided guidance for assessing the impacts of anthropogenic sound on marine mammals under their regulatory jurisdiction, which includes whales, dolphins, porpoises, seals, and sea lions, and updated this guidance in 2018 (NOAA Fisheries 2018). The guidance specifically defines marine mammal hearing groups; develops auditory weighting functions; and identifies the received levels, or acoustic threshold levels, above which individual marine mammals are predicted to experience changes in their hearing sensitivity (permanent threshold shift [PTS] or temporary threshold shift [TTS]) for acute, incidental exposure to underwater sound. Under this guidance, any occurrence of PTS constitutes a Level A, or injury, take. The sound emitted by man-made sources may induce TTS or PTS in an animal in two ways: (1) peak sound pressure levels (Lpk) may cause damage to the inner ear, and (2) the accumulated sound energy the animal is exposed to (SEL) over the entire duration of a discrete or repeated noise exposure has the potential to induce auditory damage if it exceeds the relevant threshold levels.

Research showed that the frequency content of the sound would play a role in causing damage. Sound outside the hearing range of the animal would be unlikely to affect its hearing, while the sound energy within the hearing range could be harmful. Under the NOAA Fisheries 2018 guidance, recognizing that marine mammal species do not have equal hearing capabilities, five hearing groups of marine mammals are defined as follows:

- Low-frequency (LF) Cetaceans—this group consists of the baleen whales (mysticetes) with a collective generalized hearing range of 7 hertz (Hz) to 35 kilohertz (kHz);
- Mid-frequency (MF) Cetaceans—includes most of the dolphins, all toothed whales except for Kogia spp., and all the beaked and bottlenose whales with a generalized hearing range of approximately 150 Hz to 160 kHz (renamed High-frequency cetaceans by Southall et al. [2019] because their best hearing sensitivity occurs at frequencies of several tens of kHz or higher);
- High-frequency (HF) Cetaceans—incorporates all the true porpoises, the river dolphins, plus Kogia spp., Cephalorhynchid spp. (genus in the dolphin family Delphinidae), and two species of Lagenorhynchus (Peale’s and hourglass dolphins) with a generalized hearing range estimated from 275 Hz to 160 kHz (renamed very high-frequency cetaceans by Southall et al. [2019] since some species have best sensitivity at frequencies exceeding 100 kHz);
- Phocids Underwater—consists of true seals with a generalized underwater hearing range from 50 Hz to 86 kHz (renamed Phocids carnivores in water by Southall et al. [2019]); and
- Otariids Underwater —includes sea lions and fur seals with a generalized underwater hearing range from 60 Hz to 39 kHz (termed “other marine carnivores” in water by Southall et al. [2019]) and includes otariids, as well as walrus [Family Odobenide], polar bear [*Ursus maritimus*], and sea and marine otters [Family Mustelidae]).

Within these generalized hearing ranges, the ability to hear sounds varies with frequency, as demonstrated by examining audiograms of hearing sensitivity (NOAA Fisheries 2018; Southall et al. 2019). To reflect higher noise sensitivities at particular frequencies, auditory weighting functions were developed for each functional hearing group that reflected the best available data on hearing ability (composite audiograms), susceptibility to noise-induced hearing loss, impacts of noise on hearing, and data on equal latency (NOAA Fisheries 2018). These weighting functions are applied to individual sound received levels to reflect the susceptibility of each hearing group to noise-induced threshold shifts, which is not the same as the range of best hearing (Figure Z-3).

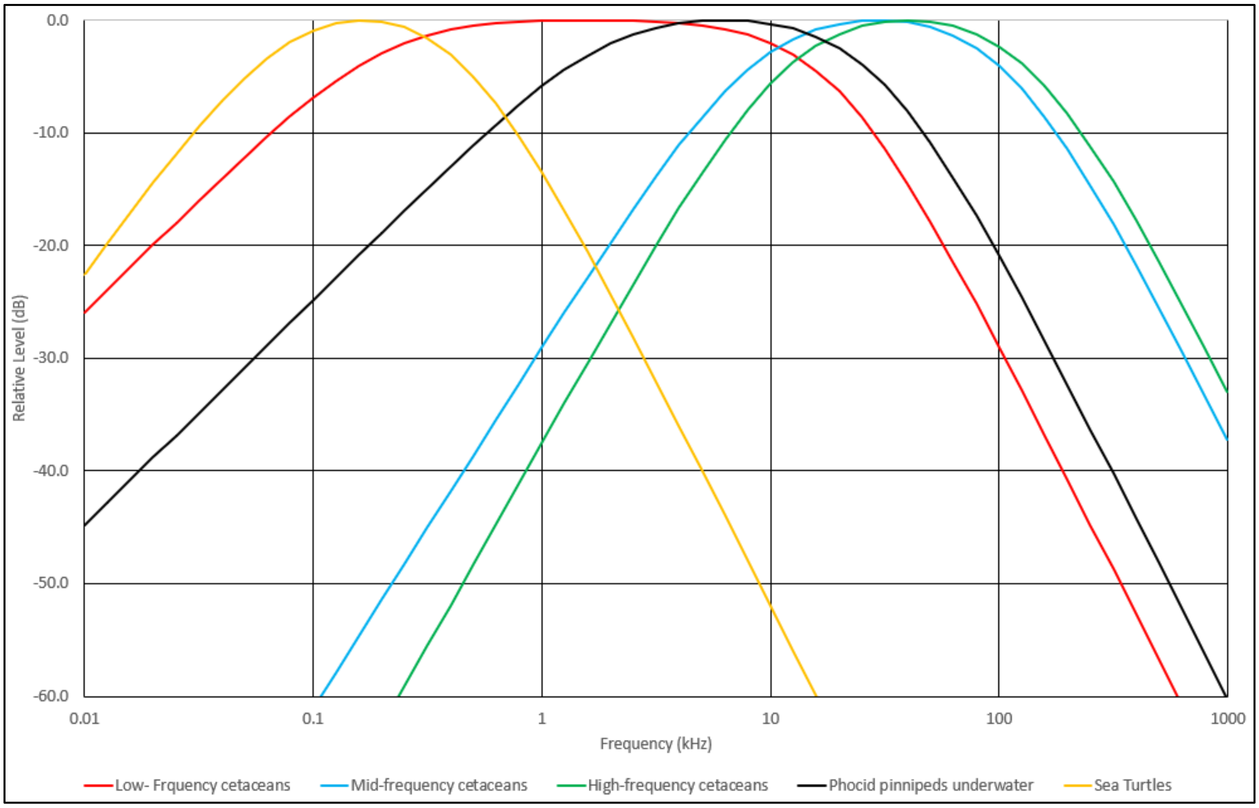

Figure Z-3. Auditory Weighting Functions for Cetaceans (Low-frequency, Mid-frequency, and High-frequency Species), Pinnipeds in water (PW), and Sea Turtles (NOAA Fisheries 2018, U.S. Navy 2017)

NOAA Fisheries (2018) defined acoustic threshold levels at which PTS and TTS are predicted to occur for each hearing group for impulsive and non-impulsive signals (Table Z-2), which are presented in terms of dual metrics; SEL and Lpk. The Level B harassment thresholds are also provided in Table Z-2.

NOAA Fisheries anticipates behavioral response for sea turtles from impulsive sources such as impact pile-driving to occur at SPL 175 dB, which has elicited avoidance behavior of sea turtles (Table Z-3; Blackstock et al. 2017). There is limited information available on the effects of noise on sea turtles, and the hearing capabilities of sea turtles are still poorly understood. In addition, the U.S. Navy introduced a weighting filter appropriate for sea turtle impact evaluation in their 2017 document titled "*Criteria and Thresholds for U.S. Navy Acoustic and Explosive Effects Analysis (Phase III)*." That weighting has been applied to impulsive criterion for PTS (204 dB SEL), impulsive criterion for TTS (189 dB SEL), and non-impulsive criteria for TTS (200 dB SEL and 226 dB Lpk) and PTS (220 dB SEL and 232 dB Lpk). The weighting for sea turtles is presented in Figure Z-3.

In a cooperative effort between federal and state agencies, interim criteria were developed to assess the potential for injury to fishes exposed to pile-driving sounds. These noise injury thresholds have been established by the Fisheries Hydroacoustic Working Group, which was assembled by NOAA Fisheries with thresholds subsequently adopted by NOAA Fisheries. The NOAA Fisheries Greater Atlantic Regional Fisheries Office (GARFO) has applied these standards for assessing the potential effects of ESA-listed fish species exposed to elevated levels of underwater sound produced during pile-driving, which were just recently updated (NOAA Fisheries 2019) These noise thresholds have been adopted by GARFO and are based on sound levels that have the potential to produce injury or illicit a behavioral response from fishes (Table Z-3).

A Working Group organized under the American National Standards Institute-Accredited Standards Committee S3, Subcommittee 1, Animal Bioacoustics, also developed sound exposure guidelines for fish and sea turtles (Table Z-4; Popper et al. 2014). They identified three types of fishes depending on how they might be affected by underwater sound. The categories include fishes with no swim bladder or other gas chamber (e.g., flounders, dab, and other flatfishes); fishes with swim bladders in which hearing does not involve the swim bladder or other gas volume (e.g., salmonids); and fishes with a swim bladder that is involved in hearing (e.g., channel catfish).

Table Z-2. Acoustic Threshold Levels for Marine Mammals

Hearing Group	Impulsive Sounds			Non-Impulsive Sounds		
	Permanent Threshold Shift Onset	Temporary Threshold Shift Onset	Behavior	Permanent Threshold Shift Onset	Temporary Threshold Shift Onset	Behavior
Low-frequency cetaceans	219 dB ($L_{p,pk}$) 183 ($L_{E,\,LF,\,24h}$)	213 dB ($L_{p,pk}$) 168 dB ($L_{E,\,LF,\,24h}$)	160 dB (L_p)	199 dB ($L_{E,\,LF,\,24h}$)	179 dB ($L_{E,\,LF,\,24h}$)	120 dB (L_p)
Mid-frequency cetaceans	230 dB ($L_{p,pk}$) 185 dB ($L_{E,\,MF,\,24h}$)	224 dB ($L_{p,pk}$) 170 dB ($L_{E,\,MF,\,24h}$)		198 dB ($L_{E,\,MF,\,24h}$)	178 dB ($L_{E,\,MF,\,24h}$)	
High-frequency cetaceans	202 dB ($L_{p,pk}$) 155 dB ($L_{E,\,HF,\,24h}$)	196 dB ($L_{p,pk}$) 140 dB ($L_{E,\,HF,\,24h}$)		173 dB ($L_{E,\,HF,\,24h}$)	153 dB ($L_{E,\,HF,\,24h}$)	
Phocid pinnipeds underwater	218 dB ($L_{p,pk}$) 185 dB ($L_{E,\,PW,\,24h}$)	212 dB ($L_{p,pk}$) 170 dB ($L_{E,\,PW,\,24h}$)		201 dB ($L_{E,\,PW,\,24h}$)	181 dB ($L_{E,\,PW,\,24h}$)	

Sources: Southall et al. 2019; NOAA Fisheries 2018
$L_{E,\,24h}$ = cumulative sound exposure over a 24 hour period (dB re 1 μPa^2·s);
$L_{p,pk}$ = peak sound pressure (dB re 1 μPa);
L_p = root mean square sound pressure (dB re 1 μPa)

Table Z-3. Acoustic Threshold Levels for Fishes and Sea Turtles

Hearing Group	Impulsive Signals		Non-impulsive Signals		Behavior (Impulsive and Non-impulsive)
	Injury	Temporary Threshold Shift Onset	Injury	Temporary Threshold Shift Onset	
Fishes	206 dB ($L_{p,pk}$) 187 dB ($L_{E,\,24h}$)	--	--	--	150 dB (L_p)
Sea turtles	232 dB ($L_{p,pk}$) 204 dB ($L_{E,\,TUW,\,24h}$)	226 dB ($L_{p,pk}$) 189 dB ($L_{E,\,TUW,\,24h}$)	220 dB ($L_{E,\,TUW,\,24h}$)	200 dB ($L_{E,\,TUW,\,24h}$)	175 dB (L_p)

Sources: Stadler and Woodbury 2009; NOAA Fisheries 2019; Blackstock et al. 2017; Department of the Navy 2017
$L_{E,\,24h}$ = cumulative sound exposure over a 24 hour period (dB re 1 μPa^2·s);
$L_{p,pk}$ = peak sound pressure (dB re 1 μPa);
L_p = root mean square sound pressure (dB re 1 μPa)

Table Z-4. Acoustic Threshold Levels for Fishes and Sea Turtles

Hearing Group	Impulsive Sounds			Non-Impulsive Sounds	
	Mortality and Potential Mortal Injury	Recoverable Injury	Temporary Threshold Shift	Recoverable Injury	Temporary Threshold Shift
Fishes without swim bladders	> 213 dB ($L_{p,pk}$) > 219 dB ($L_{E,\ 24h}$)	> 213 dB ($L_{p,pk}$) > 216 dB ($L_{E,\ 24h}$)	> 186 dB ($L_{E,\ 24h}$)	--	--
Fishes with swim bladder not involved in hearing	207 dB ($L_{p,pk}$) 210 dB ($L_{E,\ 24h}$)	207 dB ($L_{p,pk}$) 203 dB ($L_{E,\ 24h}$)	>186 dB ($L_{E,\ 24h}$)	--	--
Fishes with swim bladder involved in hearing	207 dB ($L_{p,pk}$) 207 dB ($L_{E,\ 24h}$)	207 dB ($L_{p,pk}$) 203 dB ($L_{E,\ 24h}$)	186 dB ($L_{E,\ 24h}$)	170 dB (L_p)	158 dB (L_p)
Sea turtles	207 dB ($L_{p,pk}$) 210 dB ($L_{E,\ 24h}$) 232 dB ($L_{p,pk}$) PTS	(N) High (I) Low (F) Low	226 dB ($L_{p,pk}$)	--	--
Eggs and larvae	207 dB ($L_{p,pk}$) 210 dB ($L_{E,\ 24h}$)	(N) Moderate (I) Low (F) Low	(N) Moderate (I) Low (F) Low	--	--

Sources: Popper et al. 2014
$L_{E,\ 24h}$ = cumulative sound exposure over a 24 hour period (dB re 1 μPa^2·s);
$L_{p,pk}$ = peak sound pressure (dB re 1 μPa);
L_p = root mean square sound pressure (dB re 1 μPa)
PTS = permeant threshold shift;
N = near (10s of meters);
I = intermediate (100s of meters);
F = far (1000s of meters);
-- = not applicable

Z.3 EXISTING AMBIENT CONDITIONS

Noise in the ocean associated with natural sources is generated by physical and biological processes and non-natural sources such as shipping. Examples of physical noise sources are tectonic seismic activity, wind, and waves; examples of biological noise sources are the vocalizations of marine mammals and fish. There can be a strong minute-to-minute, hour-to-hour, or seasonal variability in sounds from biological sources. The ambient noise for frequencies above 1 kHz is due largely to waves, wind, and heavy precipitation (Simmonds et al. 2004). Surface wave interaction and breaking waves with spray have been identified as significant sources of noise. Wind induced bubble oscillations and cavitation are also near-surface noise sources. Major storms can give rise to noise in the 10 to 50 kHz frequency band, which can propagate over long distances using the same mechanism and directionality as distant shipping. At areas within distances of 4 to 5 nm (8 to 10 km) of the shoreline, surf noise will be prominent in the frequencies ranging up to a few hundred Hz (Richardson et al. 2013).

A considerable amount of background noise may also be caused by biological activities. Aquatic animals generate sounds for communication, echolocation, prey manipulation, and as byproducts of other activities such as feeding. Biological sound production usually follows seasonal and diurnal patterns, dictated by variations in the activities and abundance of the vocal animals. The frequency content of underwater biological sounds ranges from less than 10 Hz to beyond 150 kHz. Source levels show a great variation, ranging from below 50 dB to more than 230 dB SPL. Likewise, there is a significant variation in other source characteristics such as the duration, temporal amplitude, frequency patterns and the rate at which sounds are repeated (Wahlberg 2012). Typical underwater noise levels show a frequency dependency in relation to different noise sources; the classic curves are given in Wenz (1962).

Anthropogenic noise sources can consist of contributions related to industrial development, offshore oil industry activities, naval or other military operations, and marine research. A predominant contributing anthropogenic noise source is generated by commercial ships and recreational watercraft. Noise from these vessels dominates coastal waters and emanates from the ships' propellers and other dynamic positioning (DP) propulsion devices such as thrusters. The sound generated from main engines, gearboxes, and generators transmitted through the hull of the vessel into the water column is considered a secondary sound source to that of vessel propulsion systems, as is the use of sonar and depth sounders which occur at generally high frequencies and attenuate rapidly. Typically, shipping vessels produce frequencies below 1 kHz, although smaller vessels such as fishing, recreational, and leisure craft may generate sound at somewhat higher frequencies (Simmonds et al. 2004).

There is limited publicly available site-specific ambient sound information collected within the Offshore Project Area. NOAA's SoundMap (NOAA Fisheries 2012), which is a mapping tool that provides maps of the temporal, spatial, and frequency characteristics of man-made underwater noise resulting from various activities, was consulted. Pressure fields associated with different contributors of underwater sound (i.e., shipping and passenger vessels) were summed and the sound pressure level values at frequencies ranging from 50 to 800 Hz were presented for various water column depths. Within the lower 50 Hz frequency range, underwater sound pressure levels were greatest, varying between approximately 80 to 100 dB depending on water depth and proximity to the coastline. The sound contribution and magnitude decreases with increasing frequency, indicating that the noise from shipping and passenger vessels is largely focused within the low-frequency range.

Z.4 ACOUSTIC MODELING METHODOLOGY

Underwater acoustic model simulations were conducted for primary noise-generating activities occurring during Project construction and operation. The following subsections describe the modeling calculations approach, modeled scenarios, and model input values. Please refer to Attachment Z-1 for additional details on the modeling principles and assumptions.

Z.4.1 Sound Propagation Model

Underwater sound propagation modeling was completed using dBSea, a software developed by Marshall Day Acoustics for the prediction of underwater noise in a variety of environments. The model is built by importing bathymetry data and placing noise sources in the environment. Each source can consist of equipment chosen from either the standard or user-defined databases. Noise mitigation methods may also be included. The user has control over the seabed and water properties including sound speed profile, temperature, salinity, and current. Noise levels are calculated to the extent of the bathymetry area. To examine results in more detail, levels may be plotted in cross sections or a detailed spectrum may be extracted at any point in the calculation area. Levels are calculated in third octave bands from 12.5 Hz to 20 kHz. Please refer to Attachment Z-1 for additional details on the modeling principles and assumptions.

Z.4.2 Modeling Environment

The accuracy of underwater noise modeling results is largely dependent on the sound source characteristics and the accuracy of the intrinsically dynamic data inputs and assumptions used to describe the medium between the path and receiver, including sea surface conditions, water column, and sea bottom. Depending on the sound source under review, it was approximated as a point source or a line source, composed of multiple points, extending downward into the water column. Furthermore, determining sound emissions for the various sources are based on a combination of factors, including known properties (e.g., hammer energy) as well as consulting empirical data. The exact information required can never be obtained for all possible modeling situations, particularly for long-range acoustic modeling of temporally varying sound sources where uncertainties in model inputs increase at greater propagation distances from the source. Model input variables incorporated into the calculations are further described in the following subsections.

Z.4.2.1 Bathymetry

Bathymetry data represent the three-dimensional nature of the subaqueous land surface and were obtained from the National Geophysical Data Center (NGDC) and a U.S. Coastal Relief Model (NOAA Satellite and Information Service 2020); the horizontal resolution of this dataset is 3 arc seconds (90 m). NGDC's 3 arc-second U.S. Coastal Relief Model provides the first comprehensive view of the U.S. coastal zone, integrating offshore bathymetry with land topography into a seamless representation of the coast. The Coastal Relief Model spans the U.S. east and west coasts, the northern coast of the Gulf of Mexico, Puerto Rico, and Hawaii, reaching out to, and in places even beyond, the continental slope. The Geophysical Data System is an interactive database management system developed by the NGDC for use in the assimilation, storage, and retrieval of geophysical data. Geographical Data System software manages several types of data including marine trackline geophysical data, hydrographic survey data, aeromagnetic survey data, and gridded bathymetry/topography. The bathymetry is imported into the model and sets the extents for displaying modeled received sound levels; therefore, prior to selecting the bathymetry, coverage test model runs are conducted to determine the anticipated distance to the lowest relevant underwater acoustic threshold values. Additional information regarding bathymetry can be found in Attachment Z-1.

Z.4.2.2 Sediment Characteristics

Sediment type (e.g., hard rock, sand, mud, clay) directly impacts the speed of sound since it is a part of the medium in which the sound propagates. For the immediate Offshore Project Area encompassing the entire Lease Area, the seafloor is expected to be predominantly sand. The geoacoustic properties with information on the compositional data of the surficial sediments were informed by site-specific geophysical and geotechnical data collected by Dominion Energy. The sediment layers and the geoacoustic properties used in the modeling analysis of the monopile and OSS within the lease area are defined in Table Z-5. The term "compressional" refers to the fact that particle motion of the sound wave is in the same direction as propagation. The term "compressional sound speed" refers to the speed of sound in the sediment along the direction of acoustic propagation. The term "compressional attenuation" refers to how much sound (dB) is lost per wavelength (λ) of the signal. Finally, density is the physical density (ρ) of the sediment. Ranges are provided for the different geoacoustic properties because the values vary depending on the location specifically being modeled for a given scenario.

Table Z-5. Geoacoustic Properties of Sub-bottom Sediments as a Function of Depth, Monopile and OSS Modeling Scenarios

Seabed Layer (meters)	Material	Geoacoustic Properties
0 to 12	Sand	Cp = 1650 m/s αs (dB/λ) = 0.8 dB/ λ ρ = 1900 kg/m^3
12 to 15	Clay	Cp = 1500 m/s αs (dB/λ) = 0.2 dB/ λ ρ = 1500 kg/m^3
15 to 22	Dense Silty Sand	Cp = 1650 m/s αs (dB/λ) = 1.1 dB/ λ ρ= 1800 kg/m^3
22 to 31	Stiff Sandy Clay	Cp = 1560 m/s αs (dB/λ) = 0.2 dB/ λ ρ = 1600 kg/m^3
31 to 37	Clay	Cp = 1500 m/s αs (dB/λ) = 0.2 dB/ λ ρ = 1500 kg/m^3
37 to 42	Silty Sand	Cp = 1650 m/s αs (dB/λ) = 1.1 dB/ λ ρ = 1800 kg/m^3
42 to 53	Clay, Fine Sand	Cp = 1598 m/s αs (dB/λ) = 0.5 dB/ λ ρ = 1575 kg/m^3

Seabed Layer (meters)	Material	Geoacoustic Properties
53 to 87	Sandy Silt	Cp = 1605 m/s αs (dB/λ) = 1.0 dB/ λ ρ = 1700 kg/m^3
> 87	Dense Sand	Cp = 1800 m/s αs (dB/λ) = 0.9 dB/ λ ρ = 2000 kg/m^3

A similar table was produced for the nearshore area and used for the acoustic modeling analysis of the cofferdam installation (Table Z-6).

Table Z-6. Geoacoustic Properties of Sub-bottom Sediments as a Function of Depth, Cofferdam Installation

Seabed Layer (meters)	Material	Geoacoustic Properties
0 to 2	Silty Sand	Cp = 1650 m/s αs (dB/λ) = 1.1 dB/ λ ρ = 1800 kg/m^3
2 to 6	Medium Dense Sand	Cp = 1725 m/s αs (dB/λ) = 0.8 dB/ λ ρ = 1950 kg/m^3
6 to 9	Lean Clay	Cp = 1485 m/s αs (dB/λ) = 0.1 dB/ λ ρ= 1300 kg/m^3
9 to 15	Silty Sand	Cp = 1650 m/s αs (dB/λ) = 1.1 dB/ λ ρ = 1800 kg/m^3
15 to 26	Sandy Lean Clay	Cp = 1560 m/s αs (dB/λ) = 0.2 dB/ λ ρ = 1600 kg/m^3
26 to 32	Medium Dense Sand	Cp = 1725 m/s αs (dB/λ) = 0.8 dB/ λ ρ = 1950 kg/m^3

Z.4.2.3 Seasonal Sound Speed Profiles

The speed of sound in sea water depends on the temperature T (^{o}C), salinity S (ppt), and depth D (m), and can be described using sound speed profiles. Oftentimes, a homogeneous or mixed layer of constant velocity is present in the first few meters. It corresponds to the mixing of superficial water through surface agitation. There can also be other features such as a surface channel, which corresponds to sound velocity increasing from the surface down. This channel is often due to a shallow isothermal layer appearing in winter conditions but can also be caused by water that is very cold at the surface. In a negative sound gradient, the sound speed decreases with depth, which results in sound refracting downward, which may result in increased bottom losses with distance from the source. In a positive sound gradient as predominantly present in the winter season, sound speed increases with depth and the sound is, therefore, refracted upward, which can aid in long-distance sound propagation. The construction timeframe for WTG and Offshore Substation Foundations with underwater noise impact is expected from May to October. For the construction modeling scenarios, the average sound speed profile for this construction period was selected.

The speed of sound profile information was obtained using the NOAA Sound Speed Manager software incorporating the World Ocean Atlas 2009 extension algorithms. Pile driving is not planned for the months of November through April; therefore, the speed of sound profile information for those months was not evaluated. The average sound speed sound profile was directly inputted into the dBSea model to be more representative of the anticipated construction timeframe. Additional details pertaining to the sound speed profile sensitivity analysis conducted for the Project can be found in Attachment Z-1.

Z.4.2.4 Threshold Range Calculations

To determine the ranges to the defined threshold isopleths, a maximum received level-over-depth approach was used. This approach uses the maximum received level that occurs within the water column at each calculation point. Both the R_{max} and the $R_{95\%}$ ranges were calculated for each of the regulatory thresholds. The R_{max} is the maximum range in the model at which the sound level was calculated. The $R_{95\%}$ is the maximum range at which a sound level was calculated excluding 5% of the R_{max}. The $R_{95\%}$ excludes major outliers or protruding areas associated with the underwater acoustic modeling environment. Regardless of shape of the calculated isopleths, the predicted range encompasses at least 95 percent of the area that would be exposed to sound at or above the specified level. All distances to injury thresholds presented in this Underwater Acoustic Assessment Report are presented in terms of the $R_{95\%}$ range.

Z.4.2.5 Goal Post Pile Installation Calculation Methodology

For the goal post pile installation two separate calculation methodologies were used to calculate distances to Level A (PTS onset) and Level B acoustic harassment thresholds, both following prescriptive guidance provided by NOAA Fisheries. The Level A harassment cumulative PTS criteria were applied to the formulaic spreadsheet provided by NOAA Fisheries, which has been updated to reflect NOAA Fisheries' 2018 Revisions to Technical Guidance (NOAA Fisheries 2018). PTS onset acoustic thresholds estimated in the NOAA Fisheries User Spreadsheets rely on overriding default values, calculating individual adjustment factors, and using the difference between levels with and without weighting functions for each of the five categories of hearing groups. The new adjustment factors in the spreadsheets allow for the calculation of SEL and Lpk distances and account for the accumulation (Safe Distance Methodology) using the source characteristics (duty cycle and speed) after Silve et al. (2014). The impact pile driving evaluated was input using the impact pile driving specific tab within the NOAA Fisheries User Spreadsheet as appropriate.

The Level B harassment distance was calculated using a simple spread calculation to estimate the horizontal distance to the 160 dB re 1 µPa isopleth:

$$SPL(r) = SL - PL(r) \quad (6)$$

Where: SPL = sound pressure level (dB re 1 µPa)
r = range (m)
SL = source level (dB re 1 µPa m)
PL = propagation loss as a function of distance

Propagation loss is calculated using:

$$PL(r) = 20\log_{10}(r) + a(f) * r/1000 \quad (7)$$

Z.5 ACOUSTIC MODELING SCENARIOS

The representative acoustic modeling scenarios were derived from descriptions of the expected construction activities and operational conditions through consultations between the Project design and engineering teams. The scenarios modeled were ones where potential underwater noise impacts of marine species were anticipated, including impact and vibratory pile-driving associated with WTG and OSS Jacket Foundation as well as cofferdam installation required in the nearshore environment for Trenchless Installation. The majority of modeling scenarios occur at representative WTG locations, which will be monopile foundations; one at a shallow water depth of 69 ft (21 m) (Universal Transverse Mercator [UTM] Coordinates: 459,846 m, 4,075,324 m) within the Lease Area and another at a deep-water depth of 121 ft (37 m) (UTM Coordinates: 480,666 m, 4,089,018 m) within the Lease Area. Jacket pin pile installation was modeled at a third location associated with the OSSs with a water depth of 92 ft (28 m) (UTM Coordinates: 474,075 m, 4,085,595 m). These locations were selected so that the effects of sound propagation at the range of water column depths occurring within the Lease Area could be observed. The Project Area showing the modeled locations and bathymetry are displayed in Figure Z-4.

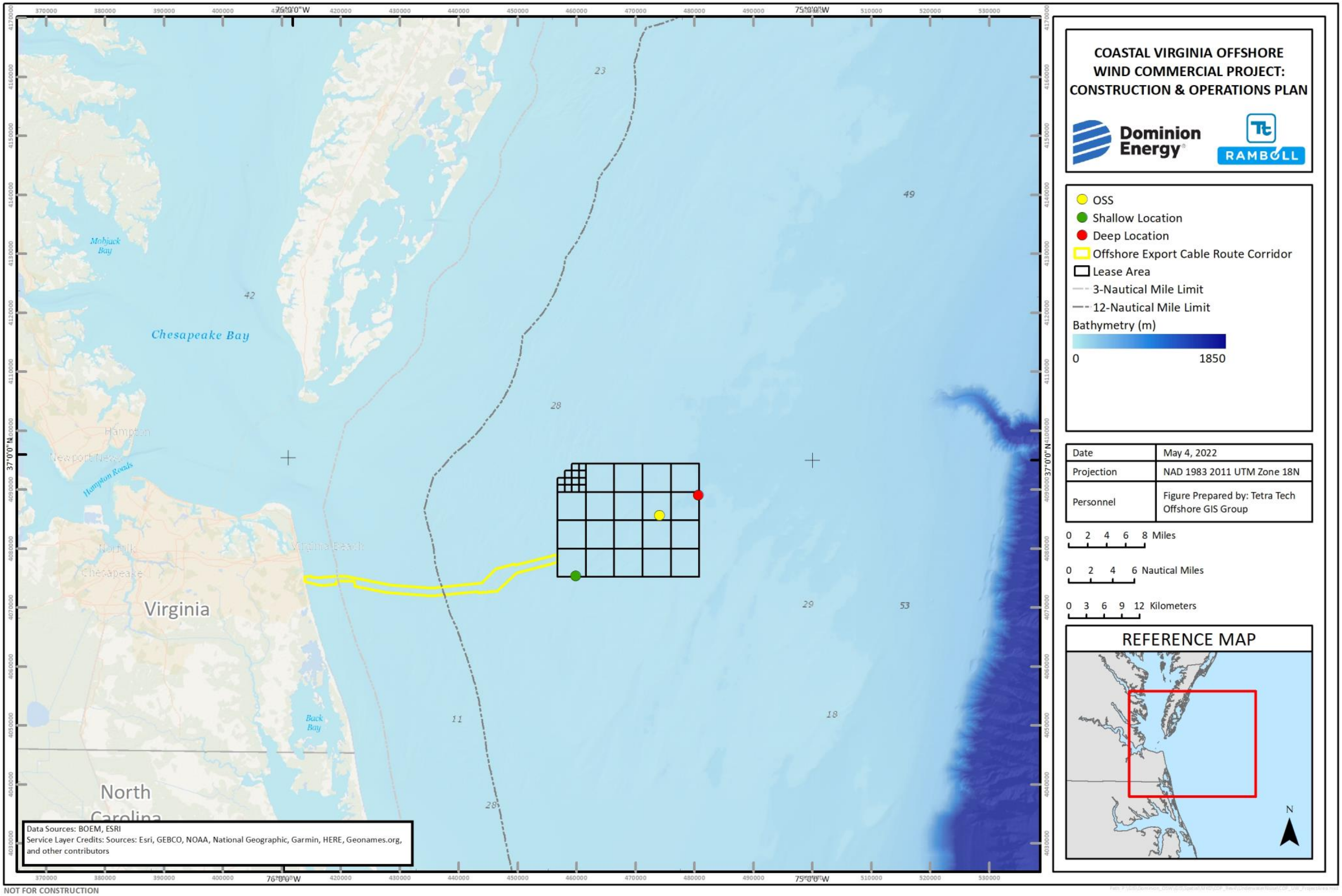

Figure Z-4. **Project Area and Bathymetry**

Modeling requires understanding of the sound source level or theoretical sound level. Impact pile-driving of offshore wind energy facilities involve piles of significantly higher pile diameters and hammer forces. Tetra Tech, Inc. (Tetra Tech) developed its empirical model based on literature, engineering guidelines, and underwater source measurements and acoustic modeling assessments of similar equipment and activities. Underwater acoustic measurement results obtained during Pilot project pile installation activities were also incorporated into the empirical model. The empirical model calculation methodology is described in detail in Attachment Z-2, Impact Pile Driving Sound Source Development for impact piling, and that methodology was used to determine the Lpk and SEL sound source levels for the scenarios including impact piling activities.

The Project is also proposing incorporating a vibratory hammer for installation of the monopiles. The vibratory hammer will be used to mitigate the pile-run risk. The vibratory hammer will be used until the pile reaches a depth in which the impact hammer can be safely used and avoid the risk of pile-run. This depth is location specific and subject to soil conditions. However, for the purpose of this analysis a conservative vibratory hammer duration from 30 to 60 minutes was used for single-pile installations. The source level for the vibratory hammer was developed using an empirical model developed by iTAP. The empirical model calculation methodology is described in detail in Attachment Z-3, Vibratory Pile Driving Sound Source Development for vibratory piling.

A summary of construction and operational scenarios included in the underwater acoustic modeling analysis is provided in Table Z-7. The model accounts for differences in hammer energy, number of strikes, installation duration, sound source level, and pile progression as appropriate for the jacket pin piles and/or monopiles. This analysis also assumes a conservative duration for the use of the vibratory hammer. The pile diameters selected for the impact pile-driving modeling scenarios were based on the proposed Project Design Envelope considerations provided by Dominion Energy. These scenarios include a standard installation and a hard-to-drive installation for the monopile. The subsections that follow provide more detailed information about the parameters used to model the noise sources associated with each scenario. Scenarios 1 through 3 occur at representative WTG locations while Scenario 4 occurs at a representative OSS location. Scenario 5 pertains to cofferdam installation and Scenario 6 pertains to goal post installation. There may be up to nine cofferdams used; however, the center cofferdam location was used as representative in the acoustic modeling analysis.

The pile driving sound installation scenarios including the broadband sound source levels are summarized in Table Z-7. For the monopile modeling, the scenarios include a standard installation, hard-to-drive installation, and the installation of two monopiles per day. These modeling scenarios are assumed to cover the range of anticipated monopile installation scenarios. Scenario 1 covers the installation of one monopile using standard methods; Scenario 2 covers the installation of one monopile using hard-to-drive methods; and Scenario 3 corresponds to the installation of two monopiles in one day, which would not occur concurrently. The installation of the two monopiles per day scenario, Scenario 3, assumed a standard installation and a hard-to-drive installation at the same representative WTG location. For all of the monopile scenarios, it was assumed that the maximum rated hammer energy of 4,000 kilojoules (kJ) would be employed; however, that hammer energy assumption is considered conservative. The actual transferred energy to the pile during installation will be less than the maximum rated hammer energy, with losses in energy from sources such as heat and friction. For the pin pile modeling scenario, it is assumed that two pin piles would be installed per day with a maximum rated hammer energy of 3,000 kJ.

Table Z-7. Underwater Acoustic Modeling Scenarios

Scenario	Activity Description	Maximum Hammer Energy (kilojoules)	Duration of Pile Installation (minutes)	Total Hammer Blows	Location (UTM Coordinates) for Modeling Locations	Sound Source Level (No Attenuation)
Scenario 1: Standard Driving Installation	Monopile Foundation (includes 1 pile per day): 9.5 m	Vibratory Pile Driving	60	N/A	Deep: 480,666 m, 4,089,018 m Shallow: 459,846 m, 4,075,324 m	202 $L_{E,1sec}$
		Impact Pile Driving: 4,000	85	3,240		249 $L_{p,pk}$ 226 $L_{E,1sec}$ 236 L_p
Scenario 2: Hard to Drive Installation	Monopile Foundation (includes 1 pile per day): 9.5 m	Vibratory Pile Driving	30	N/A	Deep: 480,666 m, 4,089,018 m Shallow: 459,846 m, 4,075,324 m	202 $L_{E,1sec}$
		Impact Pile Driving: 4,000	99	3,720		249 $L_{p,pk}$ 226 $L_{E,1sec}$ 236 L_p
Scenario 3: One Standard and One Hard to Drive Installation	Monopile Foundation (includes 2 piles per day): 9.5 m	Vibratory Pile Driving	90	N/A	Deep: 480,666 m, 4,089,018 m Shallow: 459,846 m, 4,075,324 m	202 $L_{E,1sec}$
		Impact Pile Driving: 4,000	184	6,960		249 $L_{p,pk}$ 226 $L_{E,1sec}$ 236 L_p
Scenario 4: OSS Piled Jacket Foundation	Piled Jacket Foundation (includes 2 piles per day): 2.8 m	Vibratory Pile Driving	120	N/A	OSS: 474,075 m, 4,085,595 m	194 $L_{E,1sec}$
		Impact Pile Driving: 3,000	410	15,120		240 $L_{p,pk}$ 214 $L_{E,1sec}$ 224 L_p
Scenario 5: Cofferdam Installation	Cofferdam Installation, Vibratory Pile-Driving	Vibratory Pile Driving	60	N/A	414,213 m, 4,074,917 m	195 $L_{E,1sec}$
Scenario 6: Goal Post Pile Installation	Goal Post Piles (2 per day)	Impact Pile Drive	130	260	414,396 m, 4,074,917 m	210 $L_{p,pk}$ b/ 183 $L_{E,1sec}$ b/ L_p a/

Notes:
a/ Source levels based on the SERO Pile Driving Noise Data Spreadsheet – Humboldt Bay Bridges (CALTRANS 2015)
N/A is included in the table for vibratory pile driving activities, which are not quantified in terms of total hammer blows.

Z.5.1 Impact and Vibratory Pile-Driving of WTG and Offshore Substation Foundations

Impact pile-driving involves weighted hammers that pile drive foundations into the seafloor. Different methods for lifting the weight associated with the pile driver include hydraulic, steam, or diesel. The acoustic energy is created upon impact; the energy travels into the water along different paths: (1) from the top of the pile where the hammer hits, through the air, into the water; (2) from the top of the pile, down the pile, radiating into the air while traveling down the pile, from air into water; (3) from the top of the pile, down the pile, radiating directly into the water from the length of pile below the waterline; and (4) down the pile radiating into the ground, traveling through the ground and radiating back into the water. Near the pile, acoustic energy arrives from different paths with different associated stage and time lags, which creates a pattern of destructive and constructive interference. Further away from the pile, the water- and seafloor-born energy are the dominant pathways. The underwater noise generated by a pile-driving strike depends primarily on the following factors:

- The impact energy and type of pile-driving hammer;
- The size and type of the pile;
- Water depth; and
- Subsurface hardness in which the pile is being driven.

As indicated in Table Z-7 two sites were modeled to represent the potential WTG locations for foundations within the Lease Area. Since actual WTG locations have not been finalized, one location was selected in the shallowest water depth within the Lease Area while the other location was selected in the deepest water depth within the Lease Area: 69 ft (21 m) and 121 ft (37 m). For the jacket pin pile installation, a representative location was selected. It is expected that by modeling these three locations, the range of anticipated sound fields resulting from pile-driving and vibratory hammer activities will be represented. Propagation modeling was conducted using the maximum projected blow energy to calculate Lpk and SPL; however, a soft start and pile progression were also incorporated into the model to calculate SEL for each pile scenario as shown in Table Z-8. As described in Attachment Z-2, the SPL is related the SEL by an average pulse duration of 0.09 seconds.

Table Z-8. Pile-Driving Progression Summary

Pile Diameter	Hammer Energy %	Hammer Energy	Duration (minutes)	Blows per Minute	Total Number of Blows
Scenario 1: Standard Driving Installation	20	800	8	42	324
	40	1,600	32	40	1,296
	80	3,200	36	36	1,296
	100	4,000	9	36	324
Scenario 2: Hard to Drive Installation	20	800	13	42	558
	40	1,600	19	40	744
	80	3,200	31	36	1,116
	100	4,000	36	36	1,302
Scenario 3: One Standard and One Hard to Drive Installation	20	800	21	42	882
	40	1,600	51	40	2,040
	80	3,200	67	36	2,412
	100	4,000	45	36	1,626
Scenario 4: OSS Piled Jacket Foundation	20	600	36	42	1,512
	40	1,200	38	40	1,512
	80	2,400	84	36	3,024
	100	3,000	252	36	9,072

The monopile and pin pile-driving scenarios were both modeled using a vertical array of point sources spaced at 1-meter intervals, distributing the sound emissions from pile-driving throughout the water column. The vertical array was assigned third-octave band sound characteristics adjusted for site-specific parameters discussed above, including expected hammer energy and number of blows. Third octave band center frequencies from 12.5 Hz up to 20 kHz were used in the modeling. In addition, a constant 15 dB/decade roll-off was applied to the modeled spectra for the monopile scenario after the second (and last) spectral peak as to not eliminate any prevalent characteristics of the sound source spectrum that may influence sound propagation. The spectra used in the modeling are shown in Figure Z-5 showing the 15 dB/decade roll-off assumed for the monopile sound sources. A roll-off is a filter, which can be imposed on a signal at either the low- or high-frequency range in order to more closely match expected sound propagation characteristics of that signal indicated by modeling or measurement results. Applying the 15 dB/decade roll-off is a conservative measure, which was based on guidance from NOAA Fisheries regarding the representation of monopile pile-driving sound source characteristics in the high-frequency range, which is the frequency range beyond the maximum peaks observed within the spectrum. The 15 dB/decade roll-off is applied by subtracting 1.5 dB from the preceding one-third octave band sound pressure level, and it is conservative in that it essentially allows for a more gradual drop in the high-frequency sound pressure level than what may actually be realistic. Additional detail pertaining to how the monopile and pin pile spectral source levels were calculated is provided in Attachment Z-2.

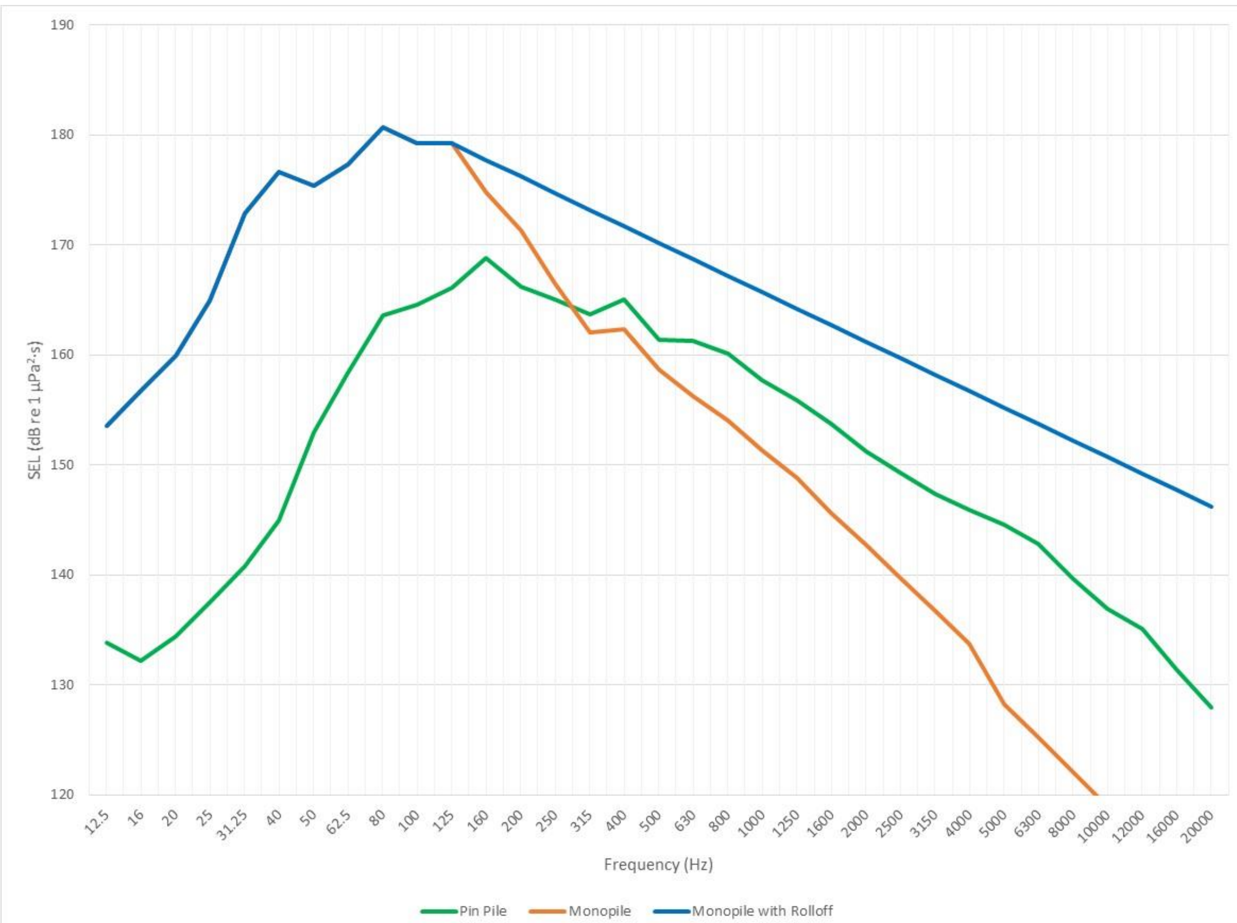

Figure Z-5. Monopile and Pin Pile Spectral Source Levels

Vibratory pile driving will also be used as an installation method for WTG or OSS Jacket Foundations. There is very limited publicly available information pertaining to vibratory pile driving installation of pile diameters of this size; however, by using reference data from sources such as ITAP (Gerke and Bellmann

2012), the California Department of Transportation (CALTRANS 2015), and from measurements collected by Tetra Tech on another facility, the spectral source levels were derived as shown in Figure Z-6.

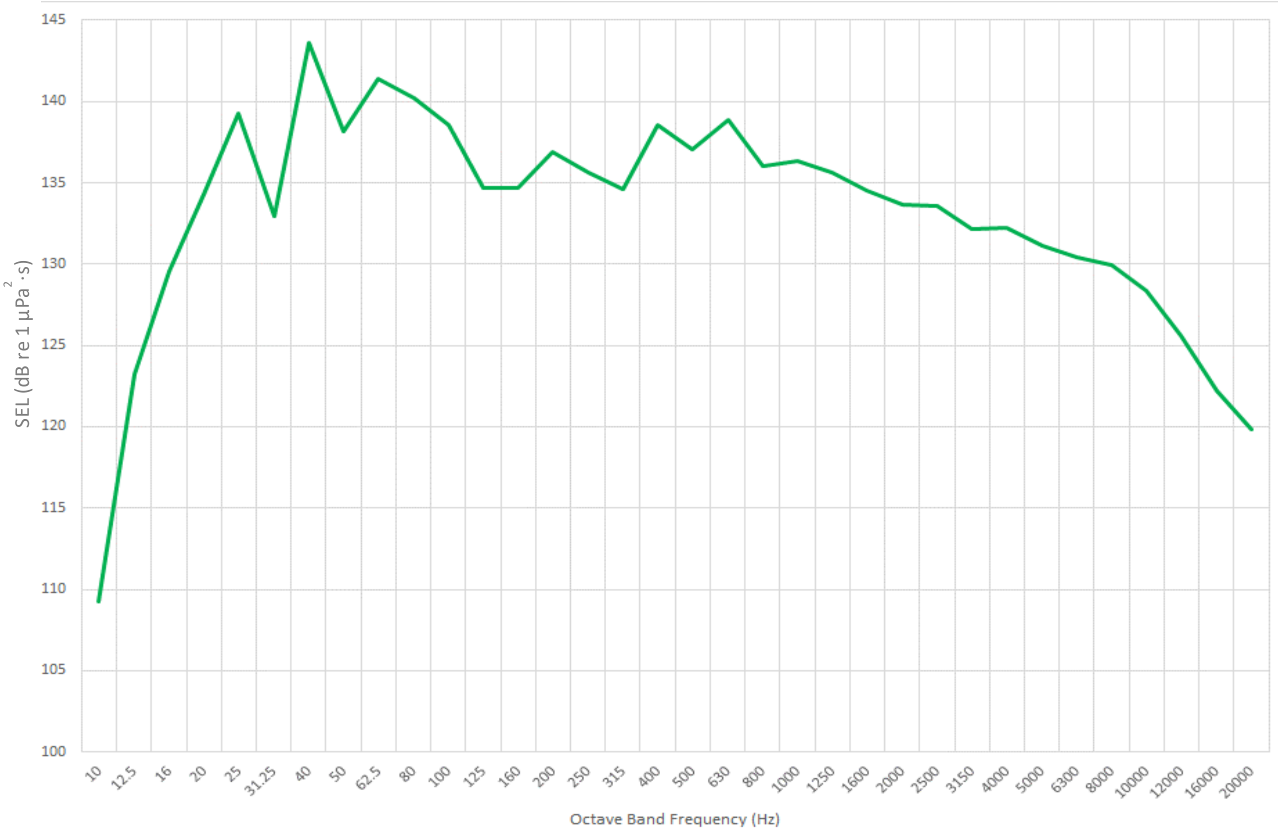

Figure Z-6. Vibratory Pile Driving Spectral Source Levels for Offshore Foundation Installation

Z.5.2 Vibratory Pile-Driving Associated with Cofferdam Installation

Up to nine temporary cofferdams will be installed at the Offshore Nearshore Trenchless Installation Punch-Out as the preferred installation method to facilitate lowering the Direct Pipe burial to 6.6 ft (2 m) below the seabed to alleviate the need for additional cable protection and to minimize the release of sediment and drilling fluids in the nearshore portion of the Offshore Export Cable Route Corridor. Since all nine potential cofferdam locations were located within close proximity to each other one, the center location was used as the representative location for the purpose of the acoustic modeling analysis.

If the preferred installation method is used, the temporary offshore cofferdams will be constructed by installing 0.51 m (20 inch) steel sheet piles in a tight configuration around an area of approximately 6.1 m by 15 m (20 ft by 50 ft). Vibratory pile drivers install piling into the ground by applying a rapidly alternating force to the pile. This is generally accomplished by rotating eccentric weights about shafts. Each rotating eccentric produces a force acting in a single plane and directed toward the centerline of the shaft. The weights are set off-center of the axis of rotation by the eccentric arm. If only one eccentric arm is used, in one revolution a force will be exerted in all directions, giving the system significant lateral whip. To avoid this problem, the eccentric arms are paired so the lateral forces cancel each other, leaving only axial force for the pile.

In general, vibratory pile-driving is less noisy than impact pile-driving. For estimating source levels and frequency spectra, the vibratory pile driver was estimated assuming an 1,800 kilonewton (kN) vibratory force. Modeling was accomplished using adjusted one-third-octave band vibratory pile-driving source levels from measurements of a similar offshore construction activity and adjusted to account for the estimated force necessary for driving the temporary offshore cofferdam sheet piles. The assumed sound source level for vibratory pile-driving corresponded to 195 dB SEL. The frequency distribution of the vibratory pile-driving sound source is displayed in Figure Z-7.

Figure Z-7. Vibratory Pile-Driving Spectral Source Levels for Cofferdam Installation

Z.5.3 Pile-Driving Associated with Goal Post Installation

Trenchless Installation will consist of Direct Steerable Pipe Thrusting (DSPT), which combines some of the benefits of both microtunneling and horizontal directional drilling. The overall bore path of a DSPT installation may be similar to that of an horizontal directional drilling alignment or shallower depending on subsurface conditions.

The DSPT construction process also incorporates goal post piles to guide the casing progress. The location of goal post installation will be near the punchout location 1,000 to 1,800 ft (304 to 549 m) offshore of the Cable Landing Location.

The goal posts would be installed with an impact hammer. Goal posts would be up to 1.07 m (42 in) steel pipe piles, with up to two installed per day for a total hammer duration of 130 minutes. The strike duration would be 0.5 to 2 seconds and there would be 260 strikes per pile. A maximum of 12 goal posts spaced 50 ft apart would be needed for each of the 9 Direct Pipe locations, for a total of 108 piles. All pile installation activities will occur only in daylight hours. They will start no earlier than 60 minutes after civil sunrise and end no later than 60 minutes before civil sunset to allow for proper visual monitoring. The assumed sound source level for impact pile-driving of the goal post installation corresponds to 183 dB SEL (Table Z-7).

Z.5.4 Cable Lay Operations

Specialist vessels designed for laying and burying cables on the seabed will be used to install the Offshore Export and Inter-Array Cables. The cables will be buried using a jet trencher or plow. Throughout the cable lay process, it is assumed that a DP-enabled cable lay vessel is the maximum design scenario. A DP-enabled cable lay vessel maintains its position (fixed location or predetermined track) by means of its propellers and thrusters using a global positioning system, which describes the ship’s position by sending information to an onboard computer that controls the thrusters. DP vessels possess the ability to operate with positioning accuracy, safety, and reliability without the need for anchors, anchor handling tugs, and mooring lines. The underwater noise produced by subsea trenching operations depend on the equipment used and the nature of the seabed sediments, but will be predominantly generated by vessel thruster use.

Thruster sound source levels may vary, in part due to technologies employed and are not necessarily dependent on either vessel size, propulsion power, or the activity engaged. DP positioning thruster noise is non-impulsive and continuous in nature and is not expected to result in harassment. Vessel sound sources are sufficiently low that no injury is expected. Distances within which injury and/or harassment might occur are generally short. For these reasons, a detailed acoustic modeling analysis was not conducted.

Z.5.5 WTG Operations

When the WTGs are operational, noise and vibration are transmitted into the sea by the structure of the tower itself, and manifests as low-frequency noise. Other sound transmission pathways are via the monopile and the seabed, or through the air and air/water interface, but those pathways are unlikely to be as important as the pathway directly through the monopile or jacket legs (Nedwell et al. 2004). Source levels from operating offshore WTGs that have monopile foundations show peak frequencies occurring predominantly below 500 Hz, and that the apparent source level ranges from 140 to 153 dB (Nedwell et al. 2004). Similar measurements by Nedwell indicate that the steady state background in an offshore oceanic environment also occurs within this frequency range, which implies masking effects of operational WTG noise. The available field data showed that although the absolute level of turbine noise increases with increasing wind speed, the noise level relative to background noise (i.e., from wave action, entrained bubbles) remained relatively constant.

Z.6 NOISE MITIGATION

As discussed in this report, Dominion Energy is considering the use of both impact and vibratory pile driving to install the WTG and offshore substation foundations. Noise mitigation strategies related to both methodologies are discussed.

Z.6.1 Impact Pile Driving

With regard to impact pile driving and, detailed in Section Z.5.1, Dominion Energy intends to implement noise mitigation in the form of the "soft-start" technique when impact piling. The soft start technique involves initially driving a pile using a low hammer energy. As the pile is driven further into the soil, the hammer energy is increased as necessary to achieve soil penetration. This technique gives fish and marine mammals an opportunity to move out of the area before full-powered impact pile-driving begins. The intended pile progressions for both the monopile and pin pile foundation installation are presented in Table Z-7.

In addition to the application of the soft-start technique, other devices may be considered to mitigate impact pile-driving sound levels. There are several types of sound attenuation devices including bubble curtains, noise mitigation screen (cofferdam type), Hydro Sound Dampers, and the AdBm noise mitigation system. The most commonly considered mitigation strategy is the use of bubble curtains. Bubble curtains create a column of air bubbles rising around a pile from the substrate to the water surface. Because air and water have a substantial impedance mismatch, the bubble curtain acts as a reflector. In addition, the air bubbles absorb and scatter sound waves emanating from the pile, thereby reducing the sound energy. Bubble curtains may be confined or unconfined. These systems may be deployed in series, such as a double bubble curtain with two rings of bubbles encircling a pile. Attenuation levels also vary by type of system, frequency band, and location. Small bubble curtains have been measured to reduce sound levels from approximately 10 dB to more than 20 dB but are highly dependent on depth of water and current, and configuration and operation of the curtain (Koschinski and Lüdemann 2013; Bellmann 2014; Austin et al. 2016). Larger bubble curtains tend to perform better and more reliably, particularly when deployed with two rings. Encapsulated bubble systems and Hydro Sound Dampers are effective within their targeted frequency ranges, e.g., 100 to 800 Hz, and when used in conjunction with a bubble curtain can further reduce noise, resulting in prolonged pulse duration or a reduced impact energy (Koschinski and Lüdemann 2020).

Effectiveness of bubble curtains is variable and depends on many factors, including the bubble layer thickness, the total volume of injected air, the size of the bubbles relative to the sound wavelength, and whether the curtain is completely closed. Decreased noise reduction has been found in cases of strong currents or sub-optimal configuration (Bellmann et al. 2017). As water depth increases, the opportunity for current-based disruption of the bubble curtain increases. In general, bubble curtain effectiveness decreases as the water depth increases (Bellmann et al. 2017). With studies reporting variable achievable attenuation rates for bubble curtains, to represent the use of bubble curtains as a mitigation option in the modeling, a range of potential sound reduction was applied to the modeled sound fields associated with impact pile-driving. Attenuation factors of 6 dB and 10 dB were applied to all impact pile-driving scenarios to evaluate potential mitigated underwater noise impacts. The 6 dB and 10 dB attenuation factors have been incorporated into the underwater acoustic analysis based on guidance from NOAA Fisheries and BOEM but can be considered conservative based on measurement results documenting the effectiveness of bubble curtains in other in-water environments (Koschinski and Lüdemann 2020).

Z.6.2 Vibratory Pile Driving

The use of vibratory pile driving itself is considered a noise mitigation strategy. The main energy associated with vibratory pile driving is radiated at lower frequencies compared to impact piling, and sound waves below a lower cut-off frequency do not propagate in shallow waters. As a result, high peak levels can be avoided and continuous sound levels can be kept low. Noise emissions from vibratory pile driving are on the order of 10 to 20 dB ($L_{eq,30s}$) below mitigated impact pile driving at identical monopiles (Koschinski and Lüdemann 2020).

To date, there is very limited information available regarding the use, effectiveness, and noise emissions produced using vibratory pile driving for installation of larger pile diameters consistent with those proposed for the Project; therefore, further investigation is required. Correspondingly, the lower frequencies radiated by vibratory pile driving may restrict the ability of a bubble curtain to allow for a further 6 to 10 dB reduction in noise level. For the purposes of the Project underwater acoustic assessment, a 6 and 10 dB reduction was still applied for consistency. From a feasibility standpoint, it is unlikely that another noise mitigation measure (e.g., isolation casing, cofferdam, etc.) along with a bubble curtain would be implemented in the field.

Z.7 RESULTS

As indicated earlier, using dBSea and site-specific parameters related to the marine environment and Project sound source characteristics, acoustic modeling was completed to assess distances to the various acoustic threshold levels identified in Section Z.2.1, Underwater Acoustic Criteria. The modeling scenarios analyzed are described in Table Z-7 and includes the following:

- Scenario 1: Standard driving installation, which includes both impact pile-driving and vibratory hammer activities for a single pile per day with a diameter of 31.2 ft (9.5 m);
- Scenario 2: Hard-to-drive installation, which includes both impact pile-driving and vibratory hammer activities for a single pile per day with a diameter of 31.2 ft (9.5 m);
- Scenario 3: Standard installation and hard-to-drive installation, which includes both impact pile-driving and vibratory hammer activities for two piles per day with a diameter of 31.2 ft (9.5 m). Installation of two monopiles is not planned to be concurrent;
- Scenario 4: OSS piled jacket foundation installation, which includes a combination of vibratory and impact pile-driving activities for a pile diameter of 8.2 ft (2.5 m);
- Scenario 5: Installation of the cofferdam using a vibratory hammer; and
- Scenario 6: Installation of goal post piles using an impact hammer at a rate of two piles per day.

All activities for scenarios 1 through 3 may occur at the two representative WTG locations within the Lease Area, where one location is in the deepest region (121 ft [37 m]) of the Lease Area while the other location is in the shallowest region (69 ft [21 m]) of the Lease Area. Jacket pin pile installation was modeled at a third location associated with the OSS with a water depth of 92 ft (28 m).

The results for the monopile modeling scenarios are provided in Table Z-9 through Table Z-17 for the deep location and Table Z-18 through Table Z-26 for the shallow location. The results for the jacket pin pile modeling scenario are provided in Table Z-27 through Table Z-35. Tables Z-36 through Z-39 provide results for the cofferdam installation and Tables Z-40 through Z-42 provide results for goal post installation. Results are presented without mitigation and with two different levels of mitigation: a 6-dB reduction and a 10-dB reduction. Noise mitigation requirements and methods have not been finalized at this stage of Project design; therefore, these two levels of reduction were applied to potentially mimic the use of noise mitigation options such as bubble curtains.

The results for the modeled scenarios indicate that the unmitigated distances to the Lpk thresholds are generally below 5,317 ft (1,621 m) for the monopile scenarios and below 2,303 ft (702 m) for the jacket pin pile scenario. Distances to the PTS onset thresholds in terms of SEL are also provided. Similar results are given for fish and sea turtles, with ranges to applicable thresholds varying depending on the threshold value and sound level weighting. Expectedly, the largest ranges to thresholds are the ones for the marine mammal and fish behavioral response, which are 150 dB and 120 dB, respectively. Figures Z-8 through Z-13 provide sound contour figures for the unmitigated SPL levels for the deep, shallow and OSS modeling locations. As indicated prior, use of vibratory pile driving is considered a somewhat mitigative activity, and unmitigated vibratory pile driving modeling results suggest that vibratory pile driving, when compared to impact pile driving results, will likely not dictate noise mitigation measures used for the Project.

The results of the analysis will be used to inform development of evaluation and mitigation measures that will be applied during construction and operation of the Project, in consultation with BOEM, NOAA Fisheries, and any additional appropriate regulatory agencies. The Project will obtain necessary permits to address potential impacts to marine mammals, sea turtles, and fisheries resources from underwater noise and will establish appropriate and practicable mitigation and monitoring measures through discussions with regulatory agencies.

Table Z-9. Marine Mammal Permanent Threshold Shift Onset Criteria Threshold Distances (meters) for Pile-Driving - Deep Location (Monopile)

Scenario	Pile Type	Maximum Hammer Energy (kilojoules)	Installation Duration (minutes)	Mitigation (dB)	Hearing Group a/							
					Low-Frequency Cetaceans		Mid-Frequency Cetaceans		High-Frequency Cetaceans		Phocid Pinnipeds	
					219 $L_{p,pk}$	183 $L_{E,24hr}$	230 $L_{p,pk}$	185 $L_{E,24hr}$	202 $L_{p,pk}$	155 $L_{E,24hr}$	218 $L_{p,pk}$	185 $L_{E,24hr}$
Scenario 1: Standard Driving Scenario	9.5 m Monopile	4,000 b/	85	0	403	12,454	156	663	2,134	5,686	441	3,674
				6	200	6,020	74	320	974	2,946	228	1,852
				10	139	4,683	33	170	718	2,139	158	1,267
Scenario 2: Hard Driving Scenario	9.5 m Monopile	4,000 b/	99	0	403	13,268	156	745	2,134	5,941	441	4,128
				6	200	6,738	74	368	974	3,157	228	2,138
				10	139	5,084	33	222	718	2,217	158	1,481
Scenario 3: One Standard and One Hard Driving Scenario	9.5 m Monopile (2 piles per day)	4,000 b/	184	0	403	15,854	156	944	2,134	7,210	441	4,689
				6	200	7,830	74	483	974	3,713	228	2,570
				10	139	5,940	33	308	718	2,517	158	1,878

Source: NOAA Fisheries 2018

Notes:
a/ Level A Injury
b/ Corresponds to the maximum rated hammer energy; however, actual hammer energy transferred to the pile during installation will be less.

Table Z-10. Sea Turtles and Fish Onset of Injury Threshold Distances (meters) for Pile-Driving – Deep Location (as per Popper et al. 2014) (Monopile)

Scenario	Pile Type	Hammer Energy (kilojoules)	Installation Duration (minutes)	Mitigation (dB)	Hearing Group a/									
					Fish: No Swim Bladder		Fish: Swim Bladder not Involved in Hearing		Fish: Swim Bladder Involved in Hearing		Eggs and Larvae		Sea Turtles	
					213 $L_{p,pk}$	219 $L_{E,24hr}$	207 $L_{p,pk}$	210 $L_{E,24hr}$	207 $L_{p,pk}$	207 $L_{E,24hr}$	207 $L_{p,pk}$	210 $L_{E,24hr}$	207 $L_{p,pk}$	210 $L_{E,24hr}$
Scenario 1: Standard Driving Scenario	9.5 m Monopile	4,000 b/	85	0	664	1,278	1,329	2,457	1,329	3,047	1,329	2,457	1,329	2,457
				6	403	640	664	1,170	664	1,467	664	1,170	664	1,170
				10	258	458	477	881	477	1,089	477	881	477	881
Scenario 2: Hard Driving Scenario	9.5 m Monopile	4,000 b/	99	0	664	1,373	1,329	2,661	1,329	3,253	1,329	2,661	1,329	2,661
				6	403	694	664	1,297	664	1,628	664	1,297	664	1,297
				10	258	509	477	967	477	1,194	477	967	477	967
Scenario 3: One Standard and One Hard Driving Scenario	9.5 m Monopile (2 piles per day)	4,000 b/	184	0	664	1,766	1,329	3,162	1,329	3,886	1,329	3,162	1,329	3,162
				6	403	817	664	1,562	664	1,940	664	1,562	664	1,562
				10	258	625	477	1,145	477	1,439	477	1,145	477	1,145

Source: Popper et al. 2014
a/ Level A Injury
b/ Corresponds to the maximum rated hammer energy; however, actual hammer energy transferred to the pile during installation will be less

Table Z-11. Fish Acoustic Injury Threshold Distances (meters) for Pile-Driving – Deep Location (as per Stadler and Woodbury 2009) (Monopile)

Scenario	Pile Type	Hammer Energy (kilojoules)	Installation Duration (minutes)	Mitigation (dB)	Hearing Group			
					Small Fish a/		Large Fish a/	
					206 $L_{p,pk}$	183 $L_{E,\ 24hr}$	206 $L_{p,pk}$	187 $L_{E,\ 24hr}$
Scenario 1: Standard Driving Scenario	9.5 m Monopile	4,000 b/	85	0	1,477	15,034	1,477	11,907
				6	718	7,593	718	6,195
				10	516	6,195	516	5,005
Scenario 2: Hard Driving Scenario	9.5 m Monopile	4,000 b/	99	0	1,477	16,152	1,477	12,722
				6	718	7,921	718	6,665
				10	516	6,665	516	5,417
Scenario 3: One Standard and One Hard Driving Scenario	9.5 m Monopile (2 piles per day)	4,000 b/	184	0	1,477	17,776	1,477	14,478
				6	718	8,960	718	7,427
				10	516	7,427	516	6,122

Source: Stadler and Woodbury 2009
Notes:
a/ Small fish are fish less than 2 grams in weight. Large fish are 2 grams or larger.
b/ Corresponds to the maximum rated hammer energy; however, actual hammer energy transferred to the pile during installation will be less

Table Z-12. Sea Turtles in National Oceanic Atmospheric Administration Fisheries Behavioral and Acoustic Injury Criteria Threshold Distances (meters) for Pile-Driving – Deep Location (Monopile)

Scenario	Pile Type	Hammer Energy (kilojoule)	Installation Duration (minutes)	Mitigation (dB)	Species				
					Sea Turtle Behavioral	Sea Turtle Temporary Threshold Shift		Sea Turtle Permanent Threshold Shift	
					175 L_p	226 $L_{p,pk}$	189 $L_{E,\ TUW,\ 24hr}$	232 $L_{p,pk}$	204 $L_{E,\ TUW,\ 24hr}$
Scenario 1: Standard Driving Scenario	9.5 m Monopile	4,000 a/	85	0	5,162	231	8,985	116	2,628
				6	2,829	116	5,553	51	1,408
				10	2,146	74	3,766	14	1,044
Scenario 2: Hard Driving Scenario	9.5 m Monopile	4,000 a/	99	0	5,162	231	10,105	116	2,918
				6	2,829	116	5,560	51	1,621
				10	2,146	74	4,279	14	1,142
Scenario 3: One Standard and One Hard Driving Scenario	9.5 m Monopile (2 piles per day)	4,000 a/	184	0	5,162	231	11,998	116	3,986
				6	2,829	116	7,037	51	2,046
				10	2,146	74	5,132	14	1,453

Source: NOAA Fisheries 2019
Note: a/ Corresponds to the maximum rated hammer energy; however, actual hammer energy transferred to the pile during installation will be less

Table Z-13. Threshold Distances (meters) for Sound Pressure Levels (L_p) for Pile Driving at the Deep Location (Monopile)

Scenario	Pile Type	Hammer Energy (kilojoules)	Installation Duration (minutes)	Mitigation (dB)	Sound Pressure Level Thresholds (dB)						
					200 L_p	190 L_p	180 L_p	175 L_p	160 L_p	150 L_p	140 L_p
Scenario 1: Standard Driving Scenario	9.5 m Monopile	4,000 a/	85	0	577	1,495	3,817	5,162	10,669	31,388	--
				6	334	895	2,013	2,829	5,893	16,096	--
				10	225	577	1,495	2,146	4,382	10,669	31,388
Scenario 2: Hard Driving Scenario	9.5 m Monopile	4,000 a/	99	0	577	1,495	3,817	5,162	10,669	31,388	--
				6	334	895	2,013	2,829	5,893	16,096	--
				10	225	577	1,495	2,146	4,382	10,669	31,388
Scenario 3: One Standard and One Hard Driving Scenario	9.5 m Monopile (2 piles per day)	4,000 a/	184	0	577	1,495	3,817	5,162	10,669	31,388	--
				6	334	895	2,013	2,829	5,893	16,096	--
				10	225	577	1,495	2,146	4,382	10,669	31,388

Note: a/ Corresponds to the maximum rated hammer energy; however, actual hammer energy transferred to the pile during installation will be less.

Table Z-14. Marine Mammal PTS Onset Criteria Threshold Distances (meters) for Vibratory Hammer – Deep Location (Monopile)

Scenario	Pile Type	Installation Duration (minutes)	Mitigation (dB)	Hearing Group a/			
				LF Cetaceans	MF Cetaceans	HF Cetaceans	Phocid Pinnipeds
				199 $L_{E, 24hr}$	198 $L_{E, 24hr}$	173 $L_{E, 24hr}$	201 $L_{E, 24hr}$
Scenario 1: Standard Driving Scenario	9.5 m Monopile	60	0	414	0	367	104
			6	199	0	193	52
			10	141	0	85	0
Scenario 2: Hard Driving Scenario	9.5 m Monopile	30	0	356	0	327	84
			6	150	0	105	23
			10	113	0	27	0
Scenario 3: One Standard and One Hard Driving Scenario	9.5 m Monopile (2 piles per day)	90	0	534	0	507	133
			6	256	0	258	72
			10	158	0	120	31

Source: NOAA Fisheries 2018
Note: a/ Level A Injury

Table Z-15. Fish Acoustic Injury Threshold Distances (meters) for Vibratory Hammer – Deep Location (Monopile)

Scenario	Pile Type	Installation Duration (minutes)	Mitigation (dB)	Hearing Group	
				Small Fish a/	Large Fish a/
				183 $L_{E, 24hr}$	187 $L_{E, 24hr}$
Scenario 1: Standard Driving Scenario	9.5 m Monopile	60	0	3,451	2,428
			6	1,831	1,212
			10	1,212	845
Scenario 2: Hard Driving Scenario	9.5 m Monopile	30	0	2,827	1,946
			6	1,564	1,058
			10	1,058	709
Scenario 3: One Standard and One Hard Driving Scenario	9.5 m Monopile (2 piles per day)	90	0	4,349	3,179
			6	2,352	1,655
			10	1,655	1,236

Source: Stadler and Woodbury 2009
Note: a/ Small fish are fish less than 2 grams in weight. Large fish are 2 grams or larger.

Table Z-16. Sea Turtles Behavioral and Acoustic Injury Criteria Threshold Distances (meters) for Vibratory Hammer – Deep Location (Monopile)

Scenario	Pile Type	Installation Duration (minutes)	Mitigation (dB)	Species		
				Sea Turtle Behavioral	Sea Turtle TTS	Sea Turtle PTS
				175 L_p	200 $L_{E,\,TUW,\,24hr}$	220 $L_{E,\,TUW,\,24hr}$
Scenario 1: Standard Driving Scenario	9.5 m Monopile	60	0	251	522	65
			6	134	298	18
			10	82	179	0
Scenario 2: Hard Driving Scenario	9.5 m Monopile	30	0	251	341	40
			6	134	176	9
			10	82	132	0
Scenario 3: One Standard and One Hard Driving Scenario	9.5 m Monopile (2 piles per day)	90	0	251	547	84
			6	134	308	29
			10	82	200	10

Source: NOAA Fisheries 2019

Table Z-17. Threshold Distances (meters) for Sound Pressure Levels (L_p) for Vibratory Hammer at the Deep Location (Monopile)

Scenario	Pile Type	Installation Duration (minutes)	Mitigation (dB)	Sound Pressure Level Thresholds (dB)					
				180 L_p	175 L_p	160 L_p	150 L_p	140 L_p	120 L_p
Scenario 1: Standard Driving Scenario	9.5 m Monopile	85	0	114	251	843	2,288	6,285	21,404
			6	59	134	473	1,359	3,618	12,267
			10	37	82	330	843	2,288	10,114
Scenario 2: Hard Driving Scenario	9.5 m Monopile	99	0	114	251	843	2,288	6,285	21,404
			6	59	134	473	1,359	3,618	12,267
			10	37	82	330	843	2,288	10,114
Scenario 3: One Standard and One Hard Driving Scenario	9.5 m Monopile (2 piles per day)	184	0	114	251	843	2,288	6,285	21,404
			6	59	134	473	1,359	3,618	12,267
			10	37	82	330	843	2,288	10,114

Note: a/ Corresponds to the maximum rated hammer energy; however, actual hammer energy transferred to the pile during installation will be less.

Table Z-18. Marine Mammal Permanent Threshold Shift Onset Criteria Threshold Distances (meters) for Pile-Driving - Shallow Location (Monopile)

Scenario	Pile Type	Maximum Hammer Energy (kilojoules)	Installation Duration (minutes)	Mitigation (dB)	Hearing Group a/							
					Low-Frequency Cetaceans		Mid-Frequency Cetaceans		High-Frequency Cetaceans		Phocid Pinnipeds	
					219 $L_{p,pk}$	183 $L_{E,\,24hr}$	230 $L_{p,pk}$	185 $L_{E,\,24hr}$	202 $L_{p,pk}$	155 $L_{E,\,24hr}$	218 $L_{p,pk}$	185 $L_{E,\,24hr}$
Scenario 1: Standard Driving Scenario	9.5 m Monopile	4,000 b/	85	0	344	9,096	123	411	1,827	3,374	371	3,405
				6	182	4,530	67	221	927	1,653	213	1,774
				10	132	3,254	29	99	663	1,089	141	1,229
Scenario 2: Hard Driving Scenario	9.5 m Monopile	4,000 b/	99	0	344	10,032	123	533	1,827	3,995	371	3,809
				6	182	4,848	67	254	927	2,044	213	2,065
				10	132	3,706	29	126	663	1,546	141	1,438
Scenario 3: One Standard and One Hard Driving Scenario	9.5 m Monopile (2 piles per day)	4,000 b/	184	0	344	12,877	123	693	1,827	4,097	371	4,651
				6	182	5,783	67	329	927	2,164	213	2,546
				10	132	4,753	29	213	663	1,651	141	1,685

Source: NOAA Fisheries 2018

Notes:
a/ Level A Injury
b/ Corresponds to the maximum rated hammer energy; however, actual hammer energy transferred to the pile during installation will be less.

Table Z-19. Sea Turtles and Fish Onset of Injury Threshold Distances (meters) for Pile-Driving – Shallow Location (as per Popper et al. 2014) (Monopile)

Scenario	Pile Type	Hammer Energy (kilojoules)	Installation Duration (minutes)	Mitigation (dB)	Hearing Group a/									
					Fish: No Swim Bladder		Fish: Swim Bladder not involved in Hearing		Fish: Swim Bladder involved in Hearing		Eggs and Larvae		Sea Turtles	
					213 $L_{p,pk}$	219 $L_{E,24hr}$	207 $L_{p,pk}$	210 $L_{E,24hr}$	207 $L_{p,pk}$	207 $L_{E,24hr}$	207 $L_{p,pk}$	210 $L_{E,24hr}$	207 $L_{p,pk}$	210 $L_{E,24hr}$
Scenario 1: Standard Driving Scenario	9.5 m Monopile	4,000 b/	85	0	605	989	1,158	1,982	1,158	2,668	1,158	1,982	1,158	1,982
				6	344	489	605	1,021	605	1,301	605	1,021	605	1,021
				10	242	352	402	748	402	955	402	748	402	748
Scenario 2: Hard Driving Scenario	9.5 m Monopile	4,000 b/	99	0	605	1,120	1,158	2,352	1,158	3,089	1,158	2,352	1,158	2,352
				6	344	540	605	1,120	605	1,466	605	1,120	605	1,120
				10	242	389	402	829	402	1,041	402	829	402	829
Scenario 3: One Standard and One Hard Driving Scenario	9.5 m Monopile (2 piles per day)	4,000 b/	184	0	605	1,284	1,158	2,833	1,158	3,747	1,158	2,833	1,158	2,833
				6	344	656	605	1,495	605	1,933	605	1,495	605	1,495
				10	242	477	402	1,002	402	1,322	402	1,002	402	1,002

Source: Popper et al. 2014

Notes:
a/ Level A Injury
b/ Corresponds to the maximum rated hammer energy; however, actual hammer energy transferred to the pile during installation will be less.

Table Z-20. Fish Acoustic Injury Threshold Distances (meters) for Pile-Driving – Shallow Location (as per Stadler and Woodbury 2009) (Monopile)

Scenario	Pile Type	Hammer Energy (kilojoules)	Installation Duration (minutes)	Mitigation (dB)	Hearing Group			
					Small Fish a/		Large Fish a/	
					206 $L_{p,pk}$	183 $L_{E,24hr}$	206 $L_{p,pk}$	187 $L_{E,24hr}$
Scenario 1: Standard Driving Scenario	9.5 m Monopile	4,000 b/	85	0	1,246	10,856	1,246	9,059
				6	663	5,422	663	4,261
				10	445	4,261	445	3,395
Scenario 2: Hard Driving Scenario	9.5 m Monopile	4,000 b/	99	0	1,246	11,712	1,246	9,572
				6	663	5,425	663	4,443
				10	445	4,443	445	3,629
Scenario 3: One Standard and One Hard Driving Scenario	9.5 m Monopile (2 piles per day)	4,000 b/	184	0	1,246	12,788	1,246	10,663
				6	663	6,034	663	5,089
				10	445	5,089	445	4,004

Source: Stadler and Woodbury 2009

Notes:
a/ Small fish are fish less than 2 grams in weight. Large fish are 2 grams or larger.
b/ Corresponds to the maximum rated hammer energy; however, actual hammer energy transferred to the pile during installation will be less

Table Z-21. Sea Turtles in National Oceanic Atmospheric Administration Fisheries Behavioral and Acoustic Injury Criteria Threshold Distances (meters) for Pile-Driving – Shallow Location (Monopile)

Scenario	Pile Type	Hammer Energy (kilojoule)	Installation Duration (minutes)	Mitigation (dB)	Species				
					Sea Turtle Behavioral	Sea Turtle Temporary Threshold Shift		Sea Turtle Permanent Threshold Shift	
					175 L_p	226 $L_{p,pk}$	189 $L_{E,TUW,24hr}$	232 $L_{p,pk}$	204 $L_{E,TUW,24hr}$
Scenario 1: Standard Driving Scenario	9.5 m Monopile	4,000 a/	85	0	4,190	231	7,370	104	2,505
				6	2,507	116	3,957	48	1,347
				10	1,823	74	2,739	10	987
Scenario 2: Hard Driving Scenario	9.5 m Monopile	4,000 a/	99	0	4,190	231	8,075	104	2,772
				6	2,507	116	4,169	48	1,534
				10	1,823	74	3,250	10	1,142
Scenario 3: One Standard and One Hard Driving Scenario	9.5 m Monopile (2 piles per day)	4,000 a/	184	0	4,190	231	9,136	104	3,681
				6	2,507	116	4,880	48	1,983
				10	1,823	74	3,968	10	1,402

Source: NOAA Fisheries 2019
Note: a/ Corresponds to the maximum rated hammer energy; however, actual hammer energy transferred to the pile during installation will be less

Table Z-22. Threshold Distances (meters) for Sound Pressure Levels (L_p) for Pile Driving at the Shallow Location (Monopile)

Scenario	Pile Type	Hammer Energy (kilojoules)	Installation Duration (minutes)	Mitigation (dB)	Sound Pressure Level Thresholds (dB)						
					200 L_p	190 L_p	180 L_p	175 L_p	160 L_p	150 L_p	140 L_p
Scenario 1: Standard Driving Scenario	9.5 m Monopile	4,000 a/	85	0	559	1,483	3,547	4,190	8,682	20,141	--
				6	308	819	1,942	2,507	4,822	10,416	25,922
				10	204	559	1,483	1,823	3,595	8,682	20,141
Scenario 2: Hard Driving Scenario	9.5 m Monopile	4,000 a/	99	0	559	1,483	3,547	4,190	8,682	20,141	--
				6	308	819	1,942	2,507	4,822	10,416	25,922
				10	204	559	1,483	1,823	3,595	8,682	20,141
Scenario 3: One Standard and One Hard Driving Scenario	9.5 m Monopile (2 piles per day)	4,000 a/	184	0	559	1,483	3,547	4,190	8,682	20,141	--
				6	308	819	1,942	2,507	4,822	10,416	25,922
				10	204	559	1,483	1,823	3,595	8,682	20,141

Note: a/ Corresponds to the maximum rated hammer energy; however, actual hammer energy transferred to the pile during installation will be less

Table Z-23. Marine Mammal PTS Onset Criteria Threshold Distances (meters) for Vibratory Hammer – Shallow Location (Monopile)

Scenario	Pile Type	Installation Duration (minutes)	Mitigation (dB)	Hearing Group a/			
				LF Cetaceans	MF Cetaceans	HF Cetaceans	Phocid Pinnipeds
				199 $L_{E,24hr}$	198 $L_{E,24hr}$	173 $L_{E,24hr}$	201 $L_{E,24hr}$
Scenario 1: Standard Driving Scenario	9.5 m Monopile	60	0	385	0	353	63
			6	193	0	168	21
			10	67	0	65	0
Scenario 2: Hard Driving Scenario	9.5 m Monopile	30	0	274	0	268	38
			6	117	0	85	0
			10	41	0	8	0
Scenario 3: One Standard and One Hard Driving Scenario	9.5 m Monopile (2 piles per day)	90	0	515	0	438	119
			6	244	0	239	61
			10	143	0	101	16

Source: NOAA Fisheries 2018
Note: a/ Level A Injury

Table Z-24. Fish Acoustic Injury Threshold Distances (meters) for Vibratory Hammer – Shallow Location (Monopile)

Scenario	Pile Type	Installation Duration (minutes)	Mitigation (dB)	Hearing Group	
				Small Fish a/	Large Fish a/
				183 $L_{E,24hr}$	187 $L_{E,24hr}$
Scenario 1: Standard Driving Scenario	9.5 m Monopile	60	0	3,270	2,397
			6	1,679	1,191
			10	1,191	845
Scenario 2: Hard Driving Scenario	9.5 m Monopile	30	0	2,629	1,879
			6	1,338	986
			10	986	673
Scenario 3: One Standard and One Hard Driving Scenario	9.5 m Monopile (2 piles per day)	90	0	4,043	3,055
			6	2,209	1,613
			10	1,613	1,167

Source: Stadler and Woodbury 2009
Note: a/ Small fish are fish less than 2 grams in weight. Large fish are 2 grams or larger.

Table Z-25. Sea Turtles Behavioral and Acoustic Injury Criteria Threshold Distances (meters) for Vibratory Hammer – Shallow Location (Monopile)

Scenario	Pile Type	Installation Duration (minutes)	Mitigation (dB)	Species		
				Sea Turtle Behavioral	Sea Turtle TTS	Sea Turtle PTS
				175 L_p	200 $L_{E,24hr}$	220 $L_{E,24hr}$
Scenario 1: Standard Driving Scenario	9.5 m Monopile	60	0	218	434	58
			6	123	230	14
			10	71	130	0
Scenario 2: Hard Driving Scenario	9.5 m Monopile	30	0	218	327	30
			6	123	159	6
			10	71	81	0
Scenario 3: One Standard and One Hard Driving Scenario	9.5 m Monopile (2 piles per day)	90	0	218	510	78
			6	123	270	21
			10	71	162	8

Source: NOAA Fisheries 2019

Table Z-26. Threshold Distances (meters) for Sound Pressure Levels (L_p) for Vibratory Hammer at the Shallow Location (Monopile)

Scenario	Pile Type	Installation Duration (minutes)	Mitigation (dB)	Sound Pressure Level Thresholds (dB)							
				200 L_p	190 L_p	180 L_p	175 L_p	160 L_p	150 L_p	140 L_p	120 L_p
Scenario 1: Standard Driving Scenario	9.5 m Monopile	85	0	0	0	99	218	806	2,141	5,223	16,308
			6	0	0	52	123	473	1,315	3,122	8,850
			10	0	0	30	71	305	806	2,141	7,326
Scenario 2: Hard Driving Scenario	9.5 m Monopile	99	0	0	0	99	218	806	2,141	5,223	16,308
			6	0	0	52	123	473	1,315	3,122	8,850
			10	0	0	30	71	305	806	2,141	7,326
Scenario 3: One Standard and One Hard Driving Scenario	9.5 m Monopile (2 piles per day)	184	0	0	0	99	218	806	2,141	5,223	16,308
			6	0	0	52	123	473	1,315	3,122	8,850
			10	0	0	30	71	305	806	2,141	7,326

Note: a/ Corresponds to the maximum rated hammer energy; however, actual hammer energy transferred to the pile during installation will be less

Table Z-27. Marine Mammal Permanent Threshold Shift Onset Criteria Threshold Distances (meters) for Pile-Driving - OSS Location

Scenario	Pile Type	Maximum Hammer Energy (kilojoules)	Installation Duration (minutes)	Mitigation (dB)	Hearing Group a/							
					Low-Frequency Cetaceans		Mid-Frequency Cetaceans		High-Frequency Cetaceans		Phocid Pinnipeds	
					219 $L_{p,pk}$	183 $L_{E,24hr}$	230 $L_{p,pk}$	185 $L_{E,24hr}$	202 $L_{p,pk}$	155 $L_{E,24hr}$	218 $L_{p,pk}$	185 $L_{E,24hr}$
Scenario 4: OSS Piled Jacket Foundation	2.8 m Pin Pile	3,000 b/	410	0	162	10,560	31	281	702	2,912	174	3,579
				6	66	4,898	0	121	319	1,483	75	1,728
				10	23	3,484	0	48	175	1,007	31	1,148

Source: NOAA Fisheries 2018
Notes:
a/ Level A Injury
b/ Corresponds to the maximum rated hammer energy; however, actual hammer energy transferred to the pile during installation will be less.

Table Z-28. Sea Turtles and Fish Onset of Injury Threshold Distances (meters) for Pile-Driving – OSS Location (as per Popper et al. 2014)

Scenario	Pile Type	Hammer Energy (kilojoules)	Installation Duration (minutes)	Mitigation (dB)	Hearing Group a/									
					Fish: No Swim Bladder		Fish: Swim Bladder not involved in Hearing		Fish: Swim Bladder involved in Hearing		Eggs and Larvae		Sea Turtles	
					213 $L_{p,pk}$	219 $L_{E,24hr}$	207 $L_{p,pk}$	210 $L_{E,24hr}$	207 $L_{p,pk}$	207 $L_{E,24hr}$	207 $L_{p,pk}$	210 $L_{E,24hr}$	207 $L_{p,pk}$	210 $L_{E,24hr}$
Scenario 4: OSS Piled Jacket Foundation	2.8 m Pin Pile	3,000 b/	410	0	246	505	392	1,074	392	1,473	392	1,074	392	1,074
				6	109	256	175	549	175	769	175	549	175	549
				10	66	173	101	376	101	491	101	376	101	376

Source: Popper et al. 2014
Notes:
a/ Level A Injury
b/ Corresponds to the maximum rated hammer energy; however, actual hammer energy transferred to the pile during installation will be less.

Table Z-29. Fish Acoustic Injury Threshold Distances (meters) for Pile-Driving – OSS Location (as per Stadler and Woodbury 2009)

Scenario	Pile Type	Hammer Energy (kilojoules)	Installation Duration (minutes)	Mitigation (dB)	Hearing Group			
					Small Fish a/		Large Fish a/	
					206 $L_{p,pk}$	183 $L_{E,24hr}$	206 $L_{p,pk}$	187 $L_{E,24hr}$
Scenario 4: OSS Piled Jacket Foundation	2.8 m Pin Pile	3,000 b/	410	0	416	9,806	416	7,418
				6	319	5,075	319	3,808
				10	175	3,808	175	2,863

Source: Stadler and Woodbury 2009
Notes:
a/ Small fish are fish less than 2 grams in weight. Large fish are 2 grams or larger.
b/ Corresponds to the maximum rated hammer energy; however, actual hammer energy transferred to the pile during installation will be less.

Table Z-30. Sea Turtles in National Oceanic Atmospheric Administration Fisheries Behavioral and Acoustic Injury Criteria Threshold Distances (meters) for Pile-Driving – OSS Location

Scenario	Pile Type	Hammer Energy (kilojoule)	Installation Duration (minutes)	Mitigation (dB)	Species				
					Sea Turtle Behavioral	Sea Turtle Temporary Threshold Shift		Sea Turtle Permanent Threshold Shift	
					175 L_p	226 $L_{p,pk}$	189 $L_{E,TUW,24hr}$	232 $L_{p,pk}$	204 $L_{E,TUW,24hr}$
Scenario 4: OSS Piled Jacket Foundation	2.8 m Pin Pile	3,000 a/	410	0	1,521	79	6,081	14	1,753
				6	972	14	3,197	0	788
				10	620	0	2,400	0	585

Source: NOAA Fisheries 2019
Note: a/ Corresponds to the maximum rated hammer energy; however, actual hammer energy transferred to the pile during installation will be less.

Table Z-31. Threshold Distances (meters) for Sound Pressure Levels (L_p) for Pile Driving at the OSS Location

Scenario	Pile Type	Hammer Energy (kilojoules)	Installation Duration (minutes)	Mitigation (dB)	Sound Pressure Level Thresholds (dB)						
					200 L_p	190 L_p	180 L_p	175 L_p	160 L_p	150 L_p	140 L_p
Scenario 4: OSS Piled Jacket Foundation	2.8 m Pin Pile	3,000 a/	410	0	192	448	1,084	1,521	4,336	11,418	26,641
				6	111	287	687	972	2,611	6,871	16,694
				10	76	192	448	620	1,812	4,336	11,418

Note: a/ Corresponds to the maximum rated hammer energy; however, actual hammer energy transferred to the pile during installation will be less.

Table Z-32. Marine Mammal PTS Onset Criteria Threshold Distances (meters) for Vibratory Hammer – OSS Location

Scenario	Pile Type	Installation Duration (minutes)	Mitigation (dB)	Hearing Group a/			
				LF Cetaceans	MF Cetaceans	HF Cetaceans	Phocid Pinnipeds
				199 $L_{E, 24hr}$	198 $L_{E, 24hr}$	173 $L_{E, 24hr}$	201 $L_{E, 24hr}$
Scenario 4: OSS Piled Jacket Foundation	2.8 m Pin Pile	120	0	220	0	73	56
			6	102	0	0	0
			10	77	0	0	0

Source: NOAA Fisheries 2018

Note: a/ Level A Injury

Table Z-33. Fish Acoustic Injury Threshold Distances (meters) for Vibratory Hammer – OSS Location

Scenario	Pile Type	Installation Duration (minutes)	Mitigation (dB)	Hearing Group	
				Small Fish a/	Large Fish a/
				183 $L_{E, 24hr}$	187 $L_{E, 24hr}$
Scenario 4: OSS Piled Jacket Foundation	2.8 m Pin Pile	120	0	1,473	981
			6	864	569
			10	569	340

Source: Stadler and Woodbury 2009

Note: a/ Small fish are fish less than 2 grams in weight. Large fish are 2 grams or larger.

Table Z-34. Sea Turtles Behavioral and Acoustic Injury Criteria Threshold Distances (meters) for Vibratory Hammer – OSS Location

Scenario	Pile Type	Installation Duration (minutes)	Mitigation (dB)	Species		
				Sea Turtle Behavioral	Sea Turtle TTS	Sea Turtle PTS
				175 L_p	200 $L_{E, TUW, 24hr}$	220 $L_{E, TUW, 24hr}$
Scenario 4: OSS Piled Jacket Foundation	2.8 m Pin Pile	120	0	85	247	18
			6	38	127	5
			10	23	94	0

Source: NOAA Fisheries 2019

Table Z-35. Threshold Distances (meters) for Sound Pressure Levels (L_p) for Vibratory Pile Driving at the OSS Location

Scenario	Pile Type	Installation Duration (minutes)	Mitigation (dB)	Sound Pressure Level Thresholds (dB)							
				200 L_p	190 L_p	180 L_p	175 L_p	160 L_p	150 L_p	140 L_p	120 L_p
Scenario 4: OSS Piled Jacket Foundation	2.8 m Pin Pile	120	0	0	0	39	86	337	905	2,277	11,024
			6	0	0	17	38	156	451	1,284	5,497
			10	0	0	0	10	116	337	905	4,349

Source: NOAA Fisheries 2019

Table Z-36. Marine Mammal PTS Onset Criteria Threshold Distances (meters) for Vibratory Hammer – Cofferdam

Scenario	Pile Type	Installation Duration (minutes)	Mitigation (dB)	Hearing Group a/			
				LF Cetaceans	MF Cetaceans	HF Cetaceans	Phocid Pinnipeds
				199 $L_{E, 24hr}$	198 $L_{E, 24hr}$	173 $L_{E, 24hr}$	201 $L_{E, 24hr}$
Scenario 5: Cofferdam Installation	Sheet Pile	60	0	142	0	0	0
			6	23	0	0	0
			10	77	0	0	0

Source: NOAA Fisheries 2018
Note:
a/ Level A Injury

Table Z-37. Fish Acoustic Injury Threshold Distances (meters) for Vibratory Hammer – Cofferdam

Scenario	Pile Type	Installation Duration (minutes)	Mitigation (dB)	Hearing Group	
				Small Fish a/	Large Fish a/
				183 $L_{E, 24hr}$	187 $L_{E, 24hr}$
Scenario 5: Cofferdam Installation	Sheet Pile	60	0	838	641
			6	389	317
			10	230	186

Source: Stadler and Woodbury 2009
Notes:
a/ Small fish are fish less than 2 grams in weight. Large fish are 2 grams or larger.

Table Z-38. Sea Turtles Behavioral and Acoustic Injury Criteria Threshold Distances (meters) for Vibratory Hammer – Cofferdam

Scenario	Pile Type	Installation Duration (minutes)	Mitigation (dB)	Species		
				Sea Turtle Behavioral	Sea Turtle TTS	Sea Turtle PTS
				175 L_p	200 $L_{E, 24hr}$	220 $L_{E, 24hr}$
Scenario 5: Cofferdam Installation	Sheet Pile	60	0	0	247	18
			6	0	127	5
			10	0	94	0

Source: NOAA Fisheries 2020

Table Z-39. Marine Mammals and Fish Behavioral Response Criteria Threshold Distances (meters) for Vibratory Hammer – Cofferdam

Scenario	Pile Type	Installation Duration (minutes)	Mitigation (dB)	Hearing Group		
				Fish	Marine Mammals	Marine Mammals
				150 L_p	160 L_p	120 L_p
Scenario 5: Cofferdam Installation	Sheet Pile	60	0	470	213	2,964
			6	239	96	1,579
			10	213	19	1,365

Table Z-40. Marine Mammal Permanent Threshold Shift Onset Criteria Threshold Distances (meters) for Pile-Driving – Goal Post Installation

Scenario	Pile Type	Maximum Hammer Energy (kilojoules)	Installation Duration (minutes)	Mitigation (dB)	Hearing Group a/							
					Low-Frequency Cetaceans		Mid-Frequency Cetaceans		High-Frequency Cetaceans		Phocid Pinnipeds	
					219 $L_{p,pk}$	183 $L_{E, 24hr}$	230 $L_{p,pk}$	185 $L_{E, 24hr}$	202 $L_{p,pk}$	155 $L_{E, 24hr}$	218 $L_{p,pk}$	185 $L_{E, 24hr}$
Scenario 6: Goal Post Installation	Goal Post Piles	N/A	130	0	2.3	591	0	21	31	704	3	316
				6	0	235	0	8	12	280	1	126
				10	0	127	0	4.5	7	152	0	68

Source: NOAA Fisheries 2018
Notes:
a/ Level A Injury
N/A – Thresholds not applicable for source type.

Table Z-41. Marine Mammals and Fish Behavioral Response Criteria Threshold Distances (meters) for Pile Driving – Goal Post Installation

Scenario	Pile Type	Maximum Hammer Energy (kilojoules)	Installation Duration (minutes)	Mitigation (dB)	Hearing Group		
					Fish	Marine Mammals	Marine Mammals
					150 L_p	160 L_p	120 L_p
Scenario 6: Goal Post Installation	Goal Post Piles	N/A	130	0	6,750	1,450	41,000
				6	2,700	580	20,500
				10	1,450	314	12,900

Table Z-42. Sea Turtles in National Oceanic Atmospheric Administration Fisheries Behavioral and Acoustic Injury Criteria Threshold Distances (meters) for Pile-Driving – Goal Post Installation

Scenario	Pile Type	Hammer Energy (kilojoule)	Installation Duration (minutes)	Mitigation (dB)	Species				
					Sea Turtle Behavioral	Sea Turtle Temporary Threshold Shift		Sea Turtle Permanent Threshold Shift	
					175 L_p	226 $L_{p,pk}$	189 $L_{E, TUW, 24hr}$	232 $L_{p,pk}$	204 $L_{E, TUW, 24hr}$
Scenario 6: Goal Post Installation	Goal Post Piles	N/A	130	0	156	0	0	0	0
				6	63	0	0	0	0
				10	34	0	0	0	0

Source: NOAA Fisheries 2019
Note: a/ Corresponds to the maximum rated hammer energy; however, actual hammer energy transferred to the pile during installation will be less.

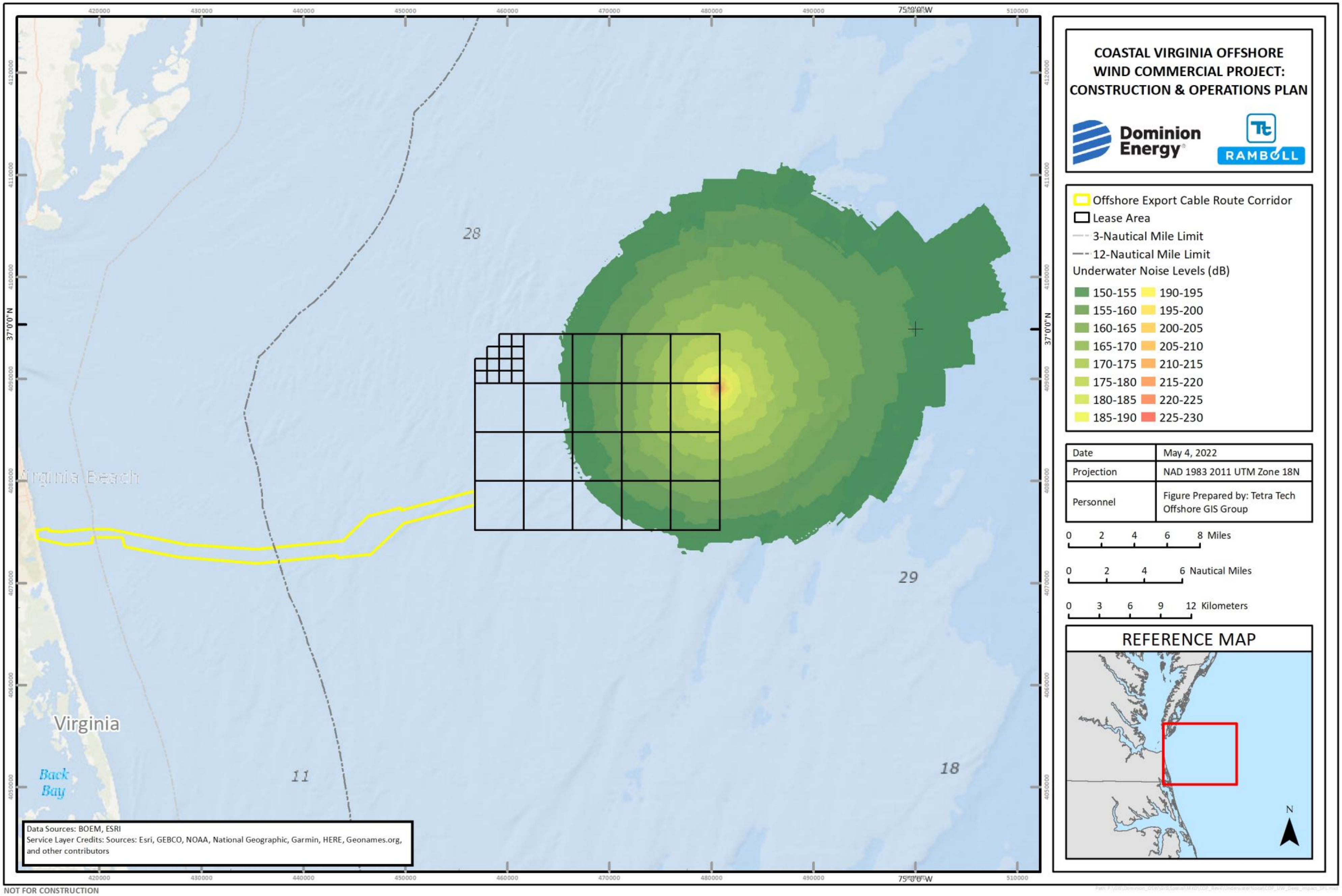

Figure Z-8. Underwater Received Sound Levels: Scenario 1 through 3, Impact Pile Driving, Unmitigated, Deep Location (SPL)

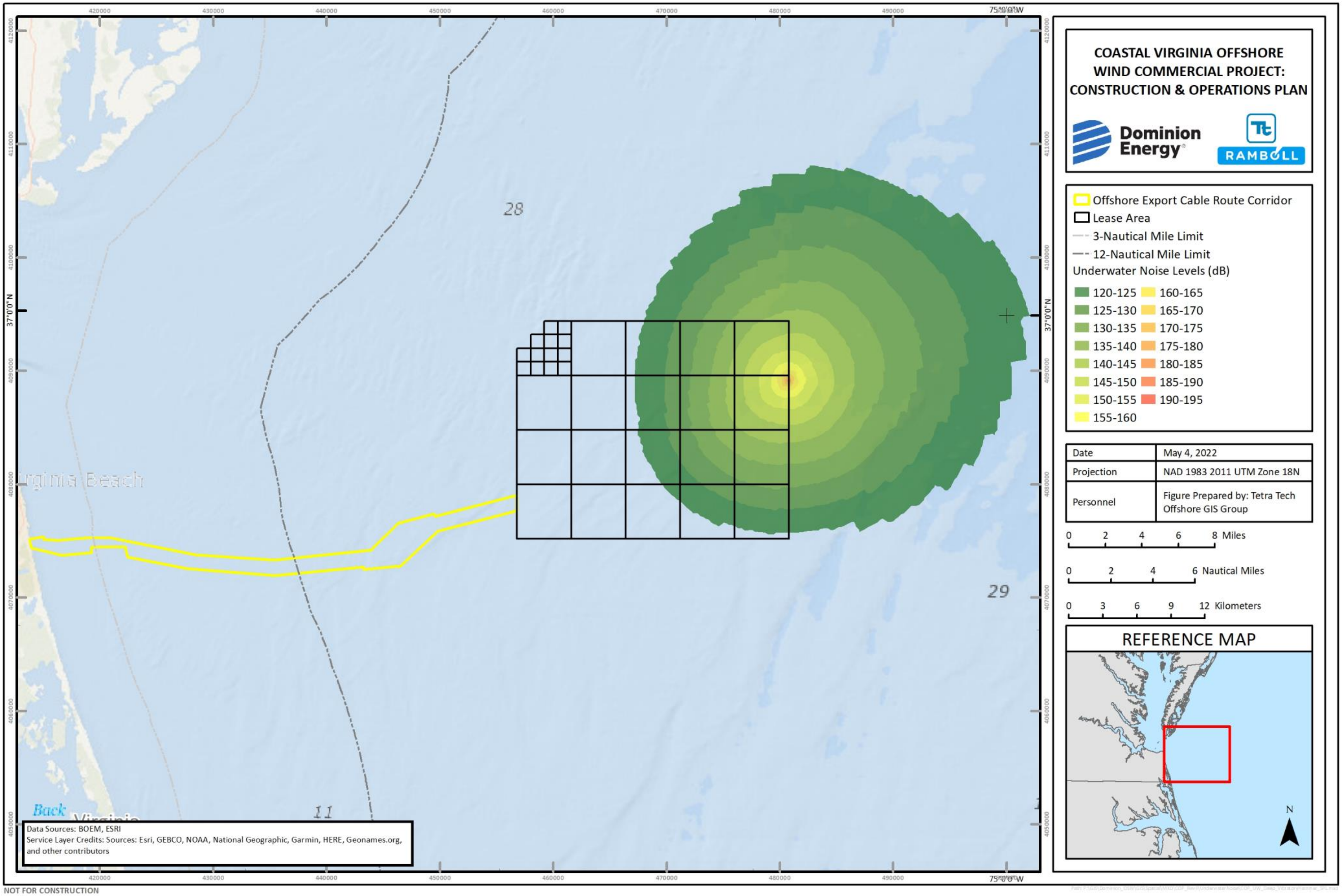

Figure Z-9. **Underwater Received Sound Levels: Scenario 1 through 3, Vibratory Pile Driving, Unmitigated, Deep Location (SPL)**

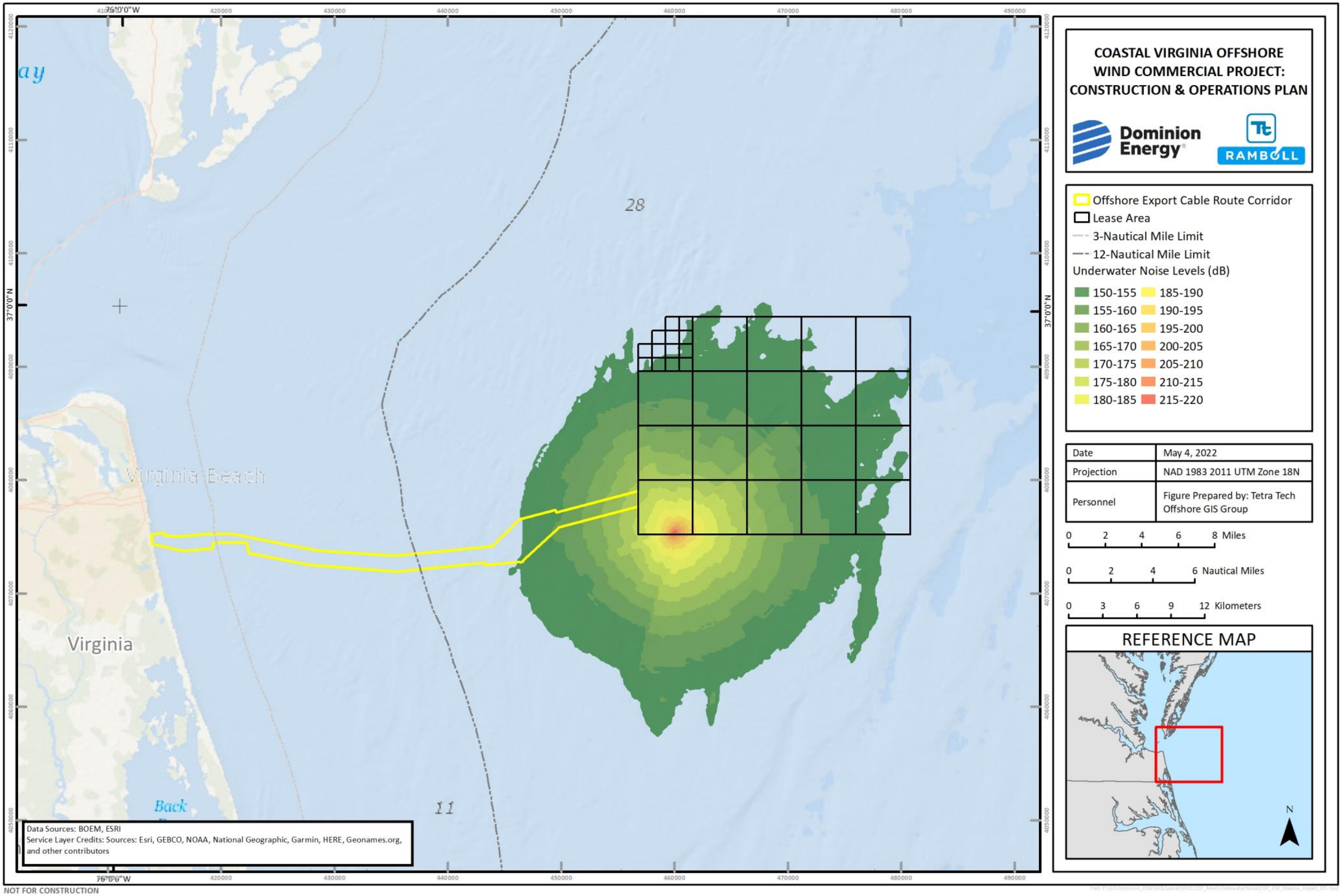

Figure Z-10. **Underwater Received Sound Levels: Scenario 1 through 3, Impact Pile Driving, Unmitigated, Shallow Location (SPL)**

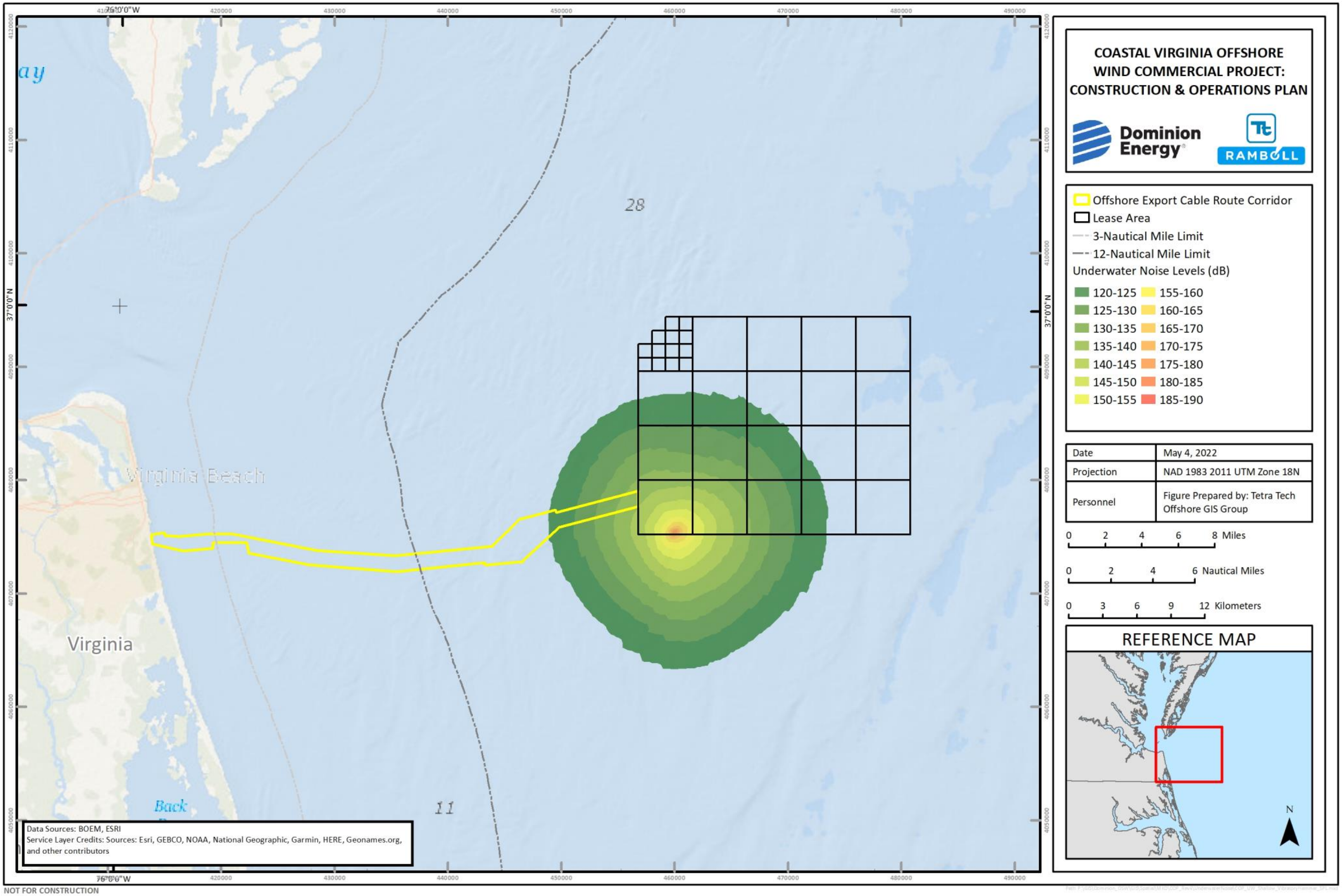

Figure Z-11. **Underwater Received Sound Levels: Scenario 1 through 3, Vibratory Pile Drivin g, Unmitigated, Shallow Location (SPL)**

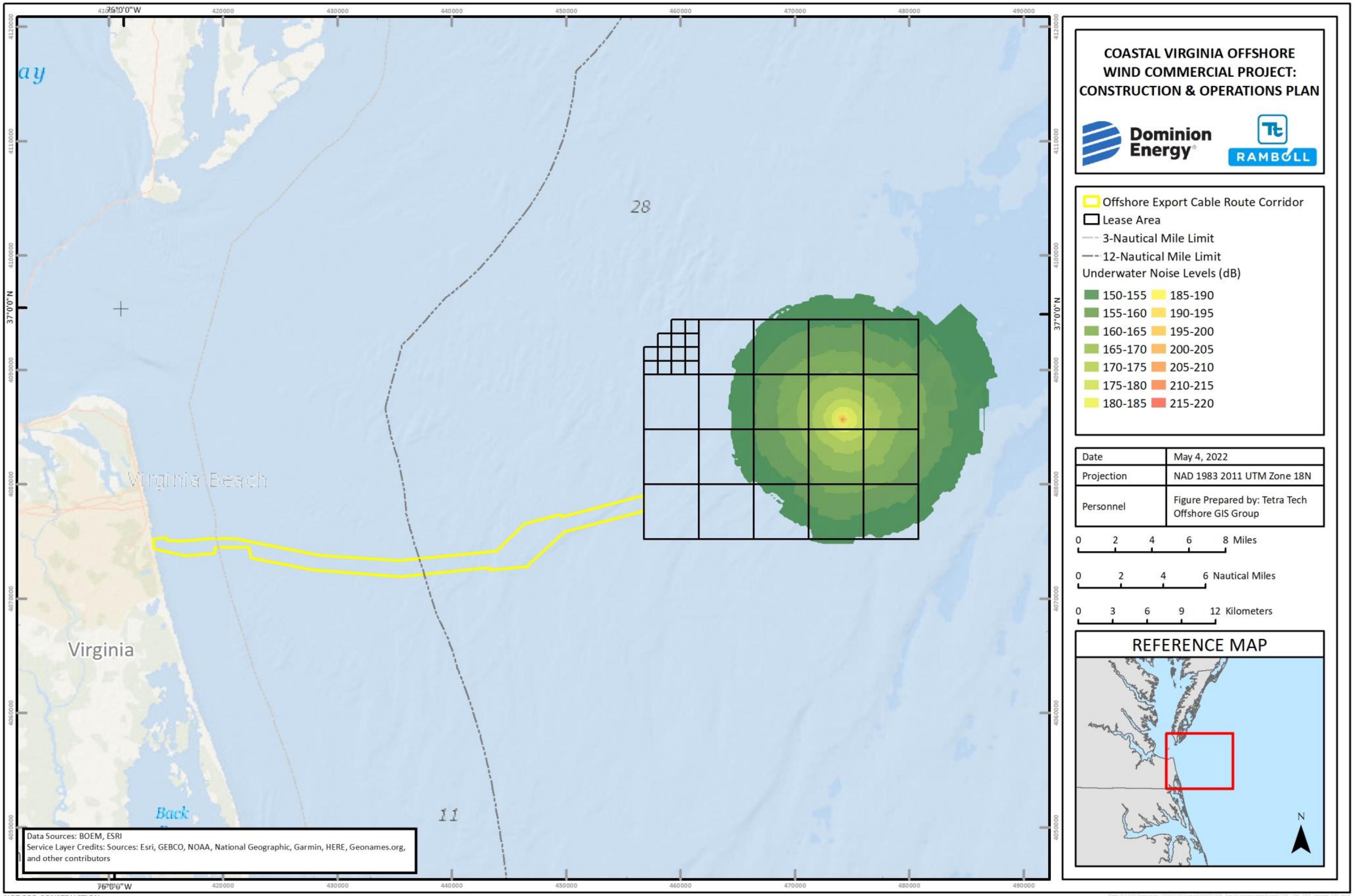

Figure Z-12. Underwater Received Sound Levels: Scenario 4, Impact Pile Driving, Unmitigated, OSS Location (SPL)

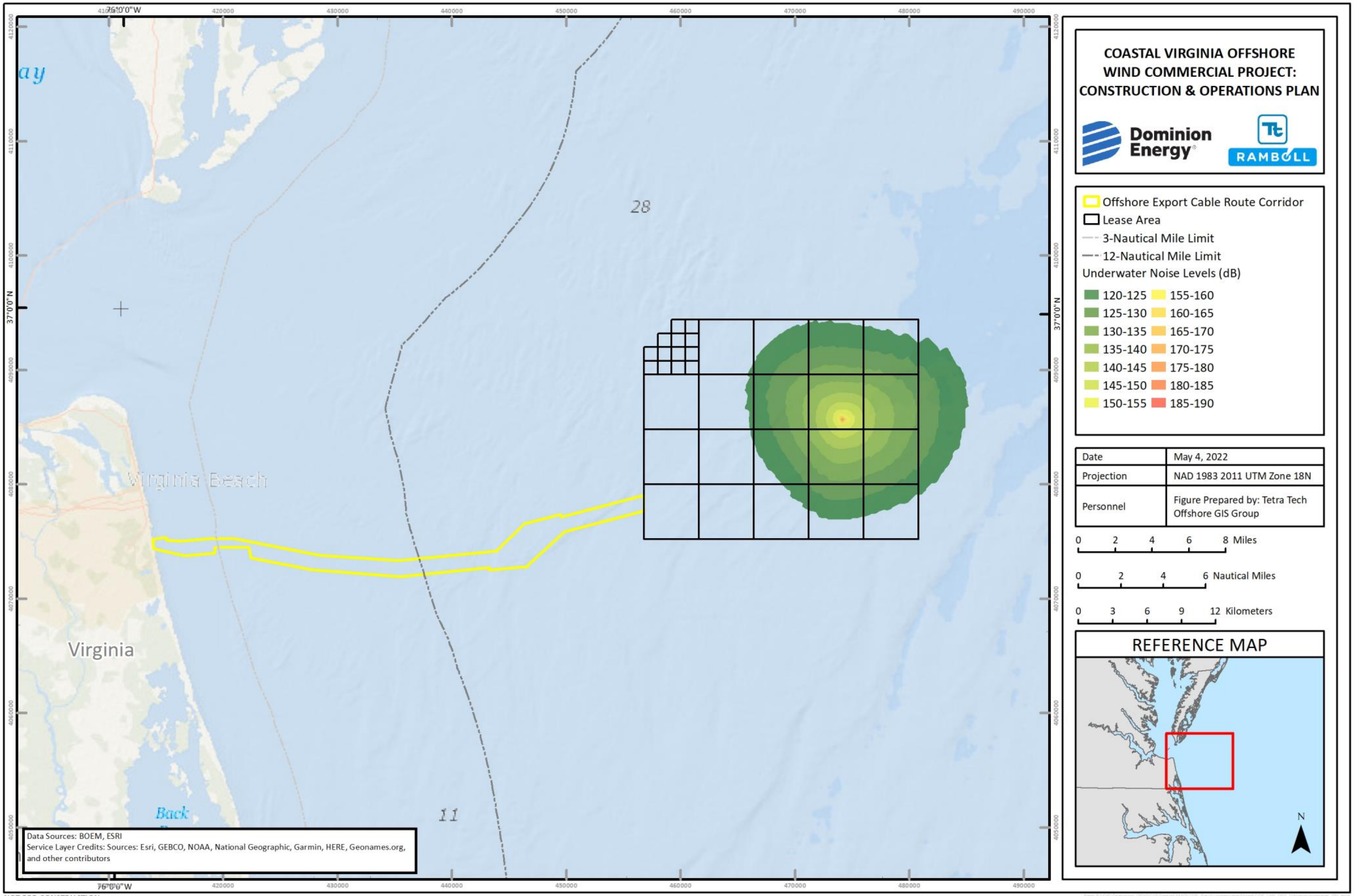

Figure Z-13. **Underwater Received Sound Levels: Scenario 4, Vibratory Pile Driving, Unmitigated, OSS Location (SPL)**

Z.8 REFERENCES

Au, Whitlow. and M. Hastings. 2008. "Principles of Marine Bioacoustics". *Springer Science & Business Media, New York, New York*. Available online at: https://link.springer.com/book/10.1007%2F978-0-387-78365-9. Accessed December 14, 2020.

Austin, M., S. Denes, J. MacDonnell, and G. Warner. 2016. *Hydroacoustic Monitoring Report: Anchorage Port Modernization Project Test Pile Program. Version 3.0*. Technical report by JASCO Applied Sciences for Kiewit Infrastructure West Co.

Bellman, M. A. 2014. *Overview of existing Noise Mitigation Systems for Reducing Pile-Driving Noise. Inter-Noise 2014*, Sydney, Australia.

Bellman, M. A., J. Schuckenbrock, S. Gündert, M. Müller, H. Holst, P. Remmers. 2017. "Is There a State-of-the-Art to Reduce Pile-Driving Noise?" *Wind Energy and Wildlife Interactions*. Available online at: https://link.springer.com/chapter/10.1007/978-3-319-51272-3_9. Accessed December 14, 2020.

Blackstock, S.A., Fayton, J.O., Hulton, P.H., Moll, T.E., Jenkins, K.K., Henderson, E., Rider, S., Martin, C., Bowman, V.. 2017. *Quantifying Acoustic Impacts on Marine Mammals and Sea Turtles: Methods and Analytical Approach for Phase III Training and Testing*. Naval Undersea Warfare Center Division, Newport United States.

CALTRANS (California Department of Transportation). 2015. *Technical Guidance for Assessment and Mitigation of the Hydroacoustic Effects of Pile Driving on Fish*. Division of Environmental Analysis; Environmental Engineering; Hazardous Waste, Air, Noise, Paleontology Office.

Department of the Navy. 2017. *Criteria and Thresholds for U.S. Navy Acoustic and Explosive Effects Analysis (Phase III).* U.S. Navy SSC Pacific.

Farcas, A., P. M. Thompson, and N. D. Merchant. 2016. "Underwater noise modelling for environmental impact assessment." *Environmental Impact Assessment Review*, 57, pp.114–122.

Fisher F. H. and V. P. Simmons. 1977. "Sound absorption in seawater." *Journal of the Acoustical Society of America*, vol. 62 3(pg. 558 -564).

Francois, R. E., and G. R. Garrison. 1982a. "Sound absorption based on ocean measurements. Part I: Pure water and magnesium sulphate contributions." *Journal of the Acoustical Society of America*, 72(3): 896–907.

Francois, R. E., and G. R. Garrison. 1982b. "Sound absorption based on ocean measurements. Part II: Boric acid contribution and equation for total absorption." *Journal of the Acoustical Society of America*, 72: 1879–1890.

Gerke, P. and M. Bellmann. 2012. Offshore Windpark Riffgat". Messung der Bauschallimmissionen. Itap Projekt Nr.: 1924-12-e-pg, 40 S, commissioned by Offshore-Windpark Riffgat GmbH & Co KG.

Hamilton, E.L. 1976. "Geoacoustic modeling of the sea floor." *Journal of the Acoustical Society of America*, 68, 1313-1340.

ISO (International Organization for Standardization). 2017. Underwater acoustics – Terminology. https://www.iso.org/obp/ui/#iso:std:iso:18405:ed-1:v1:en

Koschinski, S. and K. Lüdemann. 2013. “Development of noise mitigation measures in offshore wind farm construction.” *Federal Agency for Nature Conservation*. Available online at: https://www.bfn.de/fileadmin/BfN/meeresundkuestenschutz/Dokumente/Noise-mitigation-for-the-construction-of-increasingly-large-offshore-wind-turbines.pdf. Accessed December 14, 2020.

Koschinski, S. and K. Lüdemann. 2020. “Noise mitigation for the construction of increasingly large offshore wind turbines.” *[German] Federal Agency for Nature Conservation.*

Nedwell, J. R., J. Langworthy, and D. Howell. 2004. *Assessment of sub-sea acoustic noise and vibration from offshore wind turbines and its impact on marine wildlife; initial measurements of underwater noise during construction of offshore windfarms, and comparison with background noise.* Subacoustech Report Reference: 544R0424, November 2004, to COWRIE.

NOAA Fisheries (National Oceanic and Atmospheric Administration’s National Marine Fisheries Service). 2018. *2018 Revisions to: Technical Guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammal Hearing (Version 2.0): Underwater Thresholds for Onset of Permanent and Temporary Threshold Shifts.* U.S. Dept. of Commer., NOAA. NOAA Technical Memorandum NMFS-OPR-59, 167 p.

NOAA Fisheries. 2019. "GARFO Acoustics Tool: Analyzing the effects of pile driving on ESA-listed species in the Greater Atlantic Region". https://www.fisheries.noaa.gov/new-england-mid-atlantic/consultations/section-7-consultation-technical-guidance-greater-atlantic

NOAA Satellite and Information Service. 2020. *U.S. Coastal Relief Model. 1999 to* 2005. Available online at: https://www.ngdc.noaa.gov/mgg/coastal/crm.html. Accessed December 13, 2020.

NOAA Fisheries (National Oceanic and Atmospheric Administration’s National Marine Fisheries Service). 2012. Cetacean & Sound Mapping. Available online at: https://cetsound.noaa.gov/sound_data . Accessed December 2021.

Popper, A., A. Hawkins, R. Fay, D. Mann, and S. Bartol. 2014. *Sound Exposure Guidelines. ASA S3/SC14 TR-2014 Sound Exposure Guidelines for Fish and Sea Turtles: A Technical Report prepared by ANSI-Accredited Standards Committee S3/SC1 and registered with ANSI*. p. 33-51.

Richardson, W. J., C. R. Greene Jr., C. I. Malme, and D. H. Thomson. 2013. *Marine Mammals and Noise.* Academic Press, New York.

Sivle, L.D., P.H. Kvadsheim, and M.A. Ainslie. 2014. Potential for population-level disturbance by active sonar in herring. ICES Journal of Marine Science 72: 558-567.

Simmonds, M., S. Dolman, and L. Weilgart. 2004. *Oceans of Noise: A WDCS Science Report*. https://au.whales.org/wp-content/uploads/sites/3/2018/08/Oceans-of-Noise.pdf

Southall, B. L., J. J. Finneran, C. Reichmuth, P. E. Nachtigall, D. R. Ketten, A. E. Bowles, W. T. Ellison, D. P. Nowacek, and P. L. Tyack. 2019. “Marine Mammal Noise Exposure Criteria: Updated Scientific Recommendations for Residual Hearing Effects.” *Aquatic Mammals* 45, 125-232.

Stadler, J. H. and D. P. Woodbury. 2009. *Assessing the effects to fish from pile driving: Application of new hydroacoustic criteria.*

Wahlberg, M. 2012. "Contribution of Biological Sound Sources to Underwater Ambient Noise Levels." *Bioacoustics.* 17: 30-32.

Wenz, G. 1962. "Acoustic ambient noise in the ocean: Spectra and Sources." *Journal of Acoust. Soc. Am.*, Vol 34, p 1936.

Whyte, K. F., D. J. F. Russell, C. E. Sparling, B. Binnerts, and G. D. Hastie. 2020. "Estimating the effects of pile driving sounds on seals: Pitfalls and possibilities." *Journal of Acoust. Soc. Am.*, Vol 147, p 3948. Available online at: https://doi.org/10.1121/10.0001408.

ATTACHMENT Z-1: UNDERWATER SOUND PROPAGATION MODELING METHODOLOGY

Attachment Z-1 - Underwater Sound Propagation Modeling Methodology

Tetra Tech has developed a reliable and effective approach to evaluating underwater acoustic impacts from pile driving as well as other in-water activities. The underwater noise modeling methodology used to evaluate the Project activities is described below.

Underwater Sound Propagation Modeling

Tetra Tech uses dBSea for underwater sound propagation modeling. dBSea is a software program developed by Marshall Day Acoustics for the prediction of underwater noise. The three-dimensional model is built by importing bathymetry data and placing noise sources in the environment. Each source can consist of equipment chosen from either the standard or user-defined databases. Noise mitigation methods may also be included. The user has control over the seabed and water properties including sound speed profile (SSP), temperature, salinity, and current.

Noise levels are calculated throughout the entire Offshore Project Area and displayed in three dimensions. Levels are calculated in third octave bands. For the Project, two different solvers are used for the low- and high-frequency ranges:

- dBSeaPE (Parabolic Equation Method): The dBSeaPE solver makes use of the range-dependent acoustic model (RAM) parabolic equation method, a versatile and robust method of marching the sound field out in range from the sound source. This method is one of the most widely used in the underwater acoustics community and offers excellent performance in terms of speed and accuracy in a range of challenging scenarios.
- dBSeaRay (Ray Tracing Method): The dBSeaRay solver forms a solution by tracing rays from the source to the receiver. Many rays leave the source covering a range of angles, and the sound level at each point in the receiving field is calculated by coherently summing the components from each ray. This is currently the only computationally efficient method at high frequencies.

Calculation Grid and Source Solution Setup

The calculation grid and source solution setup are based on the resolution and extents of the bathymetry data. The calculations within dBSea are made along each radial for each range point and depth point. Radials are generated from the source location out to the extent of the bathymetry area. The range points are generated along each radial and are evenly spaced out (range step). However, this spacing does not change if the source is moved. The number of “Radial slices” and “Range points” are entered, which represents the number of radial solution slices for each source and the evaluation range points along those slices (Figure 1). The range points are determined based on the width and length of the modeled area as well as the required range step resolution (Equation 1).

$$Range\ Points = \frac{\sqrt{Width^2 + length^2}}{\text{Range Step}} \tag{1}$$

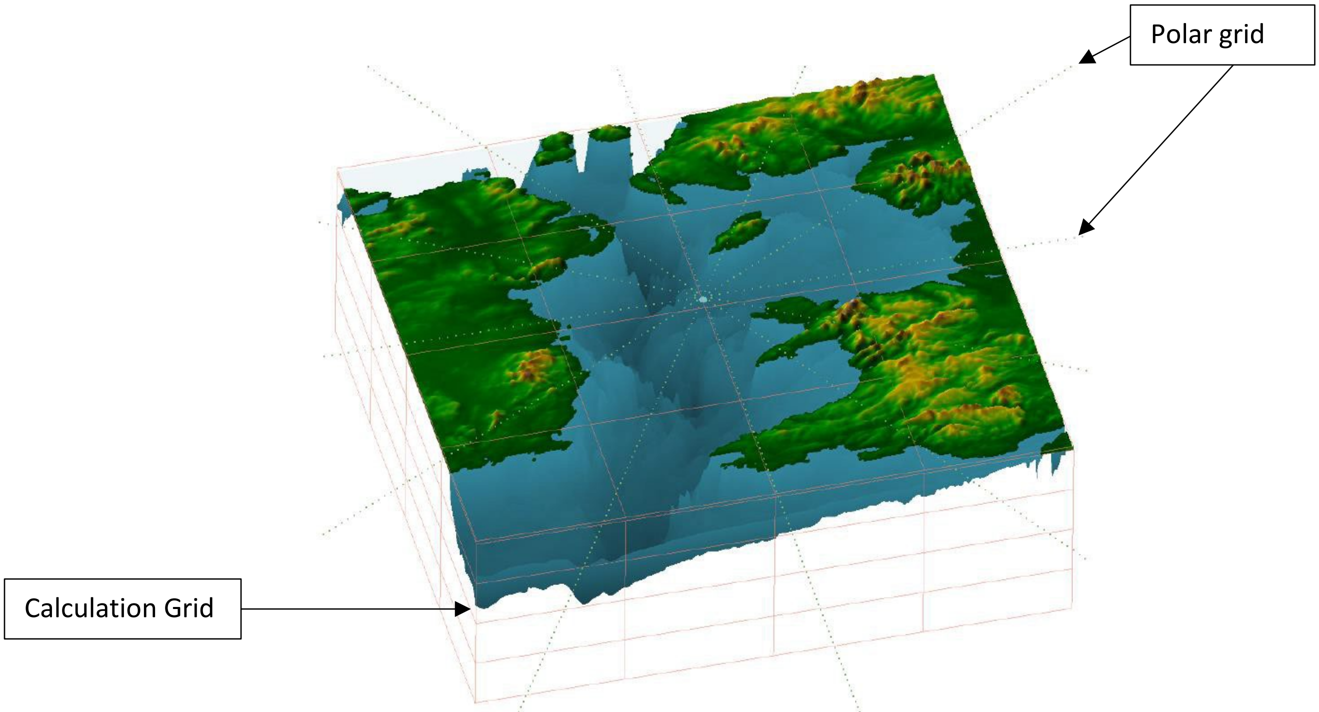

Figure 1. Example Radial Solution Points

dBSea source solution calculations are completed along the radials (polar grid) based on the defined range and depth points. The calculation grid (cartesian) is filled from the polar grid using the nearest neighbor sampling, i.e., a point in the calculation results grid takes the value of the closest point in the polar grid. The calculation steps in dBSea are summarized below:

- Calculations are done in the polar grid (radials) at multiple depths, which are the same depths as the (cartesian) calculation grid.
- The calculation of the polar grid is smoothed with a triangular kernel, the width of which is selected by the user.
- The results of the cartesian grid is filled by the nearest neighbor sampling from the calculated polar grid using an inverse distance.

The more radials and range points used, the less interpolation needed for the cartesian grid. Because the calculation happens in the polar grid, while the results grid is cartesian, every point in the cartesian grid is "filled" depending on what point of the polar grid it is closest to (Figure 2).

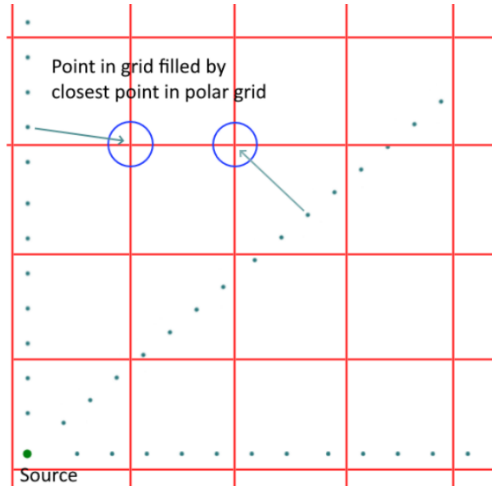

Figure 2: Example Cartesian Grid Calculation

The underwater acoustic modeling analysis for the Project used a split solver, with dBSeaPE evaluating the 12.5 Hz to 630 Hz range and dBSeaRay addressing the 800 Hz to 20,000 Hz range. The radial resolution was 10-degree intervals to the extent of the bathymetry. The specific parameters used in the modeling analysis are described below.

Bathymetry

Bathymetry data were obtained from the National Geophysical Data Center and a U.S. Coastal Relief Model (NOAA Satellite and Information Service 2020), and the horizontal resolution of this dataset is 3 arc seconds (90 meters [m]). The bathymetry data covered a 138 kilometers (km) by 144 km total area with a maximum depth of 459 m. The sound sources were placed near the middle of the bathymetry area.

Sediment Characteristics

Seafloor properties were obtained through geotechnical studies performed by Dominion Energy presented in the Marine Site Investigation report (MSIR) submitted for the Coastal Virginia Offshore Wind Commercial Project. This data was used to develop a sediment profile for the overall modeled area. The sediment profile is presented in Table 1. The geoacoustic properties given in Table 1 were directly input into dBSea for each defined sediment layer. Each sediment layer is entered directly into dBSea. The parameters entered for each sediment layer is bulleted below:

- Sediment layer depth (provided by the client)
- Material name (provide by the client)
- Speed of sound (m/s)
- Density (kg/m^3)
- Attenuation (dB/wavelength)

The acoustic parameters (speed of sound, density, and attenuation) are typically taken from Jenson 2011, Hamilton 1976, 1982, and Hamilton and Bachman 1982.

Table 1. Geoacoustic Properties of Sub-bottom Sediments as a Function of Depth

Depth	Speed of Sound	Geoacoustic Properties
0 to 12	Sand	Cp = 1650 m/s αs (dB/λ) = 0.8 dB/ λ ρ = 1900 kg/m^3

Table 1. Geoacoustic Properties of Sub-bottom Sediments as a Function of Depth

Depth	Speed of Sound	Geoacoustic Properties
12 to 15	Clay	Cp = 1500 m/s αs (dB/λ) = 0.2 dB/ λ ρ = 1500 kg/m³
15 to 22	Dense Silty Sand	Cp = 1650 m/s αs (dB/λ) = 1.1 dB/ λ ρ= 1800 kg/m³
22 to 31	Stiff Sandy Clay	Cp = 1560 m/s αs (dB/λ) = 0.2 dB/ λ ρ = 1600 kg/m³
31 to 37	Clay	Cp = 1500 m/s αs (dB/λ) = 0.2 dB/ λ ρ = 1500 kg/m³
37 to 42	Silty Sand	Cp = 1650 m/s αs (dB/λ) = 1.1 dB/ λ ρ = 1800 kg/m³
42 to 53	Clay, Fine Sand	Cp = 1598 m/s αs (dB/λ) = 0.5 dB/ λ ρ = 1575 kg/m³
53 to 87	Sandy Silt	Cp = 1605 m/s αs (dB/λ) = 1.0 dB/ λ ρ = 1700 kg/m³
> 87	Dense Sand	Cp = 1800 m/s αs (dB/λ) = 0.9 dB/ λ ρ = 2000 kg/m³

Speed of Sound Profile

Sound speed profile information for the year was obtained per month, and a sensitivity analysis was conducted to determine the sound speed profile that would yield the most conservative sound modeling results. The speed of sound profile was obtained using the NOAA Sound Speed Manager software incorporating the World Ocean Atlas 2009 extension algorithms. Dominion Energy intends to conduct pile-driving activities between May 1 and October 31. For the construction modeling scenarios, the average sound speed profile for this construction period was selected. The average sound speed profile was directly inputted into the dBSea model, and the input is shown in Figure 3.

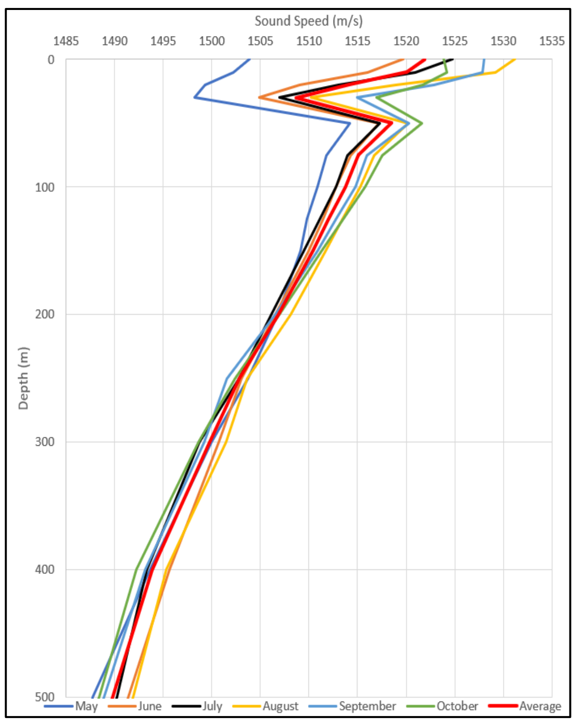

Figure 3. Average Sound Speed Profile

Pile-driving Sound Source Characterization

The pile-driving sound source level was represented using three different metrics: peak sound level (Lpk), sound exposure level (SEL), and sound pressure level

(SPL). The sound source spectrum is entered for each one-third octave band from 12.5 Hz to 20kHz based on Tetra Tech's empirical model.

For the L_{PK} underwater acoustic modeling scenario, the pile-driving sound source was represented as a point source at mid-water depth. The L_{PK} scenario evaluates a single pile-driving strike.

For the SEL underwater acoustic modeling scenario, the pile-driving sound source was represented by a moving source, which accounts for the speed of sound of steel for the pile itself. The monopile and pin pile-driving scenarios were both modeled using a vertical array of point sources spaced at 1 m intervals. Using the SEL level calculated by the empirical model, the SEL sound source is calculated using the following equation to distribute the sound emissions across the vertical array:

$$L_{E,N} = L_{E,\,1\,strike} + 10Log(N) \qquad (2)$$

Where: N is the number strikes

$L_{E,\,1\,strike}$ is obtained from the Tetra Tech, Inc. empirical model

The SPL underwater acoustic modeling scenario is set up identical to the SEL underwater acoustic modeling scenario. The difference regarding the SPL underwater acoustic modeling scenario is that the total number of anticipated pile-driving blows in the 24-hour assessment period is not incorporated into the calculation. For the SPL underwater acoustic modeling scenario, only a single pile-driving strike is evaluated.

<u>Time Domain Considerations</u>

Tetra Tech also recognizes the effect time has on pile-driving sound. As Bellman et al. (2020) reports, the noise of a single strike is thus temporally stretched with increasing distance. Additionally, the amplitude decreases steadily with the distance to the source, so that the signal-to-noise-ratio continuously decreases. Figure 5 from Bellman et al. (2020) illustrates the change in signal over time.

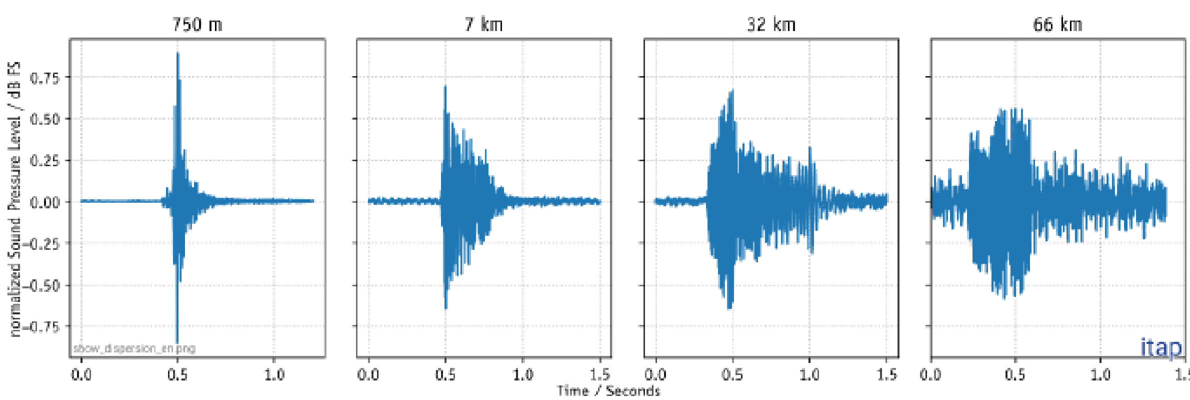

Figure 5. Time Signal of a Single Strike, Measured in Different Distances to the Pile-driving Activity (Bellman 2020)

The L_{PK} levels tend to decrease faster than the SEL sound levels as the propagation occurs. There are mixed views on whether the impulsivity of signals decrease over time, suggesting that non-impulsive limits should be applied to assess underwater acoustic impacts. While impulsivity may decrease, it is still observed that the rise times associated with impulsive signals are maintained (Martin et al. 2020). This is especially true when considering the narrow temporal windows (high temporal resolution) of many cetaceans and after application of weightings, excluding lower frequencies.

dBSea can account for the effects of the time domain using two different mechanisms. If time series information is available for use in the modelling analysis, it can be directly loaded into dBSea and used as sound source. The gaussian beam raytracer (dBSeaRay) will calculate the paths and arrival times from the source to all receiver points in the scenario for all the rays emitted from the source. At every receiver point, the transmission loss, phase inversion from the surface, loss to the sediment, and time of arrival is stored. This information is used to convolve all ray-arrivals into a single signal at that point. This means that each receptor point will receive a signal from many perceived origins and at various arrival times (depending on the length of the path travelled). This tends to “smooth” out and stretch the received signal at greater ranges or with more reflections.

Alternatively, if time series data are not known or available, dBSea can include a crest factor, which is a way to incorporate impulsiveness information into the source. The crest factor indicates the dB level above the rms level of the highest peak in the signal. It is applied when assessing peak levels and is applied to all frequency bands. Application of the crest factor is generally expected to yield more conservative results relative to using a time series for characterizing pile-driving sound source levels. Since time series data for the Project’s pile-driving activities were not available at the time of the modelling analysis, Tetra Tech used the conservative crest application methodology.

References

Bellman, M.A., A. May,, T. Wendt, S. Gerlach, P. Remmers, and J. Brinkmann. 2020. Underwater noise during percussive pile driving: Influencing factors on pile-driving noise and technical possibilities to comply with noise mitigation values. ERa Report.

Hamilton, E.L. 1976. Geoacoustic modeling of the sea floor. *Journal of the Acoustical Society of America*, 68, 1313-1340.

Hamilton, E.L. 1982. Compressional Waves in marine sediments. *Geophysics*, 37 620-646.

Hamilton, E.L. and Bachman, R.T. 1982. Sound velocity and related properties of marine sediments. Journal of the Acoustical Society of America, 72, 1891-1904.

Jensen, F.B., W.A. Kuperman, M.B. Porter, and H. Schmidt. 2011. Computational Ocean Acoustics, 2nd edition, Springer.

Martin, B., K. Lucke, and D. Barclay. 2020. Techniques for distinguishing between impulsive and non-impulsive sound in context of regulating sound exposure for marine mammals. *The Journal of the Acoustical Society of America* 147, 2159.

NOAA Satellite and Information Service. 2020. U.S. Coastal Relief Model. 1999 to 2005. Available online at: https://www.ngdc.noaa.gov/mgg/coastal/crm.html. Accessed December 13, 2020.

Word Ocean Atlas. 2009. NOAA Atlas NESDIS 68, U.S. Government Printing Office, Washington, D.C. Available online at: https://www.ngdc.noaa.gov/mgg/coastal/crm.html.

ATTACHMENT Z-2: IMPACT PILE DRIVING SOUND SOURCE DEVELOPMENT

Attachment Z-2 – Impact Pile-Driving Sound Source Development

Tetra Tech, Inc. (Tetra Tech) has developed a reliable and effective approach for evaluating underwater acoustic impacts due to offshore wind facility construction as well as other in-water activities. For offshore wind facility construction, pile driving is typically the loudest activity, and therefore, analysis of pile driving impacts is critical during the permitting process. This technical memo describes how we derive pile-driving sound source levels. Based on new measurement data and publicly available research studies, this approach has been modified for the Coastal Virginia Offshore Wind (CVOW) Commercial Project since the modeling that was completed for the CVOW Pilot Project was conducted in 2020.

Pile Driving Broadband Sound Source Development (Lpk and SEL)

Impact pile driving during construction of offshore wind energy facilities involve piles of larger diameters and use of greater hammer forces where previously collected comparable measurement data are not widely available. For that reason, Tetra Tech has developed an empirical modeling approach where source levels are derived based on a literature review of pile driving measurement reports, theoretical modeling reports, and peer-reviewed research papers (see the References section below). The data points from the cited references were obtained from piles of varying diameter, driven with hammers operated at various energies, and collected or analyzed at various ranges from the pile. To determine the source level for impact pile driving , Tetra Tech uses the following steps:

1. The first step involves normalizing the received sound pressure levels in the empirical model database assuming transmission loss associated with 15 times the common logarithm (logarithm base 10) of the distance between the source and receiver to obtain source levels associated with the scenario:

   $$TL = 15*log_{10}(D/D_{ref}) \qquad (1)$$

   Where: TL = *Transmission loss (dB)*

   D = *Distance (m)*

   D_{ref} = *Reference distance (m)*

2. The second step involves normalizing the source level assuming a relationship between hammer energy and radiated sound as 10 times the common logarithm of the hammer energy:

   $$SL_{(D)} = SL_{ref} + 10log_{10}(E/E_{ref}) \qquad (2)$$

   Where: $SL_{(D)}$ = *Sound source level for a given pile diameter (dB)*

   SL_{ref} = *Sound source level at reference distance (dB)*

   E = *Hammer energy (kJ)*

   E_{ref} = *Reference hammer energy (kJ)*

3. The third step consists of calculating a regression of the normalized source level (normalized for range and hammer energy given as SL(D)) to the logarithm of the diameters of the piles to predict the broadband SEL and peak sound levels:

   $$SL = Intercept + N*log_{10}(D) \qquad (3)$$

   Where: SL = *Sound source level for the Project (dB)*

Intercept = Factor determined from regression analyses

N = Factor determined from regression analyses

D = Pile diameter (m)

Figures 1 and 2 below illustrate the L_{PK} and SEL values documented from a number of reference sources incorporating both measurement and theoretical modeling (y-axis) plotted versus pile diameter (x-axis). These plots also illustrate the normalized values for both range and energy.

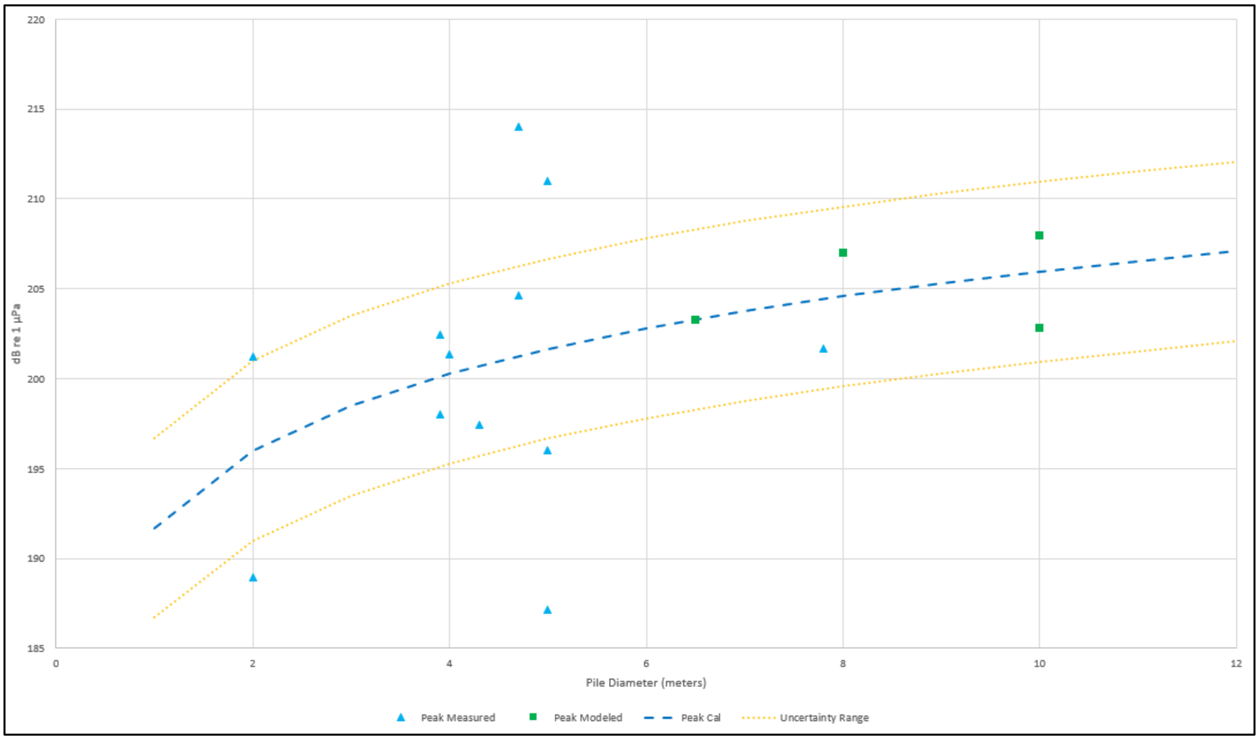

Figure 1. Measured and Modeled Peak Levels Versus Pile Diameter at 750 meters Normalized to a Hammer Energy of 4,000 kJ

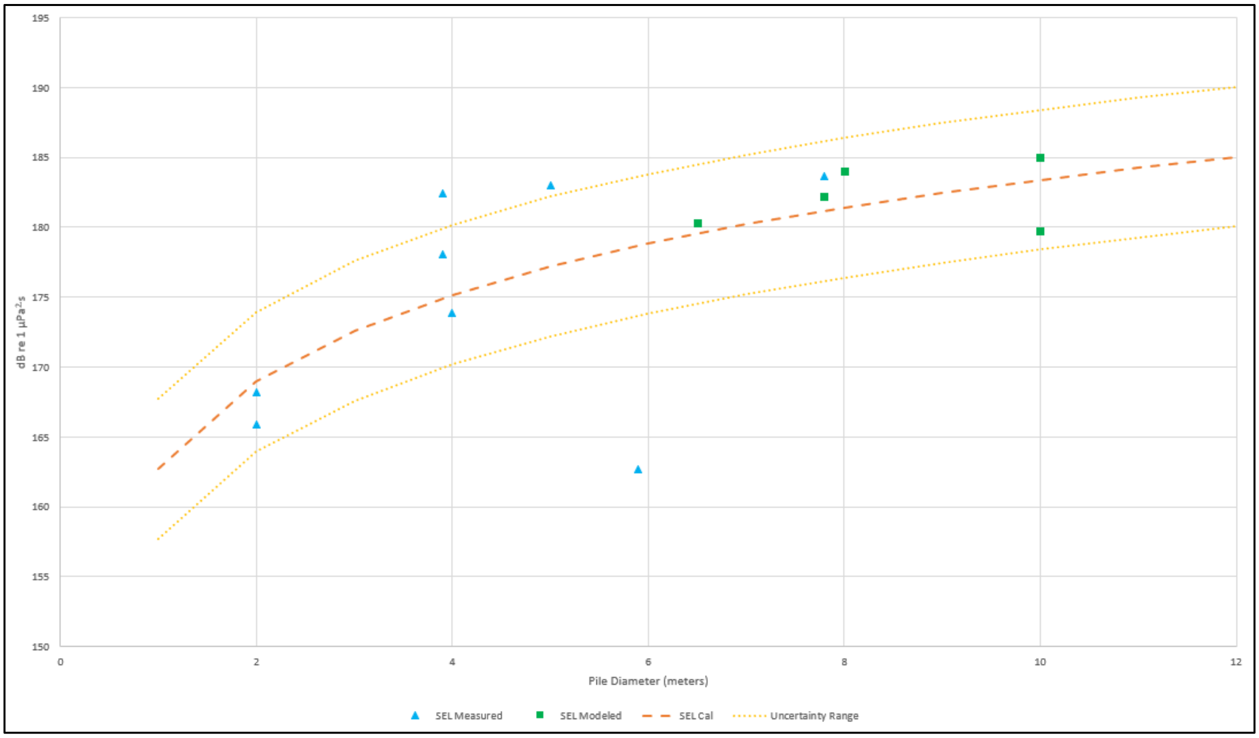

Figure 2. Measured and Modeled SEL_{ss} Levels Versus Pile Diameter at 750 meters Normalized to a Hammer Energy of 4,000 kJ

The development of the empirical model assumes that the applied hammer energy takes into account the appropriate force needed to accommodate for site-specific soil properties and penetration rate. It is Tetra Tech's understanding that the dominant factor affecting pile-driving noise and potential underwater acoustic impacts is hammer energy. Bellman et al. (2020) state that "apart from the correlation between applied blow energy and measured noise level values, however, no significant correlation between acoustic measurement data and different soil layers, nor between acoustic measurement data and soil resistances could be identified."

Pile-driving Broadband SPL Sound Source Development

Based on the research completed for the empirical model, there were only three data points to calculate the regression curve for the sound pressure level (SPL) metric where the SEL and Lpk levels contained 13 to 16 data points. Because of the lack of data points for the SPL metric, the SPL was derived assuming a relationship between the SEL and SPL as 10 times the common logarithm of the pulse duration (see equation 4). A pulse duration of 0.09 second was used for the CVOW Commercial Project based on the average pulse duration of the source level reference studies.

$$SPL\ (dB) = SEL + 10\log(nT_0/T) \qquad (4)$$

Where: n = *number of sound events*

$T_0 = 1$ *second*

T = *duration of the events*

This equation shows that the single event SPL is approximately 10 dB greater than the SEL value (Bellman et al. 2020).

Applied Safety Factor

The uncertainty range for this developed empirical model is +/- 5 dB. This uncertainty range is based on the scatter of the referenced data (Figures 1 and 2) as well as comparison to data collected by Tetra Tech for impact pile-driving activities. Therefore, 5 dB is added to the source level when entered into dBSea.

Deriving Impact Pile-driving Sound Spectrum Data

The spectrum data for the monopile and pin pile modeling scenarios are also derived using the empirical model, which includes published data from recent project applications that incorporated similar pile diameters. The spectrum for the pin pile is based on pile diameters between 2 to 4 meters (m), and the monopile spectrum is based on pile diameters between 5 and 11 m.

Using a process that is consistent with how the broadband levels were reviewed, the spectrum information collected for the empirical model was first normalized. The third octave band levels of the spectrum were normalized to both range and energy level. To ensure that the effect of the source data with the most acoustic energy (spectra for the largest pile driven at the highest hammer rating) does not contribute disproportionately to the spectral shape, the maximum value of each reference spectrum is subtracted from that spectrum so that maximum value is zero. The calculated broadband level is then added so that the peaks of all spectrums are the same. The mean of these normalized spectrums is then calculated to estimate the spectral shape. The reference spectrums for the pin pile and monopile are presented in Figures 3 and 4 in terms of dB/third octave band.

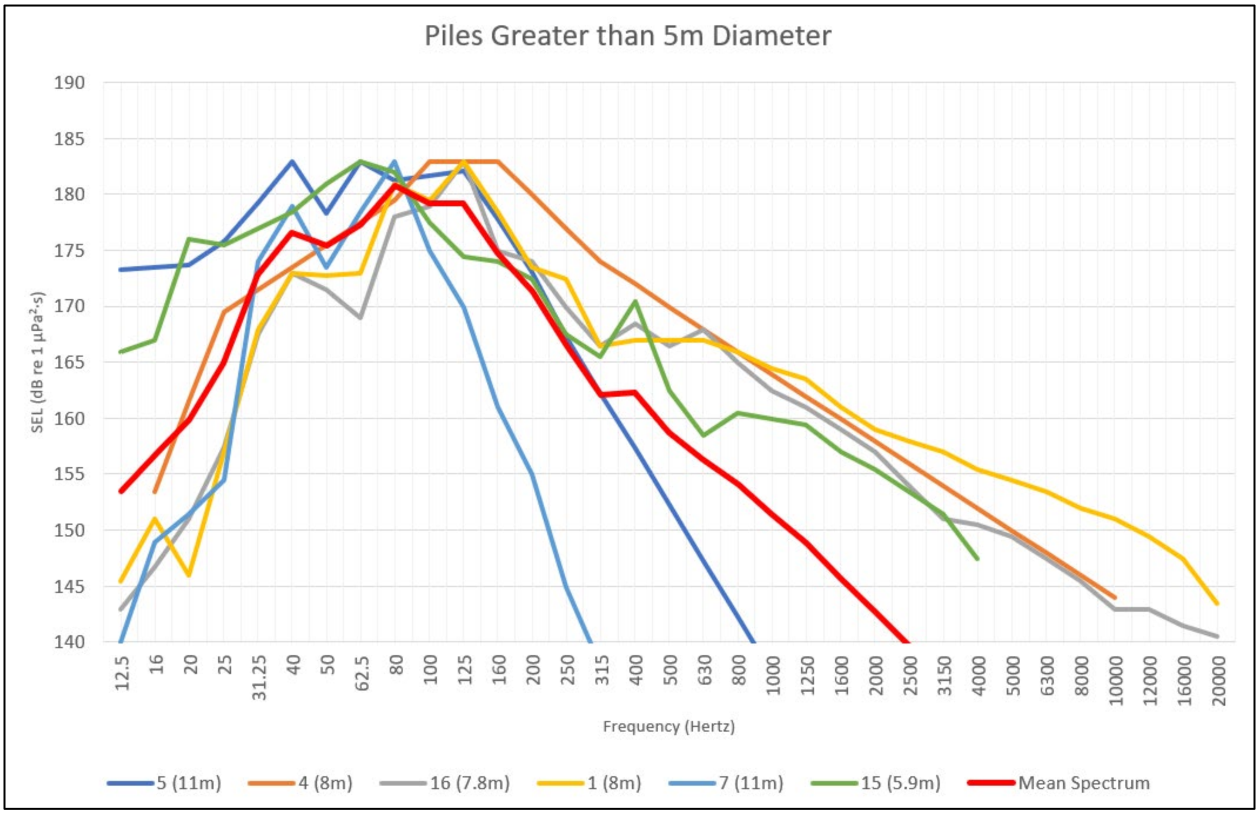

Figure 3. Model Monopile Spectrum

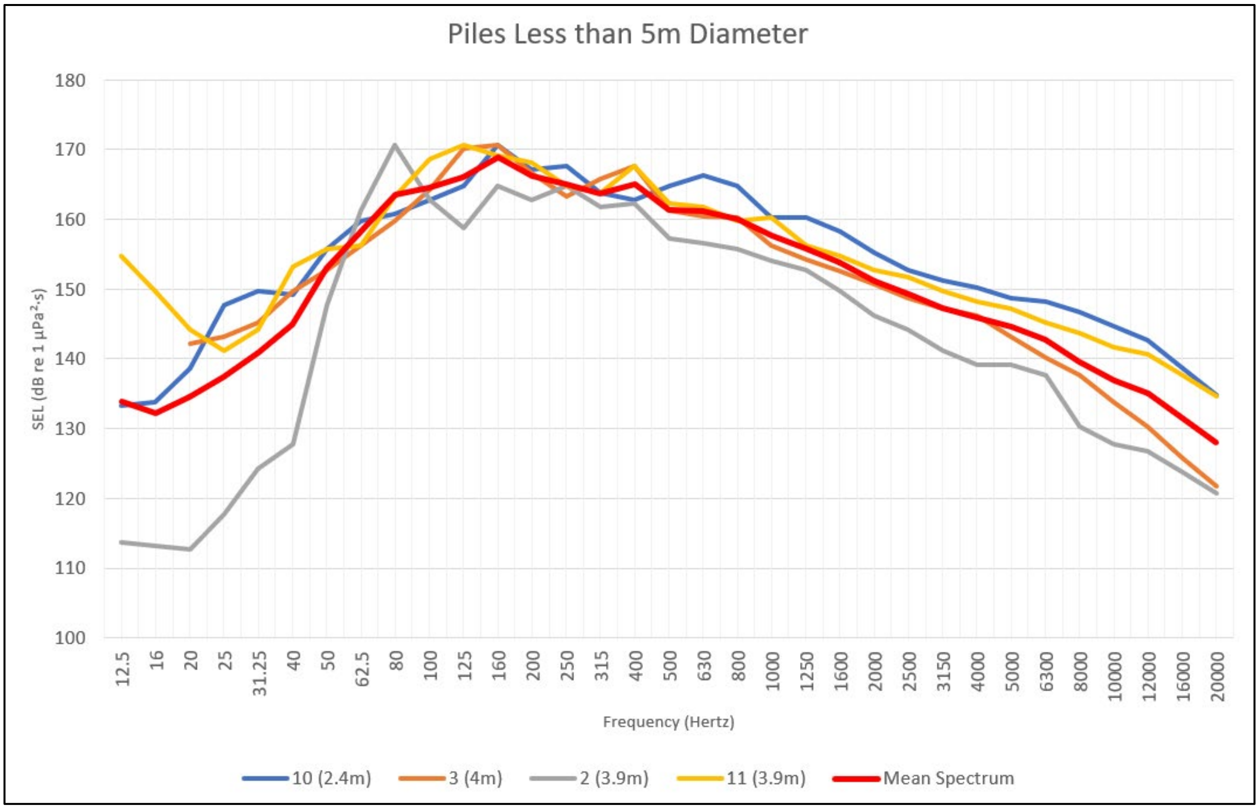

Figure 4. Model Pin Pile Spectrum

Please refer to the references section for the supporting documentation that has been used to support the development of the pile-driving sound source empirical model. References are numbered in the references section and in Figures 3 and 4 so that data can be more easily correlated to its source.

References

1. Bellman, M.A., A. May, T. Wendt, S. Gerlach, P. Remmers, and J. Brinkmann. 2020. Underwater noise during percussive pile driving: Influencing factors on pile-driving noise and technical possibilities to comply with noise mitigation values. ERa Report.
2. Brandt, M.J., A. Diederichs, K. Betke, and G. Nehls. 2011. “Responses of harbour porpoises to pile driving at the Horns Rev II offshore wind farm in the Danish North Sea.” Marine Ecology Progress Series 421:205-216.
3. De Jong, C.A.F. and M.A. Ainslie. 2008. “Underwater radiated noise due to the piling for the Q7 Offshore Wind Park.” Journal of the Acoustical Society of America, 123:2987.
4. itap Gmbh. 2019. Offshore Wind Farm "Baltic Eagle" Prognosis of the expected underwater sound emissions during pile-driving work. January 2019.
5. JASCO Applied Sciences Inc. 2021. Turbine Foundation and Cable Installation at South Fork Wind Farm Acoustic Modeling of Construction.
6. Kuhler, R.M. and M.A. Bellmann. 2019. Offshore Wind Farm "Kaskasi II" Forecast of expected underwater noise immissions during possible pile driving in Offshore Wind Farm Kaskasi II (fall-back scenario).
7. Marine Acoustics Inc. 2020. Underwater Acoustic Assessment of Construction and Operation Activities at the Bay State Wind Offshore Wind Farm.
8. Mikaelsen, M.A. 2015. Kriegers Flak Offshore Wind Farm - Underwater noise modelling EIA - Technical Report. Aarhus, January 2015: Energinet.dk.
9. Nedwell, J.R., S.J. Parvin, B. Edwards, R. Workman, A.G. Brooker, and J.E. Kynoch. 2007. Measurement and interpretation of underwater noise during construction and operation of offshore windfarms in UK waters. Report for COWRIE, Newbury, UK.
10. Nehls, G. and M. Bellmann. 2016. Weiterentwicklung und Erprobung des „Großen Blasenschleiers“zur Minderung der Hydroschallemissionen bei Offshore-Rammarbeiten. Husum: ITAP.
11. Norro, A., J. Haelters, B. Rumes, and S. Degraer. 2010. Underwater noise produced by the piling activities during the construction of the Belwin offshore wind farm.
12. Robinson, S.P., P. Lepper, and J. Ablitt. 2007. “The measurement of the underwater radiated noise from marine piling including characterisation of a" soft start" period.” In Oceans 2007-Europe (pp. 1-6). IEEE.
13. Stephen P. Robinson, Theobald, P.D., and P.A. Lepper. 2012. “Underwater sound from marine pile driving.” Proceedings of meetings on acoustics Acoustical Society of America 17(1).
14. Tougaard, J., J. Carstensen, J. Teilmann, H. Skov, and P. Rasmussen. 2009. “Pile driving zone of responsiveness extends beyond 20 km for harbor porpoises (Phocoena (L.)).” The Journal of the Acoustical Society of America, 126:11-14.
15. Von Pein, J., S. Lippert, and O. von Estorff. 2021. “Validation of a finite element modelling approach for mitigated and unmitigated pile driving noise prognosis.” The Journal of the Acoustical Society of America, 149, 1737.
16. Water Proof Marine Consultancy & Services BV. 2020. Coastal Virginia Offshore Wind Noise Monitoring during Monopile Installation A01 and A02.

17. Yang, L., X. Xu, Z. Huang, and X. Tu. 2015. "Recording and Analyzing Underwater Noise During Pile Driving for Bridge Construction." Acoustics Australia, 43:159-167.

ATTACHMENT Z-3: VIBRATORY PILE DRIVING SOUND SOURCE DEVELOPMENT

Coastal Virginia Offshore Wind

Acoustic statement of the expected underwater noise during vibro piling

Sitz
itap GmbH
Marie-Curie-Straße 8
26129 Oldenburg

Amtsgericht Oldenburg
HRB: 12 06 97

Telefon (0441) 570 61-0
Fax (0441) 570 61-10
Mail info@itap.de

Geschäftsführer
Dr. Michael A. Bellmann

Bankverbindung
Raiffeisenbank Oldenburg
IBAN:
DE80 2806 0228 0080 0880 00
BIC: GENO DEF1 OL2

Commerzbank AG
IBAN:
DE70 2804 0046 0405 6552 00
BIC: COBA DEFF XXX

USt.-ID.-Nr. DE 181 295 042

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Oldenburg, November 12th, 2021

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Contracting body: DEME Offshore
Haven 1025 - Scheldedijk 30
2070 Zwijndrecht
Belgium

Execution: Patrick Remmers, B. Eng.
Dr. Michael A. Bellmann

itap GmbH
Institute for Technical and Applied Physics GmbH
Marie-Curie-Straße 8
D – 26129 Oldenburg

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Revision table

Version		

This version replaces all previous versions.

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1. Summary

DEME Offshore BVplans to install on behalf of DOMINION the foundation structures for the Offshore Wind Turbine Generators (OWTGs) and the Offshore Supply Station (OSS) for the Coastal Virginia Offshore Wind Farm in the Atlantic Ocean at the east coast of the United States of Amerika. It is intended to install the offshore wind turbines on monopile foundations with a maximum outer diameter of 9.5 m and an Offshore Supply Station (OSS) on a jacket foundation. The pin-piles for the OSS required for this have a diameter of 2.4 m.

Currently it is under discussion if the first few meters for each pile installation will be performed by using vibro-piling due to the expected soft soil layers. The final penetration depth shall be reached by impact pile-driving method which will not be taken into account in this statement.

The *itap GmbH* was commissioned by DEME offshore BV to predict the expected underwater noise pollution during vibro-piling activities. Based on the limited available empirical data base and the existing knowledge gap of the most influencing site- and project-specific parameters on vibro-piling noise only a rough estimated of the expected noise levels incl. spectrum are compiled based on the empirical data based of *itap GmbH*.

The results were as follows:

- The sound input from vibration pile driving is generally to be classified as continuous noise and not impulsiveness noise.
- For the foundation piles in the Virginia Offshore Windfarm the following noise level are expected during vibro-piling:

Pile type	Diameter [m]	SPL in 750 m distance
pin pile	2.4	151
monopile	9.5	159

- Based on the fact that the most site- and project-specific influencing parameters on vibro-piling noise are currently unknown, the uncertainty of the predicted noise levels are currently extremely high (> ± 10 dB) compared to predicted impact pile-driving metrics.
- One of the currently known influencing parameter on vibro-piling noise is the frictional coupling between the vibratory hammer and the pile. In case of a poor coupling rattling airborne noise is audible and the underwater noise levels increase in amplitude and frequency significantly. This will most likely also have a major

impact on the installation process, as well. Therefore, a stable and good coupling must be guaranteed.

- Based on empirical data, the given water depth and soil conditions it will be expected that only low frequencies will be radiated into the water (between 50 Hz and some hundred Hz). The fundamental frequency of the vibratory hammer (up to 25 Hz) will not be propagable in this part of the Atlantic Oceans.

Oldenburg, November 12th 2021

P. Remmers Bellmann

Patrick Remmers, B.Eng Dr. Michael A. Bellmann

itap GMBH
Marie-Curie-Str. 8
26129 Oldenburg

2. Introduction and task definition

DEME Offshore BVplans to install on behalf of DOMINION the foundation structures for the Offshore Wind Turbine Generators (OWTGs) and the Offshore Supply Station (OSS) for the Coastal Virginia Offshore Wind Farm in the Atlantic Ocean at the east coast of the United States of Amerika. The offshore wind farm is located approx. 30 nm east of Virginia in water depths between 20 m and 39 m MSL. The soil in the project area consists generally of loose to medium dense sand followed by firm to stiff clay with intermediate layers of sand between clay. At numerous locations the risk of pile run has been identified. No boulders are expected.

It is intended to install the OWTGs on monopile foundations with a maximum outer diameter of 9.5 m and length between 59.6 m and 81.7 m. The penetration depth will be between 30 m and 46 m. In addition, an Offshore Supply Station (OSS) is planned on a jacket foundation. The pin-piles required for this have a diameter of 2.4 m and a length of between 62.5 and 83.5 m. Penetration depths between 61 m and 76 m are planned.

Currently it is under discussion if the first few meters for each pile installation will be performed by using vibro-piling due to the expected soft soil layers. The final penetration depth shall be reached by impact pile-driving method.

The *itap – Institute for Technical and Applied Physics GmbH* was commissioned by DEME Offshore BV to carry out the modeling of underwater vibro-piling noise during the construction phase of the Coastal Virginia Offshore Windfarm. Currently only few empirical data regarding vibro-piling were published and the site- and project-specific influencing parameters for vibro-piling noise are currently mostly unknown so that currently no reliable scientifically validated prediction model for vibro-piling is available. Therefore, the empirical data base of itap GmbH will be combined with the public available data and based on this a rough estimate of the expected underwater noise levels during vibro-piling will be compiled.

Note: Tthe German Offshore Wind Farm KASKASI will be installed by using vibro-piling till final penetration depth is reached. The construction phase is planned to start in January 2022 and will be accompanied by the funded R&D project VISSKA with an intensive monitoring plan. Aim of VISSKA is identify the site- and project-specific influencing parameters on vibro-piling noise and the generation of a validated vibro-piling noise prognosis tool by itap GmbH. Therefore, it is likely that an intensive knowledge win will be created within the next month.

3. Calculated metric

(Energy-) equivalent continuous Sound Pressure Level (SPL)

In acoustics, the intensity of continuous sounds (Energy-) is described as equivalent continuous Sound Pressure Level (SPL) and is defined as (ISO 18405 2017):

$$SPL = 10\ \log_{10}\left(\frac{1}{T}\int_{0}^{T}\frac{p(t)^2}{p_0^2}\ \mathrm{d}t\right)\ [\mathrm{dB}]$$

Equation 1

with

$p(t)$ - time-variant sound pressure,

p_0 - reference sound pressure (in underwater sound 1 µPa),

T - averaging time.

Sometimes in literature, the label SPL is used for a Sound Pressure Level without time averaging. According to this definition, the continuous Sound Pressure Level over an interval is than labeled as SPL_{rms} with the index rms for root mean square. In this report, the terminology according to the ISO 18406 (2017) is used and the index rms is omitted and the SPL in this report is equal to SPL_{rms}, since a definition according to Equation 1 already implies averaging. In some nations, the rms value of the Sound Pressure Level (SPL_{SS}) of each single strike shall be determined. Therefore, the duration of each single strike shall be considered. However, vibro-piling cause continuous noise entries in the water and not impulsiveness noise; therefore a SPL_{SS} can't be provided.

The term SPL is often used in the literature to refer to the zero-to-peak peak level. The ISO 18405 (2017) standardizes the basic acoustic terms and level quantities (terminology) and ISO 18406 (2017) is a measurement standard for impulsive underwater sound including standardized documentation. Internationally, it has been agreed to use the nomenclature Sound Pressure Level (SPL) for continuous sound and Peak Sound Pressure Level ($L_{p,pk}$).

4. Model approach

Currently, only limited empirical data exists during installation by means of vibratory pile-driving. The few data sets – mostly measured by itap GmbH - are shown in Figure 1. All available measurement data were measured in water depth between several meters till up to 40 m water depth and in distances between several meters till 750 m distance to source. However, all empirical data were normalised to a distance of 750 m using the propagation attenuation 15 $\log_{10}(R)$ with the distance ratio R and plotted as a function of the pile diameter used; Figure 1.

Each cross shown represents vibration pile driving activities at a foundation site and at one measurement location. Different pile diameters represent different Offshore Wind Farms (OWF). The solid blue line symbolises a statistical regression curve over all measured values shown. The grey marked area represents the statistically 95 % confidence range over all measured values shown. Based on the fact that the most site- and project-specific influencing parameters on vibro-piling noise are currently unknown, the uncertainty of the predicted noise levels are currently extremely high compared to predicted impact pile-driving metrics.

There is a tendency for the measured continuous sound level (SPL) to increase with the increase in pile diameter. However, it is striking that the scatter in the measurement data is very high (> 10 dB) for the same or comparable pile diameters. The reason for this has not yet been conclusively scientifically investigated. It is assumed that a significant influencing factor is the frictional coupling between the pile and the vibration hammer; see Figure 2. The better the frictional coupling between the pile and the vibro-hammer the less noise the vibro-piling is.

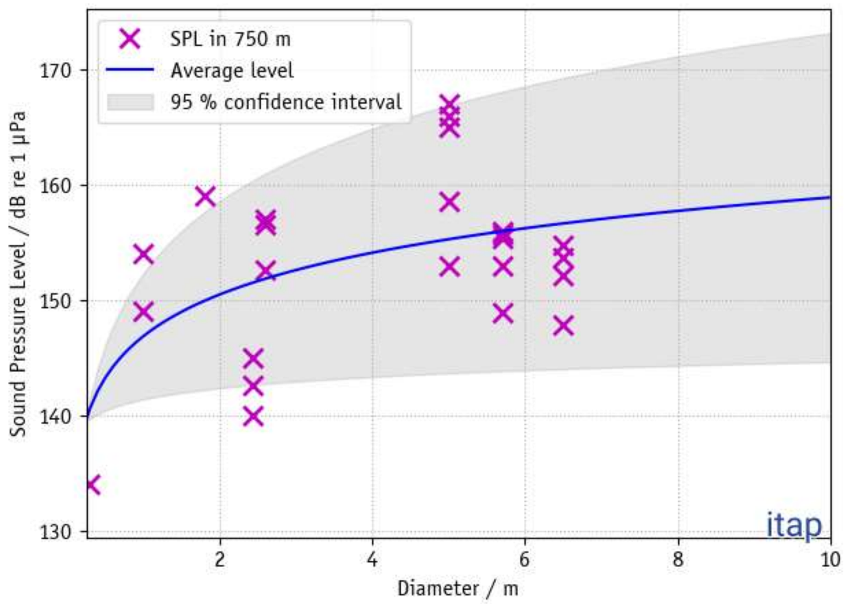
The pile diameters of 5 m and 5.7 m are monopile installations in two different wind farms with non-comparable soil conditions in the upper sediment layers (one within the North Sea with mostly sand and clay and one within Baltic Sea with also very hard soil layers consisting of glacial drift and chalkstone). Due to the normalisation to a measurement distance of 750 m, uncertainties of < 3 dB are to be expected. The differences at the same pile diameter result from comparative measurements within one offshore wind farm

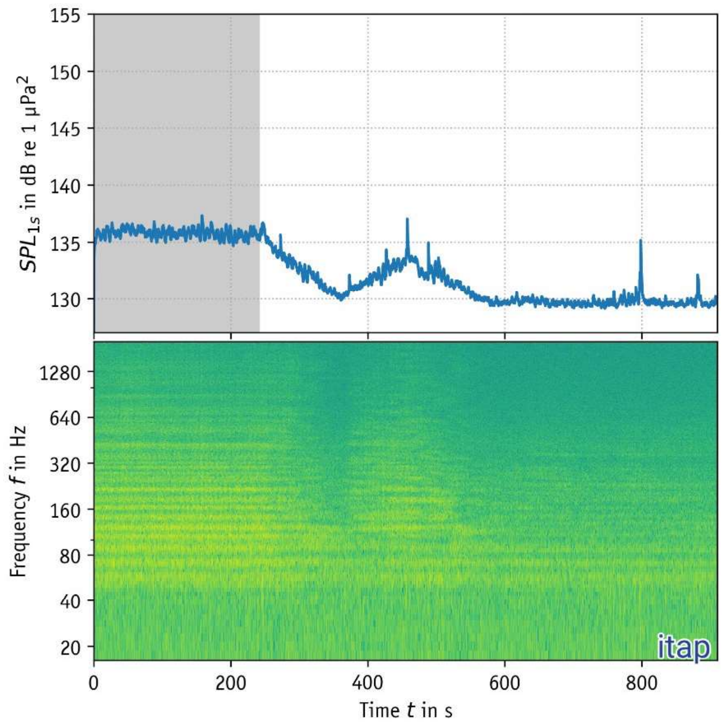
(i) at different foundation locations or

(ii) partly at the same pile in different penetration depth sections.

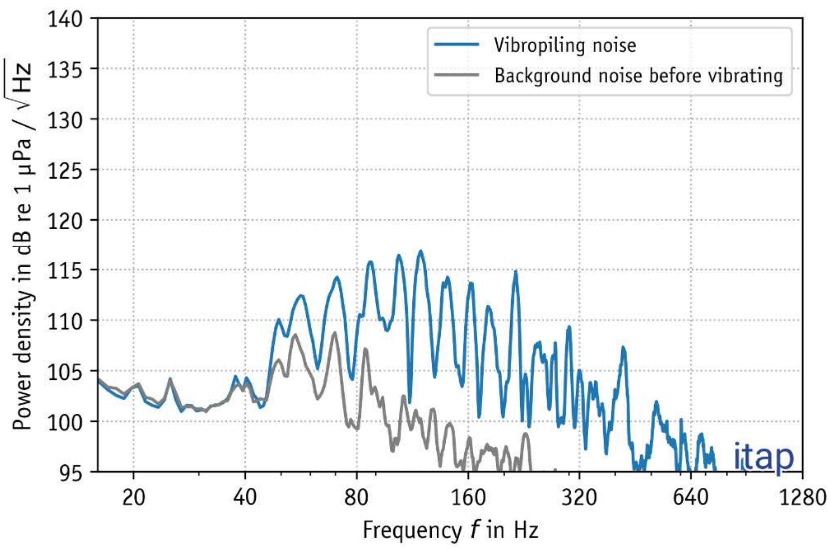
It can be demonstrated that the differences between different foundation locations with the same vibratory hammer show in part higher scatter or deviations in the measured noise levels than between different pile diameters, offshore wind farms and the vibratory hammers used.

However, within the OWF with a Monopile diameter of 5 m a very high deviation of the measured SPL values in 750 m were observed. Based on the vibro-hammerlogs and offshore observations these large variations can be explained by different frictional couplings between the Monopiles and the vibratory hammer.





SPL_{1s} in dB re 1 µPa²
Frequency f in Hz
Time t in s
itap



Vibropiling noise
Background noise before vibrating
Power density in dB re 1 µPa / √Hz
Frequency f in Hz
itap

5. Prediction of vibro-piling noise

For the first rough prediction of the expected underwater noise levels during vibro-piling, the pile diameter of 2.4 m for the OSS and 9.5 m for the OWTGs were used. This results in the following calculated continuous Sound Pressure Level (SPL):

Table 1: *Roughly calculated continuous sound pressure Level (SPL) for different pile diameter*

Pile type	Diameter [m]	SPL in 750 m distance
pin pile	2.4	151
monopile	9.5	159

6. Discussion of the results and forecast uncertainty

6.1 Limitations of the forecast model approach

Up to now, no measurement data are available for vibrations of a Monopile with a diameter of > 6.5 m, whereby the influence of the pile diameter is presumably smaller on the vibro-piling noise than on impact pile-driving (Bellmann, et al. 2020). Frankly speaking, an empirical approach, as shown in Figure 1, should also only be used to a limited extent for a pile diameter of 6.5 m for scientific reasons. However, due to the large scatter of the measurement results and the small influence of the pile diameter, an application for such an application is conceivable for a first estimation.

In addition, no measurement data currently exist during the vibro-piling procedure of piles down to an embedment depth of more than 20 m. Based on the current measurement data, the influence of bottom resistance on underwater sound emissions cannot be estimated. Evidence from the Baltic Sea indicates that the emitted continuous sound can also increase with increasing soil resistance.

In addition, it cannot be clearly excluded from the empirical data sets that there was a frictional connection between the vibratory hammer and the pile head at all times. A few measurement data show that the sound entry into the water increases significantly both in the frequency range (more higher frequencies) and in the level when there is no frictional coupling. A poor frictional coupling is always be correlated with an intensive increase of airborne noise (rattling noise), as well.

Thus, in the first estimation of the expected sound inputs, it can be assumed that the current model overestimates the expected sound inputs at 750 m with a force-locked connection between the pile head and the vibratory hammer.

6.2 Spectral shape of the vibro-piling noise

A comparable underwater sound spectrum as in Figure 2 can be assumed, since all vibratory hammers available on the market have their fundamental frequency between 14 Hz and 25 Hz (partly tune- and controllable). It is therefore to be expected that the vibration spectrum will also consist of the fundamental frequency and their first harmonics and will therefore be very low-frequency (< 1.000 Hz).

The water depth and the soil conditions will have a significant influence on the sound propagation in water since below a curtained cut-off frequency a suifficient noise entry incl. propagation is not possible, Figure 4. Based on the soil conditions and the project-specific water depth of 20 m to 39 m it is unlikely that the fundamental frequency of the vibratory hammer (up to 25 Hz) is propagable in water (Kipple et al). It will be expected from acoustic point of view that only the first few harmonics will be able to fully propagate in the water (< several hundred Hz).

For any further environmental impact assessment (EIA) based on frequency weightings of Southall et al. and NOAA guideline it is unlikely that vibro-piling noise will have any significant influence on marine mammals since theses species are most likely more sensitive for higher frequencies. But for fishes and benthos -which are capable to perceive low frequency noise – vibro-piling noise might have an impact on the species.

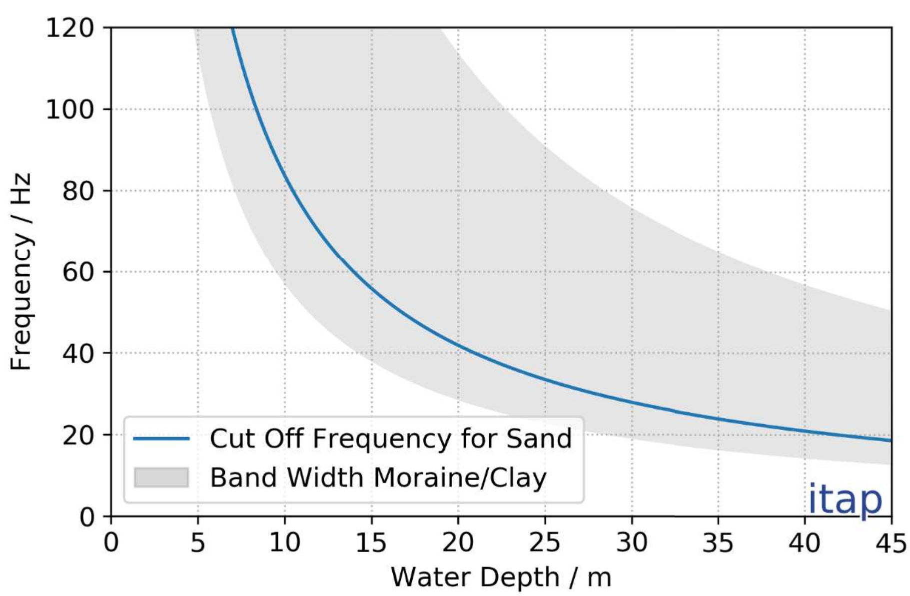


Figure 3: Theoretical lower (limit) frequency (f_g) for an undisturbed sound propagation in water as a function of the water depth for different soil stratifications (example adapted from Urick (1983); Jensen et al., (2011); the example shows the possible range caused by different layers, the layer does not necessarily correspond to the layers in the construction field).

7. References

Bellmann, Michael A., Jana Brinkmann, Adrian May, Torben Wendt, Stephan Gerlach, und Patrick Remmers. „Unterwasserschall während des Impulsrammverfahrens: Einflussfaktoren auf Rammschall und technische Möglichkeiten zur Einhaltung von Lärmschutzwerten. Gefördert durch das Bundesministerium für Umwelt, Naturschutz und nukleare Sicherheit (BMU), FKZ UM16 881500. Beauf-tragt und geleitet durch das Bundesamt für Seeschifffahrt und Hydrographie (BSH), Auftrags-Nr. 10036866. Editiert durch die itap GmbH.“ Tech. rep., itap GmbH, 2020.

ISO 18405. „ISO 18405:2017, Underwater acoustics — Terminology.“ Standard, International Organization for Standardization, Geneva, CH, 2017.

ISO 18406. „ISO 18406:2017, Underwater acoustics – Measurement of radiated underwater sound from percussive pile driving.“ Standard, International Organization for Standardization, Geneva, CH, 2017.

Jensen, Finn B., William A. Kuperman, Michael B. Porter, und Henrik Schmidt. *Computational ocean acoustics*. Springer Science & Business Media, 2011.

Urick, R. J. *Principles of underwater sound*. 3. McGraw-Hill, Inc., 1983.

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