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Appendix Z: Underwater Acoustic Assessment

Coastal Virginia Offshore Wind Commercial Project

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APPENDIX Z UNDERWATER ACOUSTIC ASSESSMENT

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ACRONYMS AND ABBREVIATIONS

dB	decibel
dB/km	decibels per kilometer
DP	dynamic positioning
GARFO	Greater Atlantic Regional Fisheries Office
HF	high-frequency
Hz	Hertz
kHz	kilohertz
kJ	kilojoule
km	kilometers
Lease Area	BOEM-designated Renewable Energy Lease Area OCS-A 00483
LF	low-frequency
LPK	peak sound pressure
m	meter
m/s	meters per second
MF	mid-frequency
MMPA	Marine Mammal Protection Act
NOAA Fisheries	National Oceanic and Atmospheric Administration's National Marine Fisheries Service
OW	Otariids Underwater
Project	Virginia Commercial Offshore Wind
Offshore Project Area	The area where the Project facilities are physically located
PTS	permanent threshold shift
PW	Phocids Underwater
RMS	root-mean-square
SEL	sound exposure level
SEL_{cum}	cumulative sound exposure level
SPL	sound pressure level
SPL RMS	sounds pressure level root mean square
TTS	temporary threshold shift
USFWS	U.S. Fish and Wildlife Service
WTG	wind turbine generator
µPa	micropascal
λ	wavelength

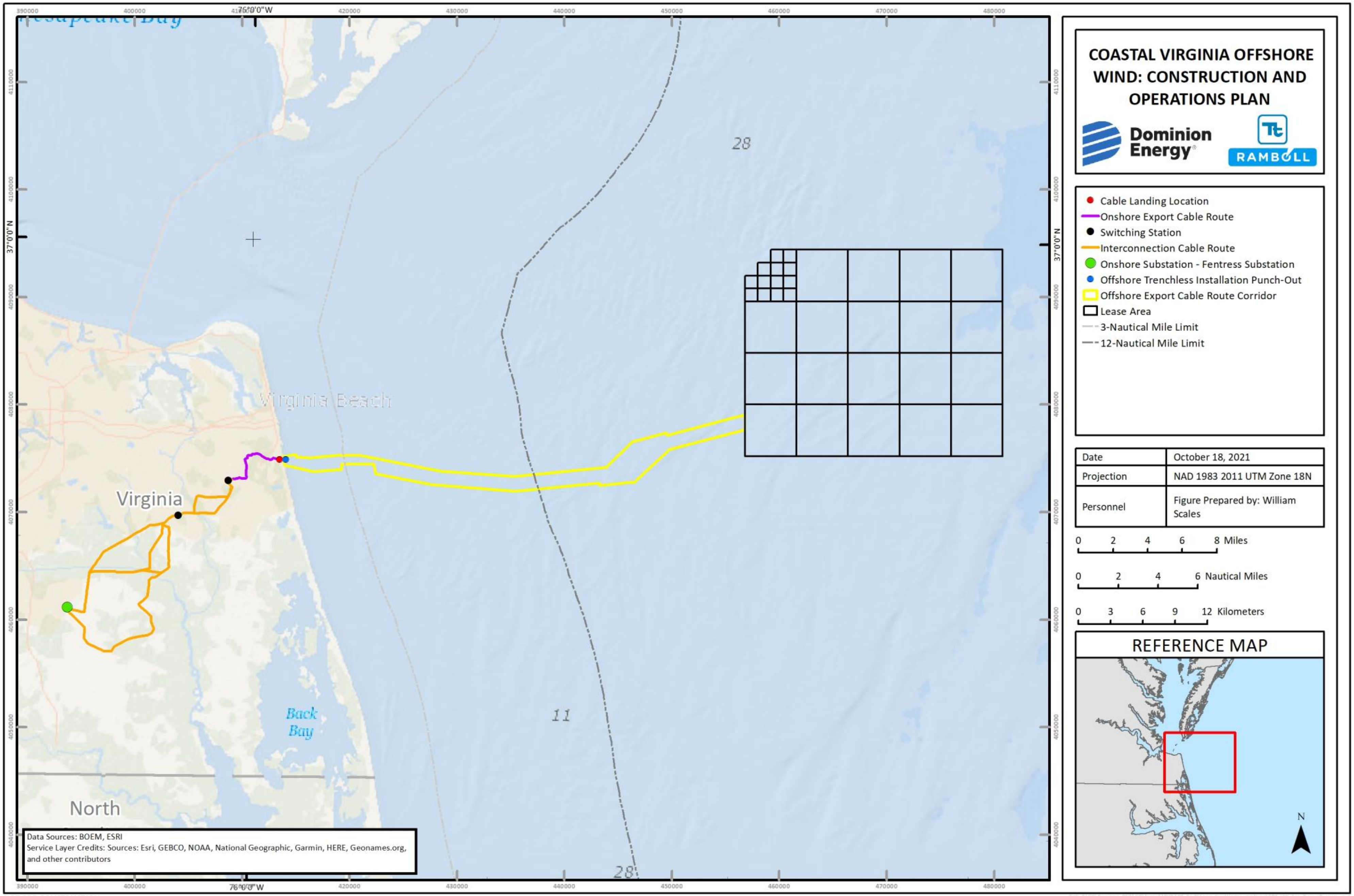
Z.1 INTRODUCTION

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 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-5).

The Offshore Project Components, including the Wind Turbine Generators (WTGs), Offshore Substations, 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 Base 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 Offshore Substation Foundation installation and vibratory pile-driving during cofferdam installation. 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 Underwater Acoustic Assessment is undergoing revisions related to changes to the anticipated Project construction scenarios. In addition, the revised Underwater Acoustic Assessment and modeling analysis will reflect feedback received during recent consultations with 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 will be provided under confidential cover in the revised Underwater Acoustic Assessment to be submitted in November, 2021



NOT FOR CONSTRUCTION

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.

Sound levels are typically reported in units of decibels (dB). The decibel is defined as a ratio of measured acoustic intensity (I) and a reference intensity level (I_{ref}).

$$dB = 10 \text{ x } \log10(I/I_{ref}) \qquad (1)$$

However, sound is often measured as pressure (P) rather than directly as intensity. The intensity of a sound wave is proportional to the square of its pressure, as shown in the following equation:

$$I = P^2/\rho c \qquad (2)$$

where ρ is the density of the medium (e.g., water or air) and c is the speed of sound in that medium. The sound level in dB can be computed directly from the measured pressure with the following equations:

$$dB = 20 \text{ x } \log10(P/P_{ref}) \qquad (3)$$

P_{ref} is the reference 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) of 150 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. This section provides an overview of basic acoustical terms, descriptors, and concepts that should help frame the discussion of acoustics in this document. The majority of the information in the following sections is given to provide further insight into how data and modeling results have been presented in accordance with regulatory reporting requirements and established criteria. Noise descriptors that are commonly used in underwater acoustics to present measured or received levels include the following:

Sound pressure level, which is referred to by National Oceanic and Atmospheric Administration's National Marine Fisheries Service (NOAA Fisheries) as SPL (dB re 1 µPa) in the 2018 revision to "*Technical Guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammal Hearing (Version 2.0)*" 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 RMS 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 RMS 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 RMS 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 $0 \leq t \leq T$.

$$\text{SPL RMS} = 10\log_{10}\left(\frac{1}{T}\int_{T} p^2(t)dt \bigg/ p_0^2\right) \tag{4}$$

For pulsed noise, the SPL RMS level is measured over the pulse duration. For impulsive noise, the time interval (T_{90}) is defined as the “90 perfect energy pulse duration,” which is the interval over which the pulse energy curve rises from 5 percent to 95 percent of the total energy rather than a fixed time window. In addition, because the window length is used as a divisor, pulses that are more spread out in time have a lower SPL RMS for the same total acoustic energy. The SPL RMS_{90} level is determined over the pulse duration according to the following equation:

$$\text{SPL RMS}_{90} = 10\log_{10}\left(\frac{1}{T_{90}}\int_{T_{90}} p^2(t)dt \bigg/ p_0^2\right) \tag{5}$$

Sound exposure level (SEL or L_E) – Sound exposure level (SEL) is similar to the SPL RMS but further specifies the sound pressure over a specified time interval or event, for a specified frequency range, expressed in dB re 1 $\mu\text{Pa}^2\text{s}$. Underwater sounds are classified according to whether they are impulsive or non-impulsive. Impulsive sounds are typically transient, brief (less than 1 second), broadband, and consist of high peak sound pressure with rapid rise time and rapid decay. Non-impulsive sound can be broadband, narrowband or tonal, brief or prolonged, continuous or intermittent, and typically do not have a high peak sound pressure with rapid rise/decay time that impulsive sounds do. Fixed-location, non-impulsive sounds are associated with an operational offshore WTG. The SEL for a single event is computed from the time-integral of the squared pressure over the full event duration (T_{100}):

$$\text{SEL} = 10\log_{10}\left(\int_{T_{100}} p^2(t)dt \bigg/ T_0 p_0^2\right) \tag{6}$$

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. 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 behavior over a 24-hour time period. The $\mathrm{SEL_{cum}}$ (dB re 1 µPa^2·s) can be computed by summing (in linear units) the SELs of the N individual events:

$$\mathrm{SEL_{cum}} = 10\log_{10}\left(\sum_{i=1}^{N} 10^{\frac{\mathrm{SEL}_i}{10}}\right) \tag{7}$$

Peak sound pressure (L_{PK} or $\mathrm{dB_{Peak}}$) – 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 L_{PK} can be a valid criterion for assessing whether a sound is potentially injurious; however, as 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 L_{PK} can be calculated using the formula below where is t the time. Pulses 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.

$$L_{PK} = 10\log_{10}\left[\frac{\max\left(\left|p^2(t)\right|\right)}{p_0^2}\right] \tag{8}$$

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 per kilometer.

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 largest 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. It 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.

Frequency dependence due to destructive interference contributes to the weakening of the sound signal. 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 reports were available and reviewed for the Offshore Project Area and expected geophysical parameters of the seabed were incorporated into the modeling analysis up to a depth of 164 ft (50 m) below the survey of the seabed. The geoacoustic parameters of the seabed materials, including but not limited to compressional speed, density, attenuation rates, and shear speed, were assigned using the empirical model based on measurements developed by Hamilton over many years; this method has been widely used for practical modeling purposes (Farcas et al. 2016). Further details pertaining to sediment characteristics are given in Section Z.4.2.2, Sediment Characteristics.

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:

$$f_c = \frac{C_{water}}{4h} / \sqrt{1 - (C_{water})^2 / (C_{sediment})^2} \tag{9}$$

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.

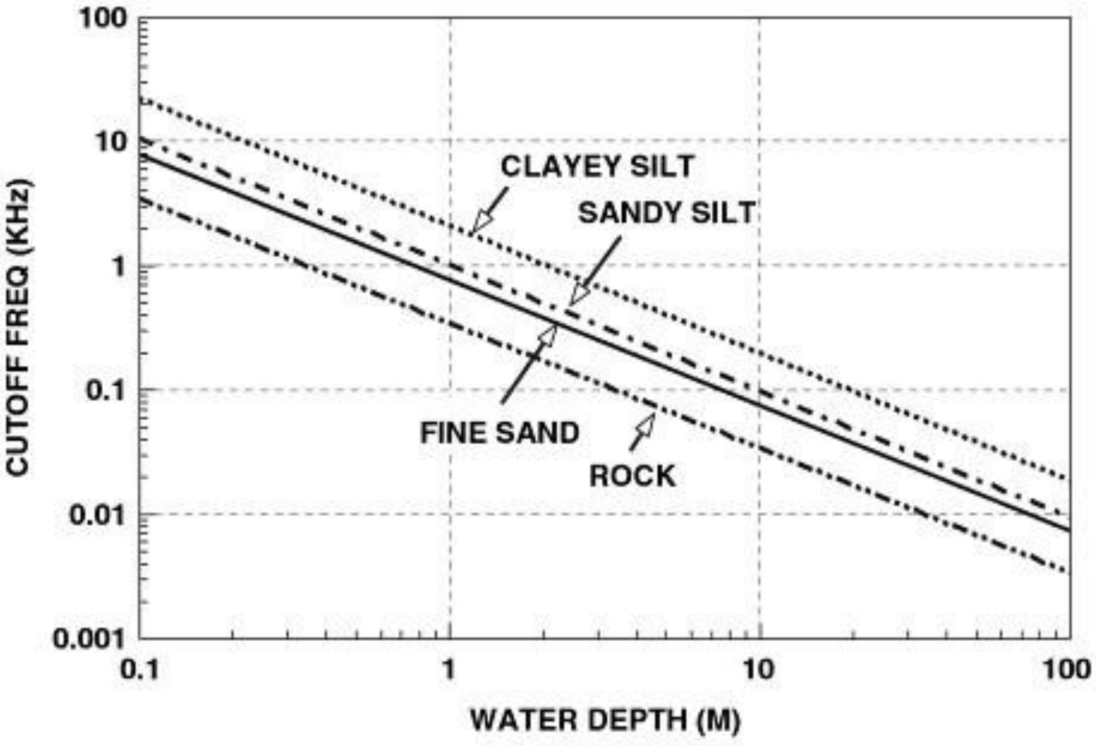


Figure Z-2. Cut-off Frequencies for Different Bottom Materials

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 re 1µPa for impulsive sound, averaged over the duration of the signal and at 120 dB re 1µPa 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, which was updated 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 (L_{PK}) may cause damage to the inner ear, and (2) the accumulated sound energy the animal is exposed to (cumulative sound exposure levels, SEL_{cum}) 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).

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-1), which are presented in terms of dual metrics; SEL_{cum} and L_{PK}. The Level B harassment thresholds are also provided in Table Z-1. The TTS threshold is defined as 20 dB less than the PTS threshold.

For sea turtles, NOAA Fisheries has considered injury onset beginning at SPL RMS 180 dB re 1 µPa to prevent mortalities, injuries, and most auditory impacts and behavioral response from impulsive sources such as impact pile-driving at SPL RMS 166 dB re 1 µPa, which has elicited avoidance behavior of sea turtles (Table Z-2; 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. However, NOAA Fisheries recently updated the prescribed behavioral response threshold for sea turtles to SPL RMS 175 dB re 1 µPa.

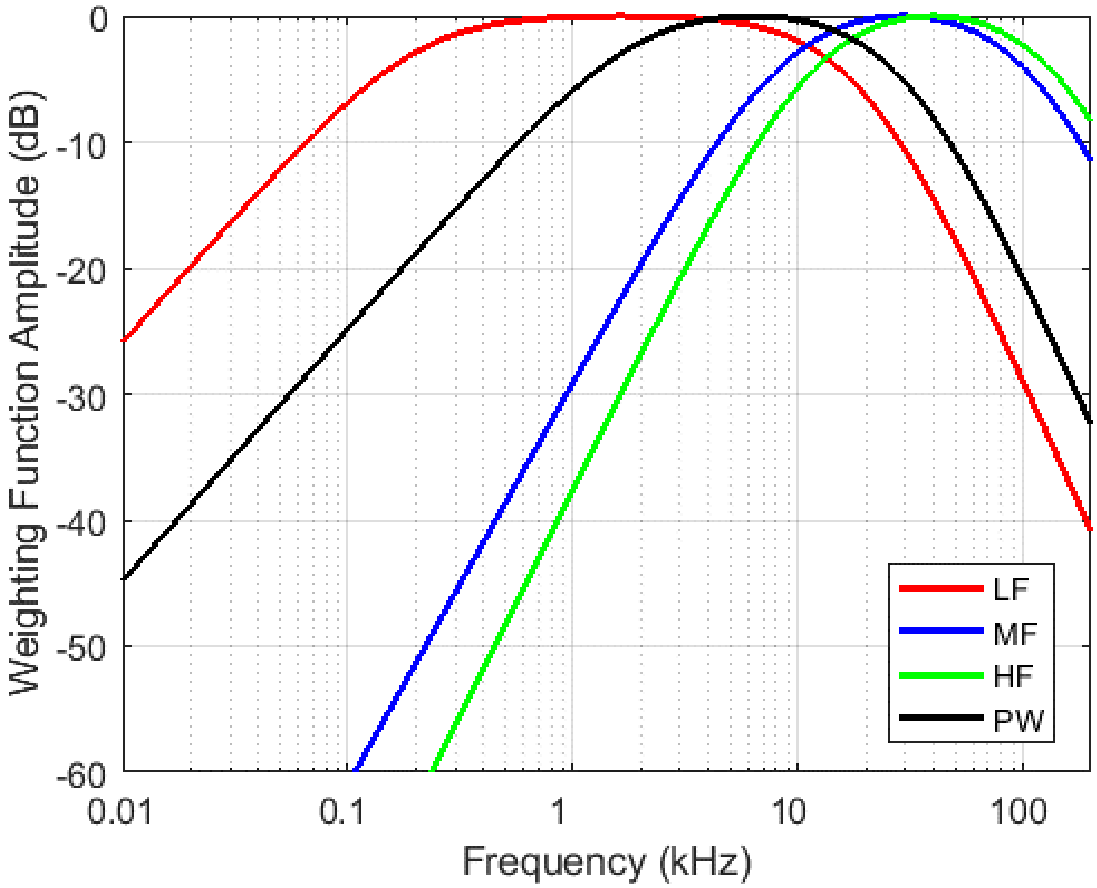


Figure Z-3. **Auditory Weighting Functions for Cetaceans (Low-frequency, Mid-frequency, and High-frequency Species) and Pinnipeds in water (PW) from NMFS (2018)**

In a cooperative effort between federal and state agencies, interim criteria were developed to assess the potential for injury to fishes and sea turtles 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 and sea turtles exposed to elevated levels of underwater sound produced during pile-driving, which were just recently updated (GARFO 2019) These noise thresholds are based on sound levels that have the potential to produce injury or illicit a behavioral response from fishes (Table Z-2).

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-3; 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-1. 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 (LPK) 183 dB SELcum	213 dB (LPK) 168 dB SEL$_{cum}$	160 dB SPL RMS	199 dB SEL$_{cum}$	179 dB SEL$_{cum}$	120 dB SPL RMS
Mid-frequency cetaceans	230 dB (LPK) 185 dB SELcum	224 dB (LPK) 170 dB SEL$_{cum}$		198 dB SEL$_{cum}$	178 dB SEL$_{cum}$	
High-frequency cetaceans	202 dB (LPK) 155 dB SEL$_{cum}$	196 dB (LPK) 140 dB SEL$_{cum}$		173 dB SEL$_{cum}$	153 dB SEL$_{cum}$	
Phocid pinnipeds underwater	218 dB (LPK) 185 dB SEL$_{cum}$	212 dB (LPK) 170 dB SEL$_{cum}$		201 dB SEL$_{cum}$	181 dB SEL$_{cum}$	

Sources: NOAA Fisheries 2018, Southall et al. 2019

SEL = sound exposure level (dB re 1 μPa^2·s); Lpk = peak sound pressure (dB re 1 μPa); RMS SPL = root mean square sound pressure (dB re 1 μPa)
TTS = temporary threshold shift

Table Z-2. Acoustic Threshold Levels for Fishes

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 (LPK) 187 dB SEL$_{cum}$	--	--	--	150 dB SPL RMS
Sea turtles	232 dB (LPK) 204 dB SEL$_{cum}$	226 dB (LPK) 189 dB SEL$_{cum}$	200 dB SEL$_{cum}$	220 dB SEL$_{cum}$	175 dB SPL RMS

Sources: Stadler and Woodbury (2009); GARFO 2019; Blackstock et al., 2017; Department of the Navy 2017.

SEL = sound exposure level (dB re 1 μPa2·s); Lpk = peak sound pressure (dB re 1 μPa); RMS SPL = root mean square sound pressure (dB re 1 μPa)

Table Z-3. 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$_{\text{PK}}$) > 219 dB SEL$_{\text{cum}}$	> 213 dB (L$_{\text{PK}}$) > 216 dB SEL$_{\text{cum}}$	> 186 dB SEL$_{\text{cum}}$	--	--
Fishes with swim bladder not involved in hearing	207 dB (L$_{\text{PK}}$) 210 dB SEL$_{\text{cum}}$	207 dB (L$_{\text{PK}}$) 203 dB SEL$_{\text{cum}}$	>186 dB SEL$_{\text{cum}}$	--	--
Fishes with swim bladder involved in hearing	207 dB (L$_{\text{PK}}$) 207 dB SEL$_{\text{cum}}$	207 dB (L$_{\text{PK}}$) 203 dB SEL$_{\text{cum}}$	186 dB SEL$_{\text{cum}}$	170 dB RMS SPL	158 dB RMS SPL
Sea turtles	207 dB (L$_{\text{PK}}$) 210 dB SEL$_{\text{cum}}$ 232 dB (L$_{\text{PK}}$) PTS 204 dB SEL$_{\text{cum}}$ PTS	(N) High (I) Low (F) Low	226 dB (L$_{\text{PK}}$) 189 dB SEL$_{\text{cum}}$	--	--
Eggs and larvae	207 dB (L$_{\text{PK}}$) 210 dB SEL$_{\text{cum}}$	(N) Moderate (I) Low (F) Low	(N) Moderate (I) Low (F) Low	--	--

Sources: GARFO 2019, Popper et al., 2014
SEL = sound exposure level (dB re 1 µPa2·s); Lpk = peak sound pressure (dB re 1 µPa); RMS SPL = root mean square sound pressure (dB re 1 µPa)
TTS = temporary threshold shift., N = near (10s of meters), I = intermediate (100s of meters), and 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 RMS re 1 µPa at 1 m. 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, 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.

Z.4.1 Sound Propagation Model

Underwater sound propagation modeling was completed using dBSea, a powerful software developed by Marshall Day Acoustics for the prediction of underwater noise in a variety of environments. 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, temperature, salinity, and current.

Noise levels are calculated throughout the entire Offshore Project Area and displayed in three dimensions. 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 octave or third octave bands. Three different solvers are available, and the user may choose different solvers for the low- and high-frequency ranges.

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 strength) 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 as follows.

Z.4.2.1 Bathymetry

In shallow water, sound propagation is dominated by boundary effects. 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 bathymetric data were sampled by creating a fan of radials at a given angular spacing. This grid was then used to determine depth points along each modeling radial transect. The underwater acoustic modeling takes place over these radial planes in set increments depending on the acoustic wavelength and the sampled depth. These radial transects were used for modeling acoustic impacts during both the construction and operation of the Project, with each radial centered on the given Project sound source or activity.

Z.4.2.2 Sediment Characteristics

Sediment type (e.g., hard rock, sand, mud, clay) directly impacts the speed of sound as 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 geotechnical studies completed in support of the adjacent Coastal Virginia Offshore Wind Pilot project, which were assumed to extend over the entire Offshore Project Area as analysis of Project specific geotechnical survey data had not yet been completed for the Project. The sediment layers used in the modeling and the main geoacoustic properties are defined in Table Z-4. 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-4. Geoacoustic Properties of Sub-bottom Sediments as a Function of Depth

Seabed Layer (meters)	Material	Geoacoustic Properties
0 to 4	Silty Fine Sand	Cp = 1650 m/s αs (dB/λ) = 0.8 dB/ λ ρ = 1900 kg/m^3
. 4 to 12	Sandy Clean Clay	Cp = 1560 m/s αs (dB/λ) = 0.2 dB/ λ ρ = 1600 kg/m^3
12 to 24	Clay	Cp = 1470 m/s αs (dB/λ) = 0.1 dB/ λ ρ= 1200 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 June sound speed profile was selected as it exhibited maximum case characteristics for long-range noise propagation effects. Figure Z-4 displays the monthly sound speed profiles for the Offshore Project Area. 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.

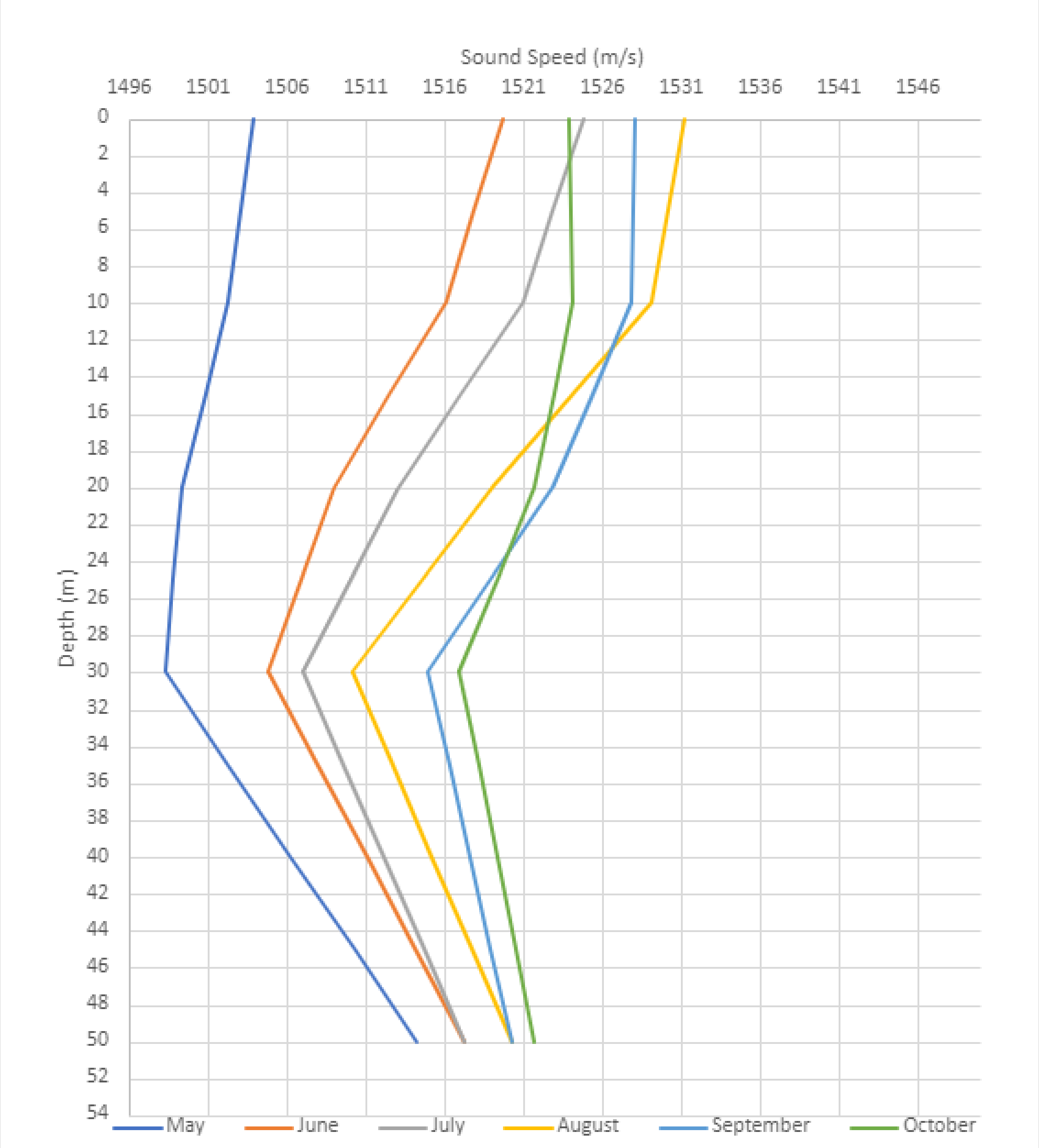


Figure Z-4. **Monthly Sound Speed Profile as a Function of Depth**

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 horizontal sampling point. Both the R_{max} and the $R_{95\%}$ ranges were calculated foreach of the regulatory thresholds. The R_{max} is the maximum range in the model at which the sound level is calculated. The $R_{95\%}$ is the maximum range at which a sound level was calculated excluding 5 percent 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 horizontal area that would be exposed to sound at or above the specified level. All ranges to injury thresholds presented in this Underwater Acoustic Assessment Report are presented in terms of the $R_{95\%}$ range.

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 pile-driving associated with WTG and Offshore Substation Foundation installation, and cofferdam installation associated with nearshore trenchless installation activities. The majority of modeling scenarios occur at representative WTG locations; one at a shallow water depth of 69 ft (21 m) (Universal Transverse Mercator [UTM] Coordinates: 459846 m, 4075324 m) within the Lease Area and another at a deep-water depth of 121 ft (37 m) (UTM Coordinates: 48066 m, 4089018 m) within the Lease Area. These two 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. Vibratory pile-driving activities were modeled at the Nearshore Trenchless Installation Area.

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. 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.

Using those resources, regression analyses could be used to illustrate the relationship between apparent source level (L_{PK} and SEL) relative to pile diameter normalized to a set distance from the pile installation and those correlations could be extended to larger pile diameters. The increase in anticipated apparent sound power is not only due to the increase of radiating surface, but the diameter implicitly also includes the blow energy, since larger piles require larger pile drivers. To account for blow energy, it was assumed that the underwater noise output of a pile strike is proportional to the energy delivered to the pile as in:

$$\text{Blow Energy Correction (dB)} = 10\log(E/E_{ref}) \qquad (10)$$

The broadband L_{PK} and SEL levels were derived using the trend data and blow energy. Maximum design parameters were considered in order to develop a conservative assessment and evaluate potential reasonable worst-case underwater noise impacts.

A summary of construction and operational scenarios included in the underwater acoustic modeling analysis is provided in Table Z-5. The model accommodates 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. The pile diameters selected for the impact pile-driving modeling scenarios were based on maximum Project Design Envelope considerations provided by Dominion Energy. The subsections that follow provide more detailed information about the parameters used to model the noise sources associated with each scenario. Scenarios 1 through 4 occur at representative WTG locations while Scenario 5 occurs at the cofferdam locations at the Nearshore Trenchless Installation Area. Scenario 1 describes the potentially most impactful Project activity, which is monopile foundation impact pile driving using the maximum rated hammer energy of 4,000 kilojoules (kJ); 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. The relationship between hammer energy and pile driving sound source level is described by Whyte et al. 2020.

Table Z-5. Underwater Acoustic Modeling Scenarios

Scenario	Activity Description	Maximum Hammer Energy (kilojoules)	Location (UTM Coordinates)	Sound Source Level dB re: dB re 1 µPa^2·s
Scenario 1	Monopile Foundation Impact Pile-Driving, Diameter: 9.5 m	4,000 a/	Deep: 48066 m, 4089018 m Shallow: 459846 m, 4075324 m	251 L_{PK} 229 SEL
Scenario 2	Monopile Foundation Impact Pile-Driving, Diameter: 9.5 m	3,124	Deep: 48066 m, 4089018 m Shallow: 459846 m, 4075324 m	249 L_{PK} 227 SEL
Scenario 3	Two (2) Monopile Foundation Impact Pile-Driving 10 km apart, Diameter: 9.5 m	3,124	Deep: 48066 m, 4089018 m 471303 m, 4085595 m Shallow: 459846 m, 4075324 m 467653 m, 408059 m	249 L_{PK} 227 SEL
Scenario 4	Piled Jacket Foundation (includes 4 piles). Pin Pile Impact Pile-Driving, Diameter: 3.5 m	1,105	Deep: 48066 m, 4089018 m Shallow: 459846 m, 4075324 m	239 L_{PK} 214 SEL
Scenario 5	Cofferdam Installation, Vibratory Pile-Driving	N/A	414006 m, 4075013 m	195 SEL

a/ 4,000 kJ corresponds to the maximum rated hammer energy; however, actual hammer energy transferred to the pile during installation will be less.

kJ = kilojoule

SEL = sound exposure level; L_{PK} = peak sound pressure (dB re 1 µPa)

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

Impact pile-driving involves weighted hammers that pile foundations into the seafloor. Different methods for lifting the weight 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-5 two sites were modeled to represent the potential 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). It is expected that by modeling these two locations, the range of anticipated sound fields resulting from pile-driving activities will be represented. Propagation modeling was conducted using the maximum projected blow energy of 4,000 kJ for the monopile in scenario 1, 3,124 kJ for scenario 2, 3,124 kJ for scenario 3, and 1,115 kJ for the pin pile in scenario 4; however, a soft start and pile progression were also incorporated into the model for each pile as shown in Table Z-6.

Table Z-6. Pile-Driving Progression Summary

Pile Diameter	Hammer Energy %	Hammer Energy	Duration	Blows per minute	Total Number of Blows
Scenario 1 (31.2 ft [9.5m])	20	800	4	45	180
	40	1,600	4	45	180
	80	3,200	4	45	180
	100	4,000	87	45	3,907
Scenario 2 (31.2 ft [9.5m])	20	625	4	45	180
	40	1,250	4	45	180
	80	2,499	4	45	180
	100	3,124	57	45	2,584
Scenario 3 (2x31.2 ft [9.5m])	20	625	4	45	180
	40	1,250	4	45	180
	80	2,499	4	45	180
	100	3,124	57	45	2,584
Scenario 4 (11.4 ft [3.5m])	20	221	4	45	180
	40	442	4	45	180
	80	884	4	45	180
	100	1,105	123	45	5,515

The monopile and pin pile-driving scenarios were both modeled using a vertical array of eight point sources for the deep location and five point sources for the shallow location, 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 after the second spectral peak. 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 pile-driving sound source characteristics in the high frequency range. Note that vibratory pile driving may also be used as an installation method for WTG or Offshore Substation Foundations. Modelling of vibratory pile driving will be incorporated into the revised Underwater Acoustic Assessment.

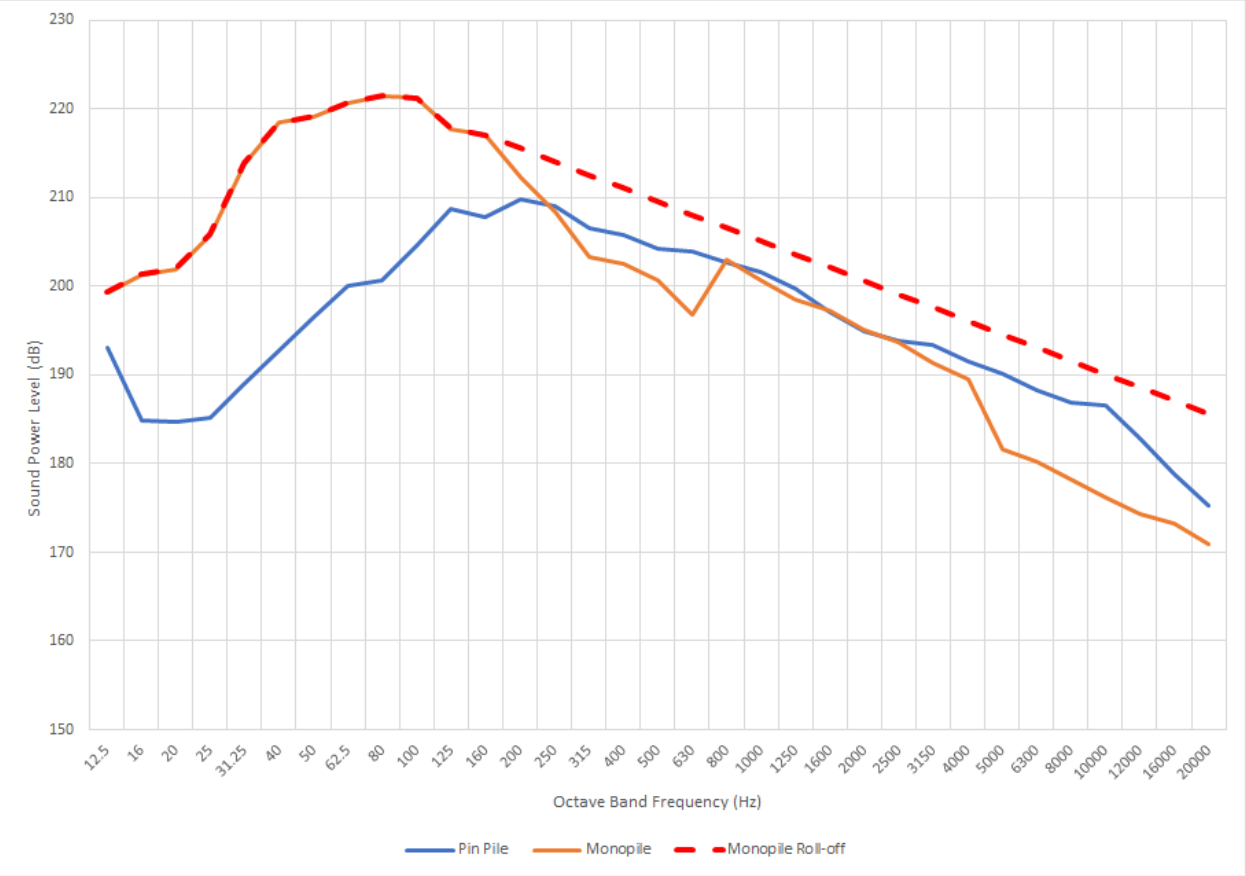


Figure Z-5. **Monopile and Pin Pile Spectral Source Levels**

Z.5.2 Vibratory Pile-Driving Associated with Cofferdam Installation

The exit point of the long-distance trenchless installation would be approximately 3,281 ft (1,000 m) offshore. Should this option be selected, temporary offshore cofferdams may be required. If required, the temporary offshore cofferdams will be constructed by installing steel sheet piles in a tight configuration around an area of approximately 20 ft by 50 ft (6.1 m by 15 m). 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 is used, in one revolution a force will be exerted in all directions, giving the system significant lateral whip. To avoid this problem, the eccentrics 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. Impact pile-driving produces a loud impulse sound that can propagate through the water and substrate, whereas vibratory pile-driving produces a continuous sound with peak pressures lower than those observed in pulses generated by impact pile-driving. For estimating source levels and frequency spectra, the vibratory pile driver was estimated assuming an 1,800 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 Project 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-6.

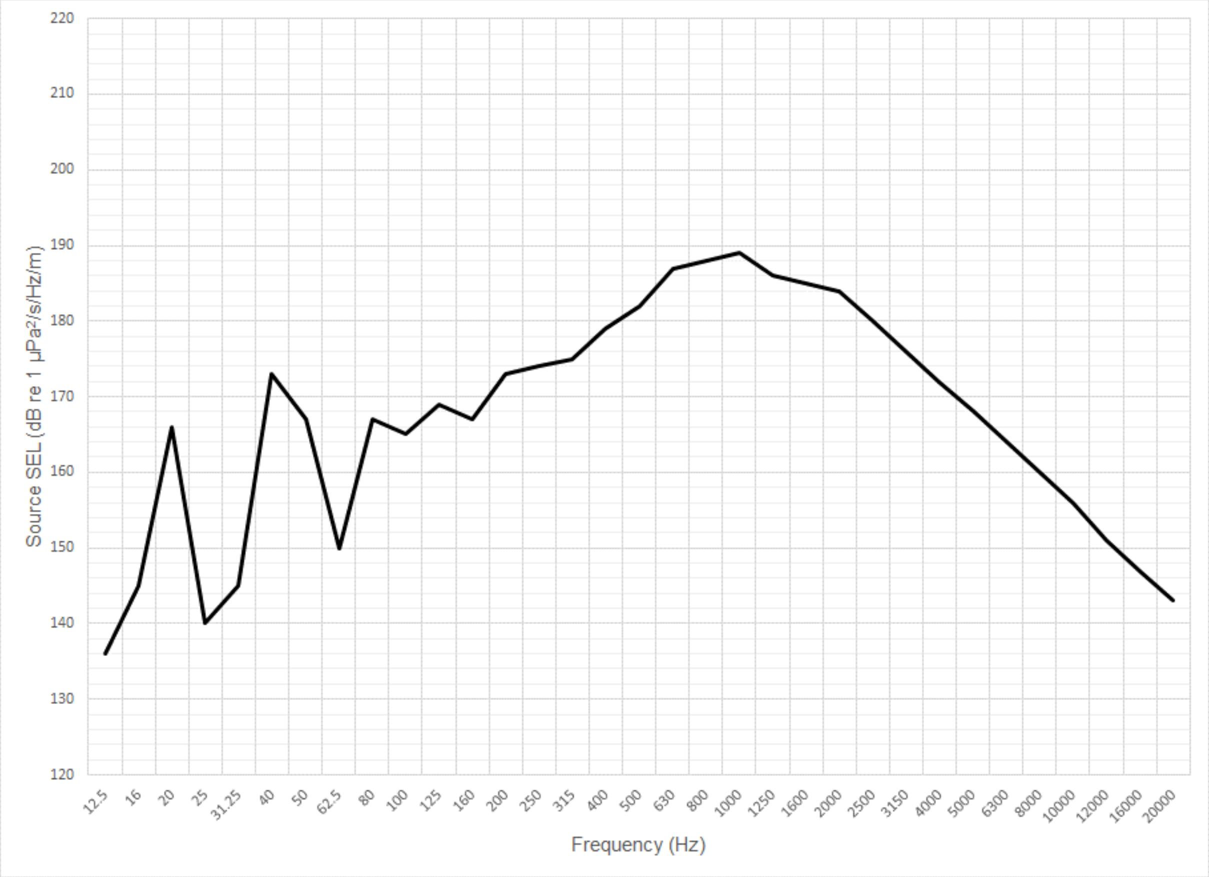


Figure Z-6. **Vibratory Pile-Driving Spectral Source Levels**

Z.5.3 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. No injury zone for swimming animals and generally tens of meters even if the mammals were to spend an hour in the vicinity of a vessel, which is not a realistic scenario. For these reasons, a detailed acoustic modeling analysis was not conducted.

Z.5.4 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). A review of other published studies indicates that source levels from operating offshore WTGs that have monopile foundations show peak frequencies occurring predominantly below 500 Hz, and that the apparent source level range from 140 to 153 dB re 1 µPa at 1 m (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. 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 described in Section A.5.1, Dominion Energy intends to implement noise mitigation in the form of the pile-driving “soft-start” technique. 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-6.

In addition to the application of the soft-start technique, other devices may be considered to mitigate 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. 2018). 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 12 dB were applied to all impact pile-driving scenarios to evaluate potential mitigated underwater noise impacts.

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-5 and include monopile impact pile-driving activities for 31.2 ft (9.5 m) pile diameters using a hammer energy of 4,000 kJ, a hammer energy of 3,124 kJ, two 31.2-ft (9.5-m) monopiles that are 5.4 nm (10 km) apart using a hammer energy of 3,124 kJ, and pin pile impact pile-driving for 13-ft (4-m) pile diameter. All those activities 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. Vibratory pile-driving will occur at the cofferdam location in the Nearshore Trenchless Installation Area.

The results for impact pile-driving (monopile and pin pile) for the representative WTG location at the deepest water depth are shown in Table Z-7, Table Z-8, Table Z-9, Table Z-10, and Table Z-11. Results are presented without mitigation and with two different levels of mitigation: a 6-dB reduction and a 12-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 in Table Z-7 indicate that the unmitigated distances to the LPK thresholds are generally below 3,281 ft (1,000 m) except for results for the high-frequency cetaceans group. Thresholds 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 160 dB RMS and 150 dB RMS, respectively. Figure Z-7. Figure Z-8, Figure Z-9, Figure Z-10 show the unweighted and unmitigated underwater received sound pressure levels for the

31.2-ft (9.5-m) monopile scenarios and the 13-ft (4-m) pin pile impact pile-driving scenario, respectively, at the deep location. Underwater sound pressure level ranges are displayed in 10 dB increments and sound propagation characteristics are shown throughout the Lease Area and beyond, as applicable.

Table Z-7. Marine Mammal Permanent Threshold Shift Onset Criteria Threshold Distances (meters) for Impact Pile-Driving – Deep Location

Scenario	Pile Type	Hammer Energy (kilojoules)	Mitigation	Hearing Group a/							
				Low-Frequency cetaceans		Mid-Frequency cetaceans		High-Frequency cetaceans		Phocid pinnipeds	
				219 L_{PK}	183 SEL_{cum}	230 L_{PK}	185 SEL_{cum}	202 L_{PK}	155 SEL_{cum}	218 L_{PK}	185 SEL_{cum}
Scenario 1	31.2 feet (ft) (9.5 meter [m]) Monopile	4,000 b/	Unmitigated	159	10,670	103	927	1,212	5,440	178	4,134
			Mitigation (-6 decibels [dB])	120	7,298	81	553	648	4,077	124	2,728
			Mitigation (-12 dB)	52	5,225	60	315	252	2,700	103	1,622
Scenario 2	31.2 ft (9.5 m) Monopile	3,124	Unmitigated	135	7,488	93	719	829	4,258	148	3,175
			Mitigation (-6 dB)	111	6,134	71	227	383	3,106	116	2,030
			Mitigation (-12 dB)	52	3,925	49	165	216	2,234	93	1,303
Scenario 3	Two (2) 31.2 ft (9.5 m) Monopiles 5.4 nm (10 km) apart	3,124	Unmitigated	135	14,835	93	719	829	4,258	148	3,175
			Mitigation (-6 dB)	111	12,080	71	227	383	3,106	116	2,030
			Mitigation (-12 dB)	52	5,098	49	165	216	2,234	93	1,303
Scenario 4	13 ft (4 m) Pin Pile	1,105	Unmitigated	94	8,447	51	828	288	5,317	98	3,612
			Mitigation (-6 dB)	70	6,205	0	504	143	3,583	74	2,358
			Mitigation (-12 dB)	47	4,210	0	239	114	2,576	50	1,484

Source: NOAA Fisheries 2018
a/ Level A Injury
b/ 4,000 kJ corresponds to the maximum rated hammer energy; however, actual hammer energy transferred to the pile during installation will be less.
SEL_{cum} = sound exposure level (dB re 1 $\mu Pa^2 \cdot s$); L_{PK} = peak sound pressure (dB re 1 μPa)

Table Z-8. Sea Turtles and Fish Onset of Injury Threshold Distances (meters) for Impact Pile-Driving – Deep Location (as per Popper et al. 2014)

Scenario	Pile Type	Hammer Energy (kilojoules)	Mitigation	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_{PK}	219 SEL_{cum}	207 L_{PK}	210 SEL_{cum}	207 L_{PK}	207 SEL_{cum}	207 L_{PK}	210 SEL_{cum}	207 L_{PK}	210 SEL_{cum}
Scenario 1	31.2 feet (ft) 9.5 meter (m) Monopile	4,000 b/	Unmitigated	271	781	676	1,982	676	2,524	676	1,982	676	1,982
			Mitigation (-6 decibels [dB])	160	357	272	1,208	272	1,503	272	1,208	272	1,208
			Mitigation (-12 dB)	120	170	160	577	160	781	160	577	160	577
Scenario 2	31.2 ft (9.5 m) Monopile	3,124	Unmitigated	234	539	619	1,408	619	1,887	619	1,408	619	1,408
			Mitigation (-6 dB)	134	227	234	766	234	1,147	234	766	234	766
			Mitigation (-12 dB)	111	104	134	328	134	538	134	328	134	328
Scenario 3	Two (2) 31.2 ft (9.5 m) Monopiles 5.4 nm (10 km) apart	3,124	Unmitigated	234	539	619	1,408	619	1,887	619	1,408	619	1,408
			Mitigation (-6 dB)	134	227	234	766	234	1,147	234	766	234	766
			Mitigation (-12 dB)	111	104	134	328	134	538	134	328	134	328
Scenario 4	13 ft (4 m) Pin Pile	1,105	Unmitigated	118	542	163	1,408	163	1,915	163	1,408	163	1,408
			Mitigation (-6 dB)	94	151	118	710	118	1,161	118	710	118	710
			Mitigation (-12 dB)	70	0	94	270	94	542	94	270	94	270

Source: Popper et al. 2014

a/ Level A Injury

b/ 4,000 kJ corresponds to the maximum rated hammer energy; however, actual hammer energy transferred to the pile during installation will be less

SEL_{cum} = sound exposure level (dB re 1 μPa^2·s); L_{PK} = peak sound pressure (dB re 1 μPa)

Table Z-9. Fish Acoustic Injury Threshold Distances (meters) for Impact Pile-Driving – Deep Location (as per Stadler and Woodbury 2009)

Scenario	Pile Type	Hammer Energy (kilojoules)	Mitigation	Hearing Group			
				Small Fish a/		Large Fish a/	
				206 L_{PK}	183 SEL_{cum}	206 L_{PK}	187 SEL_{cum}
Scenario 1	31.2 feet (ft) 99.5 meter [m]) Monopile	4,000 b/	Unmitigated	716	13,164	716	10,528
			Mitigation (-6 decibels [dB])	298	9,340	298	7,132
			Mitigation (-12 dB)	179	6,300	179	4,657
Scenario 2	31.2 ft (9.5 m) Monopile	3,124	Unmitigated	648	10,813	648	8,414
			Mitigation (-6 dB)	251	7,364	251	5,778
			Mitigation (-12 dB)	143	4,923	143	3,640
Scenario 3	Two (2) 31.2 ft (9.5 m) Monopiles 5.4 nm (10km) apart	3,124	Unmitigated	648	16,650	648	14,978
			Mitigation (-6 dB)	251	14,146	251	12,413
			Mitigation (-12 dB)	143	5,121	143	3,640
Scenario 4	13 ft (4 m) Pin Pile	1,105	Unmitigated	187	10,528	187	8,129
			Mitigation (-6 dB)	122	7,155	122	7,155
			Mitigation (-12 dB)	98	5,089	98	3,640

Source: Stadler and Woodbury 2009
a/ Small fish are fish less than 2 grams in weight. Large fish are 2 grams or larger.
b/ 4,000 kJ corresponds to the maximum rated hammer energy; however, actual hammer energy transferred to the pile during installation will be less
SEL_{cum} = sound exposure level (dB re 1 μPa^2·s); L_{PK} = peak sound pressure (dB re 1 μPa)

Table Z-10. Sea Turtles in National Oceanic Atmospheric Administration Fisheries Behavioral and Acoustic Injury Criteria Threshold Distances (meters) for Impact Pile-Driving – Deep Location

Scenario	Pile Type	Hammer Energy (kilojoule)	Mitigation	Species				
				Sea Turtle Behavioral	Sea Turtle Temporary Threshold Shift		Sea Turtle Permanent Threshold Shift	
				175 SPL RMS	226 L_{PK}	189 SEL_{cum}	232 L_{PK}	204 SEL_{cum}
Scenario 1	31.2 feet (ft) (9.5 meter [m]) Monopile	4,000 a/	Unmitigated	2,263	116	9,340	95	3,213
			Mitigation (-6 dB)	1,360	95	6,300	73	1,982
			Mitigation (-12 dB)	710	73	4,115	52	1,208
Scenario 2	31.2 ft (9. m) Monopile	3,124	Unmitigated	2,101	108	7,345	86	2,377
			Mitigation (-6 dB)	1,284	86	4,923	64	1,408
			Mitigation (-12 dB)	624	64	3,070	43	738
Scenario 3	Two (2) 31.2 ft (9.5 m) Monopiles 5.4 nm (10 km) apart	3,124	Unmitigated	2,103	108	14,123	86	2,377
			Mitigation (-6 dB)	1,284	86	11,368	64	1,408
			Mitigation (-12 dB)	628	64	3,070	43	738
Scenario 4	13 ft (4 m) Pin Pile	1,105	Unmitigated	833	67	7,155	43	2,405
			Mitigation (-6 dB)	443	44	5,825	0	5,089
			Mitigation (-12 dB)	113	0	3,118	0	710

Source: GARFO 2019

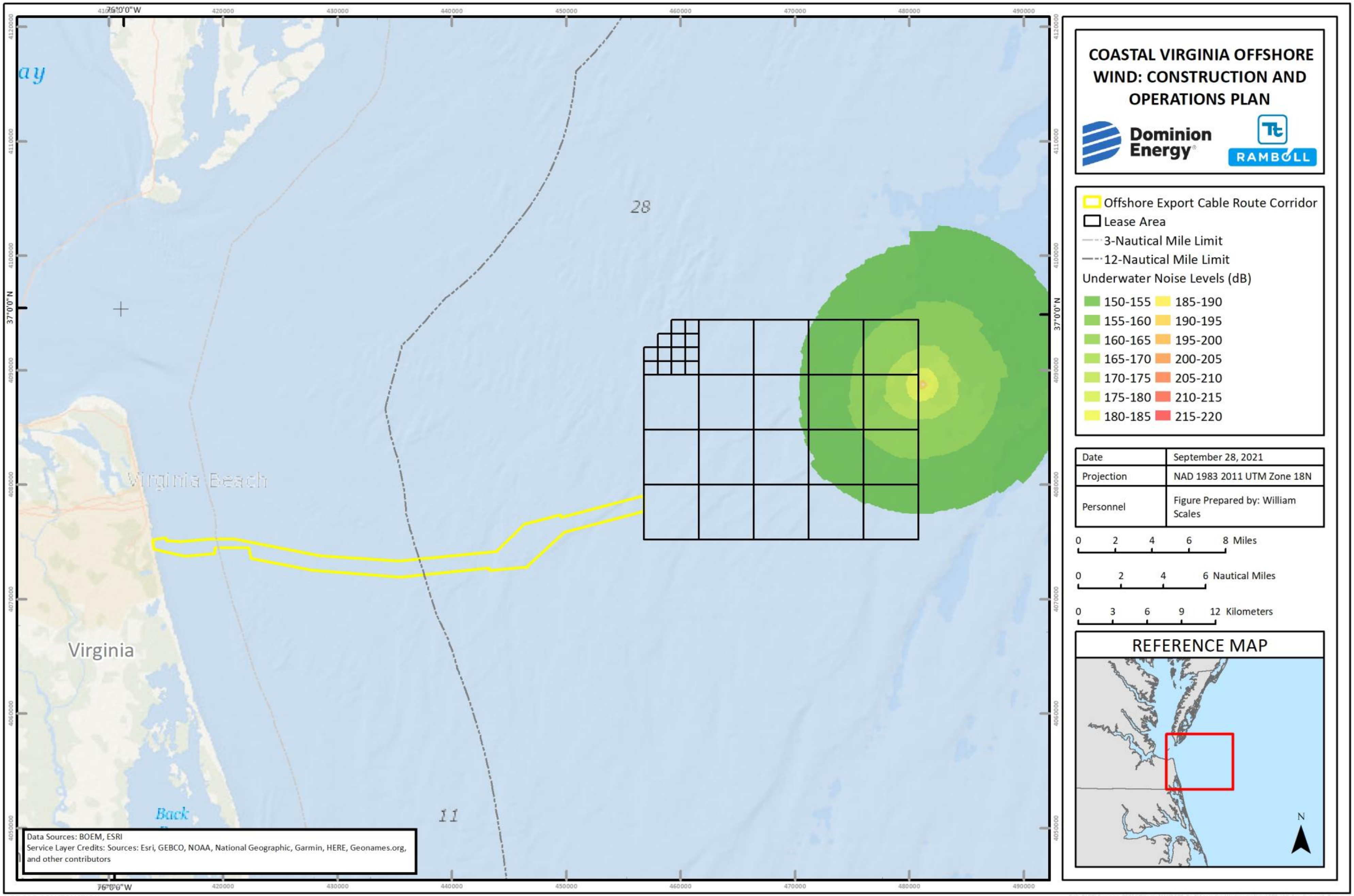
a/ 4,000 kJ corresponds to the maximum rated hammer energy; however, actual hammer energy transferred to the pile during installation will be less

SEL_{cum} = sound exposure level (dB re 1 μPa^2·s); L_{PK} = peak sound pressure (dB re 1 μPa)

Table Z-11. Marine Mammals and Fish Behavioral Response Criteria Threshold Distances (meters) for Impact Pile-Driving – Deep Location

Scenario	Pile Type	Hammer Energy (kilojoules)	Mitigation	Hearing Group: Fish 150 SPL RMS	Hearing Group: Marine Mammals 160 SPL RMS
Scenario 1	31.2 feet (9.5 meter [m]) Monopile	4,000 a/	Unmitigated	13,188	7,155
			Mitigation (-6 decibels [dB])	9,350	4,662
			Mitigation (-12 dB)	6,300	2,975
Scenario 2	31.2 ft (9.5 m) Monopile	3,124	Unmitigated	12,352	6,538
			Mitigation (-6 dB)	8,652	4,472
			Mitigation (-12 dB)	6,039	2,738
Scenario 3	Two (2) 31.2 ft (9.5 m) Monopiles 5.4 nm (10 km) apart	3,124	Unmitigated	17,400	13,458
			Mitigation (-6 dB)	15,191	4,476
			Mitigation (-12 dB)	12,603	2,738
Scenario 4	13 ft (4 m) Pin Pile	1,105	Unmitigated	7,060	3,574
			Mitigation (-6 dB)	4,647	2,120
			Mitigation (-12 dB)	2,999	1,308

Source: GARFO 2019
a/ 4,000 kJ corresponds to the maximum rated hammer energy; however, actual hammer energy transferred to the pile during installation will be less
SPL RMS = root mean square sound pressure (dB re 1 µPa)



Data Sources: BOEM, ESRI
Service Layer Credits: Sources: Esri, GEBCO, NOAA, National Geographic, Garmin, HERE, Geonames.org, and other contributors

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Figure Z-7. Underwater Received Sound Levels: Scenario 1, Unmitigated, Deep Location (SPL)

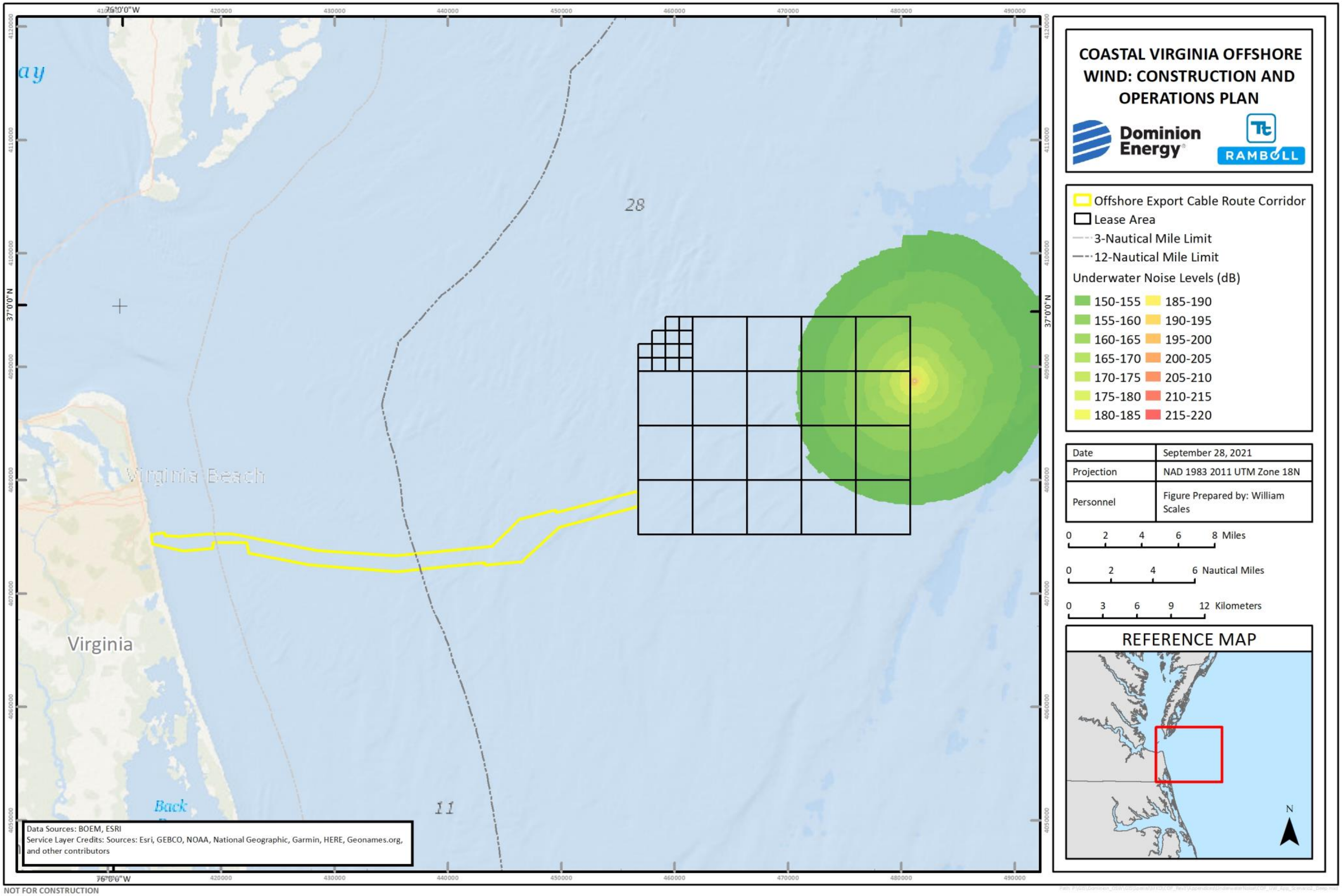

Figure Z-8. Underwater Received Sound Levels: Scenario 2, Unmitigated, Deep Location (SPL)

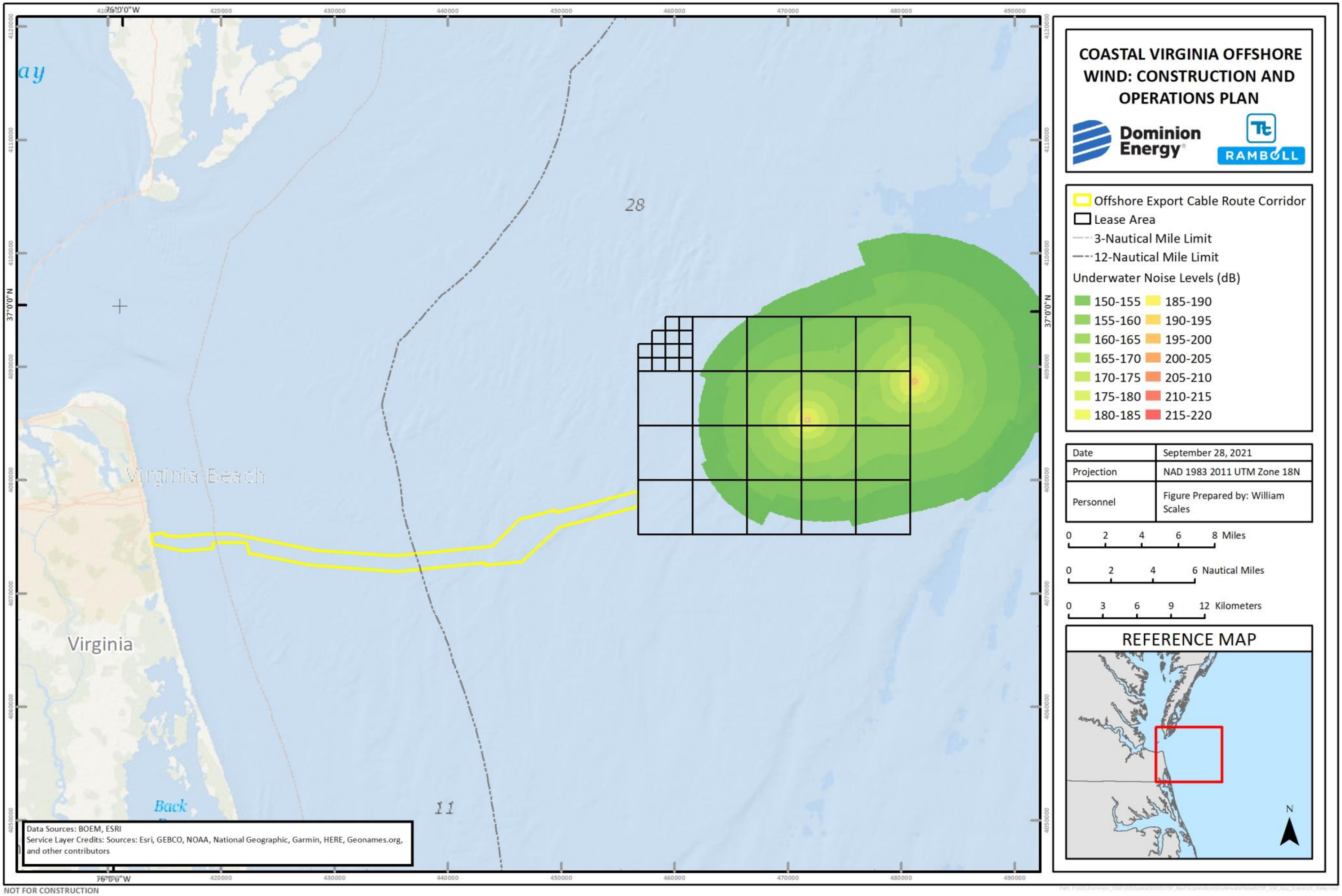

Figure Z-9. **Underwater Received Sound Levels: Scenario 3, Unmitigated, Deep Location (SPL)**

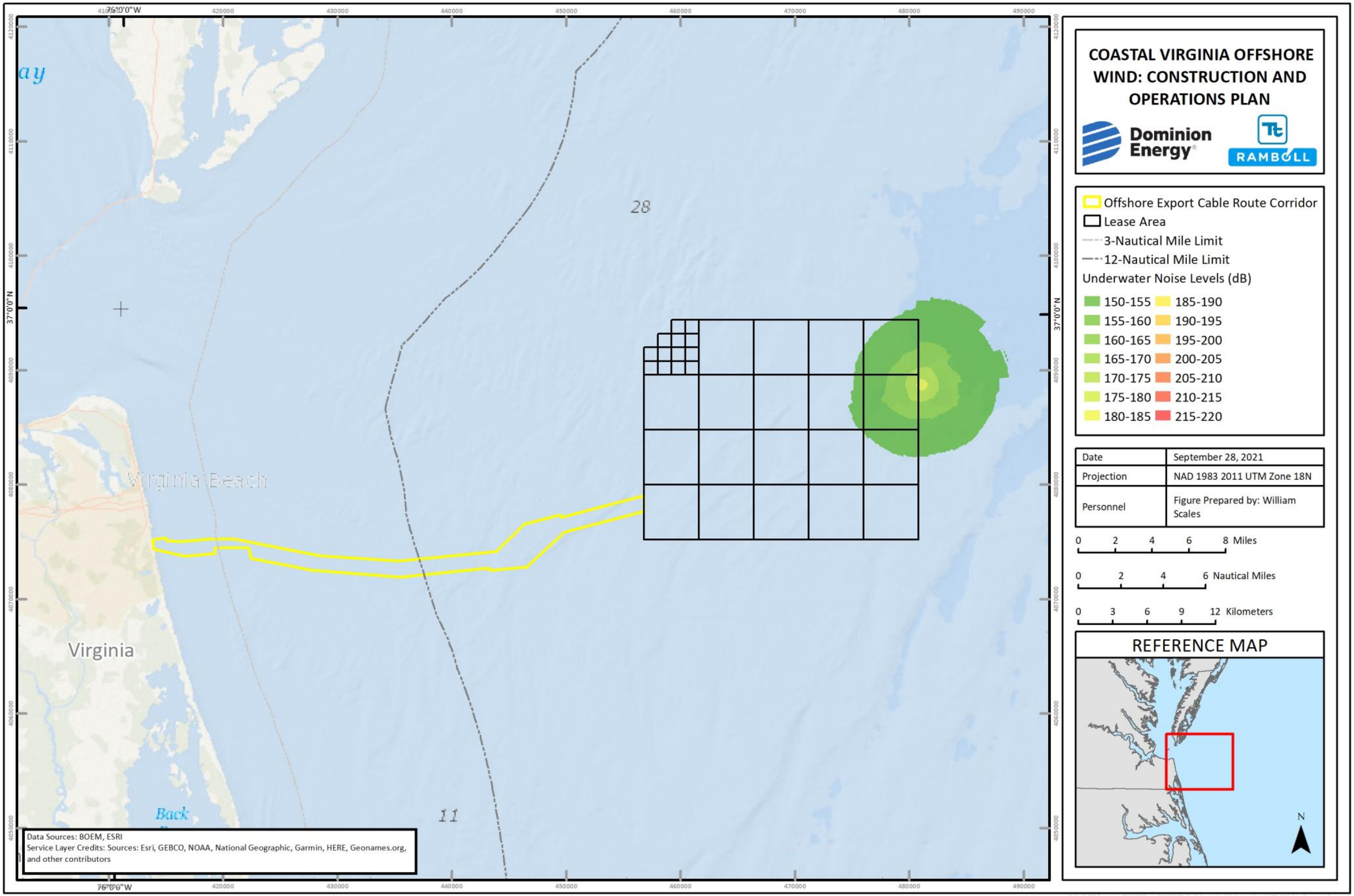

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Figure Z-10. Underwater Received Sound Levels: Scenario 4, Unmitigated, Deep Location (SPL)

Similar trends in results were observed for modeling results of impact pile-driving at the shallow WTG location, although in most cases, distances to thresholds were less, likely due to the boundary layers affecting sound propagation and absorption through the seabed. Results for the representative WTG location in shallow water are given in Table Z-12, Table Z-13, Table Z-14, Table Z-15, and Table Z-16. Figure Z-11, Figure Z-12, Figure Z-13, and Figure Z-14 show the unweighted and unmitigated underwater received sound pressure levels for the 44-ft (13.5-m) monopile scenarios and the 13-ft (4-m) pin pile impact pile-driving scenario, respectively, at the shallow location.

Table Z-12. Marine Mammal PTS Onset Criteria Threshold Distances (meters) for Impact Pile-Driving – Shallow Location

Scenario	Pile Type	Hammer Energy (kilojoules)	Mitigation	Hearing Group a/							
				Low-Frequency cetaceans		Mid-Frequency cetaceans		High-Frequency cetaceans		Phocid pinnipeds	
				219 L_{PK}	183 SEL_{cum}	230 L_{PK}	185 SEL_{cum}	202 L_{PK}	155 SEL_{cum}	218 L_{PK}	185 SEL_{cum}
Scenario 1	31.2 feet (ft) (9.5 meter [m]) Monopile	4,000 b/	Unmitigated	150	10,009	105	849	954	6,722	167	3,205
			Mitigation (-6 decibels [dB])	125	6,967	82	488	498	3,860	129	1,989
			Mitigation (-12 dB)	52	4,822	15	261	224	2,540	105	1,115
Scenario 2	31.2 ft (9.5 m) Monopile	3,124	Unmitigated	142	8,233	98	688	821	5,267	146	2,692
			Mitigation (-6 dB)	117	5,571	74	403	412	3,139	121	1,511
			Mitigation (-12 dB)	52	3,462	52	89	194	2,160	97	954
Scenario 3	Two (2) 31.2 ft (9.5 m) Monopiles 5.4 nm (10 km) apart	3,124	Unmitigated	142	11,143	98	688	821	5,267	146	2,692
			Mitigation (-6 dB)	117	10,311	74	403	412	3,139	121	1,511
			Mitigation (-12 dB)	52	3,462	52	89	194	2,160	97	954
Scenario 4	13 ft (4 m) Pin Pile	1,105	Unmitigated	94	8,411	0	745	270	5,915	98	2,806
			Mitigation (-6 dB)	72	5,561	0	409	146	3,538	76	1,571
			Mitigation (-12 dB)	0	3,091	0	222	114	2,236	22	1,020

Source: NOAA Fisheries 2018
a/ Level A Injury
b/ 4,000 kJ corresponds to the maximum rated hammer energy; however, actual hammer energy transferred to the pile during installation will be less
SEL_{cum} = sound exposure level (dB re 1 µPa^2·s); L_{PK} = peak sound pressure (dB re 1 µPa)

Table Z-13. Sea Turtles and Fish Onset of Injury Threshold Distances (meters) for Impact Pile-Driving – Shallow Location (as per Popper et al. 2014)

Scenario	Pile Type	Hammer Energy (kilojoules)	Mitigation	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_{PK}	219 SEL_{cum}	207 L_{PK}	210 SEL_{cum}	207 L_{PK}	207 SEL_{cum}	207 L_{PK}	210 SEL_{cum}	207 L_{PK}	210 SEL_{cum}
Scenario 1	31.2 feet (ft) (9.5 meter [m]) Monopile	4,000 b/	Unmitigated	256	794	550	1,932	550	2,531	550	1,932	550	1,932
			Mitigation (-6 dB)	151	395	248	1,030	248	1,457	248	1,030	248	1,030
			Mitigation (-12 dB)	125	210	151	595	151	737	151	595	151	595
Scenario 2	31.2 ft (9.5 m) Monopile	3,124	Unmitigated	208	604	450	1,495	450	1,980	450	1,495	450	1,495
			Mitigation (-6 dB)	142	300	210	813	210	1,077	210	813	210	813
			Mitigation (-12 dB)	117	165	142	443	142	614	142	443	142	443
Scenario 3	Two (2) 31.2 ft (9.5 m) Monopiles 5.4 nm (10 km) apart	3,124	Unmitigated	208	604	450	1,495	450	1,980	450	1,495	450	1,495
			Mitigation (-6 dB)	142	300	210	813	210	1,077	210	813	210	813
			Mitigation (-12 dB)	117	165	142	443	142	614	142	443	142	443
Scenario 4	13 ft (4 m) Pin Pile	1,105	Unmitigated	118	317	162	916	162	1,258	162	916	162	916
			Mitigation (-6 dB)	94	170	118	507	118	716	118	507	118	507
			Mitigation (-12 dB)	72	0	94	232	94	317	94	232	94	232

Source: Popper et al. 2014
a/ Level A Injury
b/ 4,000 kJ corresponds to the maximum rated hammer energy; however, actual hammer energy transferred to the pile during installation will be less
SEL_{cum} = sound exposure level (dB re 1 μPa^2·s); *L_{PK}* = peak sound pressure (dB re 1 μPa)

Table Z-14. Fish Acoustic Injury Threshold Distances (meters) for Impact Pile-Driving – Shallow Location (as per Stadler and Woodbury 2009)

Scenario	Pile Type	Hammer Energy (kilojoules)	Mitigation	Hearing Group			
				Small Fish a/		Large Fish a/	
				206 L_{PK}	183 SEL_{cum}	206 L_{PK}	187 SEL_{cum}
Scenario 1	31.2 feet (ft) (9.5 meter [m]) Monopile	4,000 b/	Unmitigated	609	10,786	609	8,687
			Mitigation (-6 decibels [dB])	289	7,718	289	6,378
			Mitigation (-12 dB)	165	5,846	165	4,440
Scenario 2	31.2 ft (9.m) Monopile	3,124	Unmitigated	498	9,145	498	7,708
			Mitigation (-6 dB)	227	7,034	227	5,561
			Mitigation (-12 dB)	145	4,887	145	3,633
Scenario 3	Two (2) 31.2 ft (9.5 m) Monopiles 5.4 nm (10 km) apart	3,124	Unmitigated	498	13,565	498	11,451
			Mitigation (-6 dB)	227	10,311	227	5,799
			Mitigation (-12 dB)	145	4,887	145	3,633
Scenario 4	13 ft (4 m) Pin Pile	1,105	Unmitigated	177	9,886	177	7,420
			Mitigation (-6 dB)	123	6,888	123	6,888
			Mitigation (-12 dB)	98	4,013	98	2,901

Source: Stadler and Woodbury 2009

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

b/ 4,000 kJ corresponds to the maximum rated hammer energy; however, actual hammer energy transferred to the pile during installation will be less

SEL_{cum} = sound exposure level (dB re 1 $\mu Pa^{2}\cdot s$); L_{PK} = peak sound pressure (dB re 1 µPa)

Table Z-15. Sea Turtles in National Oceanic Atmospheric Administration Fisheries Behavioral and Acoustic Injury Criteria Threshold Distances (meters) for Impact Pile-Driving – Shallow Location

Scenario	Pile Type	Hammer Energy (kilojoules)	Mitigation	Species				
				Sea Turtle Behavioral	Sea Turtle Temporary Threshold Shift		Sea Turtle Potential Threshold Shift	
				175 SPL RMS	226 L_{PK}	189 SEL_{cum}	232 L_{PK}	204 SEL_{cum}
Scenario 1	31.2 feet (ft) (9.5 meter [m]) Monopile	4,000 a/	Unmitigated	2,141	121	7,841	97	3,110
			Mitigation (-6 decibels [dB])	1,163	97	5,761	4	1,932
			Mitigation (-12 dB)	652	74	3,870	0	1,030
Scenario 2	31.2 ft (9.5 m) Monopile	3,124	Unmitigated	2,056	113	7,043	89	2,597
			Mitigation (-6 dB)	1,117	89	4,887	9	1,495
			Mitigation (-12 dB)	642	67	3,186	32	832
Scenario 3	Two (2) 31.2 ft (9.5 m) Monopiles 5.4 nm (10 km) apart	3,124	Unmitigated	2,056	113	10,311	89	2,597
			Mitigation (-6 dB)	2,056	89	4,820	9	1,495
			Mitigation (-12 dB)	642	67	3,186	32	832
Scenario 4	13 ft (4 m) Pin Pile	1,105	Unmitigated	555	2	6,274	0	1,790
			Mitigation (-6 dB)	241	47	4,792	0	4,013
			Mitigation (-12 dB)	124	0	2,521	0	498

Source: GARFO 2019

a/ 4,000 kJ corresponds to the maximum rated hammer energy; however, actual hammer energy transferred to the pile during installation will be less

SEL_{cum} = sound exposure level (dB re 1 μPa^2·s); L_{PK} = peak sound pressure (dB re 1 μPa)

Table Z-16 Marine Mammals and Fish Behavioral Response Criteria Threshold Distances (meters) for Impact Pile-Driving – Shallow Location

Scenario	Pile Type	Hammer Energy (kilojoules)	Mitigation	Hearing Group	
				Fish	Marine Mammals
				150 SPL RMS	160 SPL RMS
Scenario 1	31.2 feet (ft) (9.5 meters [m]) Monopile	4,000 a/	Unmitigated	10,228	6,226
			Mitigation (-6 decibels [dB])	7,746	4,203
			Mitigation (-12 dB)	5,647	2,797
Scenario 2	31.2 ft (9.5 m) Monopile	3,124	Unmitigated	10,133	6,035
			Mitigation (-6 dB)	7,528	4,089
			Mitigation (-12 dB)	5,419	2,664
Scenario 3	Two (2) 31.2 ft (9.5 m) Monopiles 5.4 nm (10 km) apart	3,124	Unmitigated	14,776	6,084
			Mitigation (-6 dB)	11,641	5,913
			Mitigation (-12 dB)	6,321	2,664
Scenario 4	13 ft (4 m) Pin Pile	1,105	Unmitigated	5,845	2,616
			Mitigation (-6 dB)	3,538	1,410
			Mitigation (-12 dB)	2,113	773

Source: GARFO 2019
a/ 4,000 kJ corresponds to the maximum rated hammer energy; however, actual hammer energy transferred to the pile during installation will be less
SPL RMS = root mean square sound pressure (dB re 1 μPa)

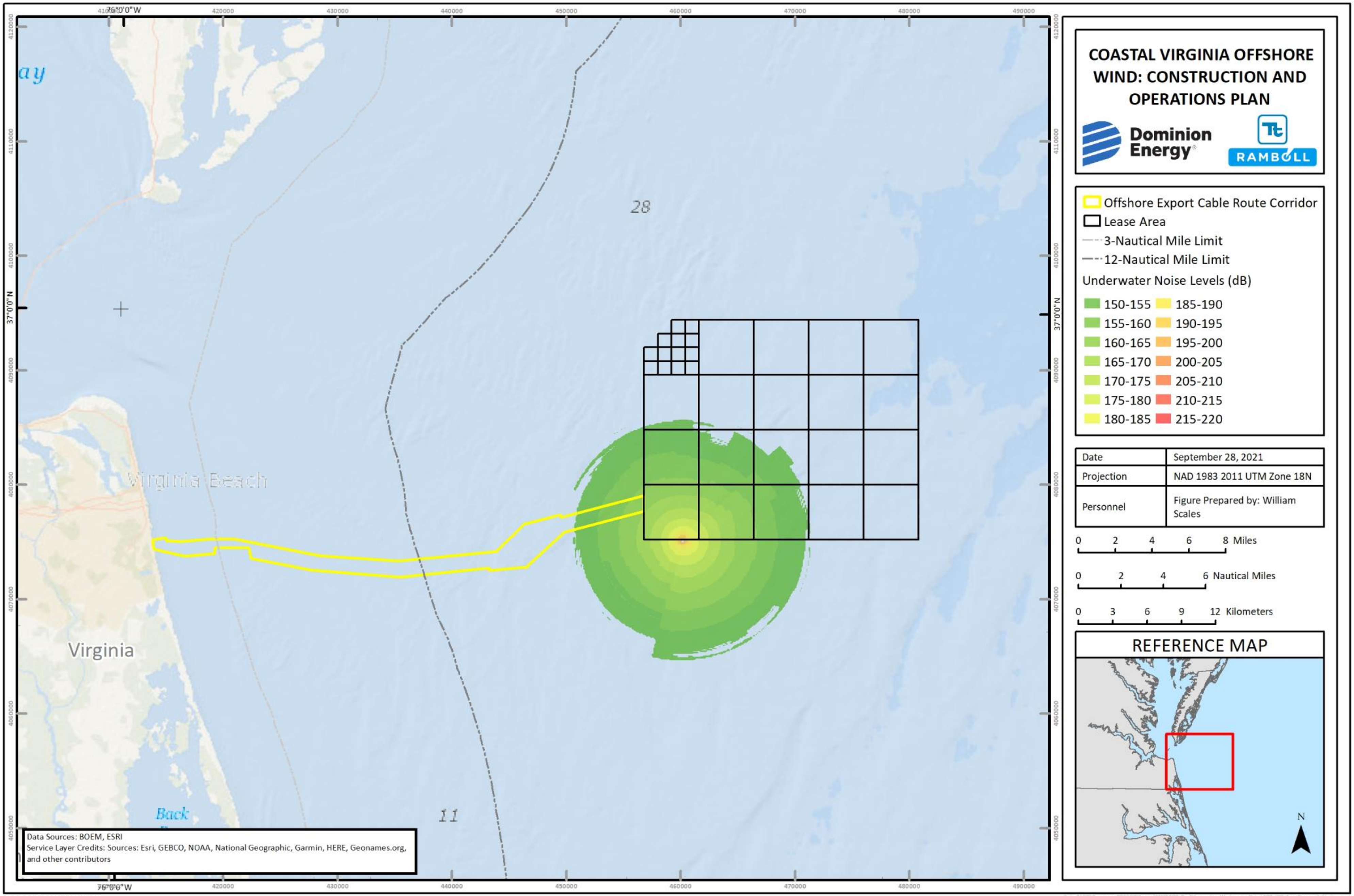

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Figure Z-11. Underwater Received Sound Levels: Scenario 1, Unmitigated, Shallow Location (SPL)

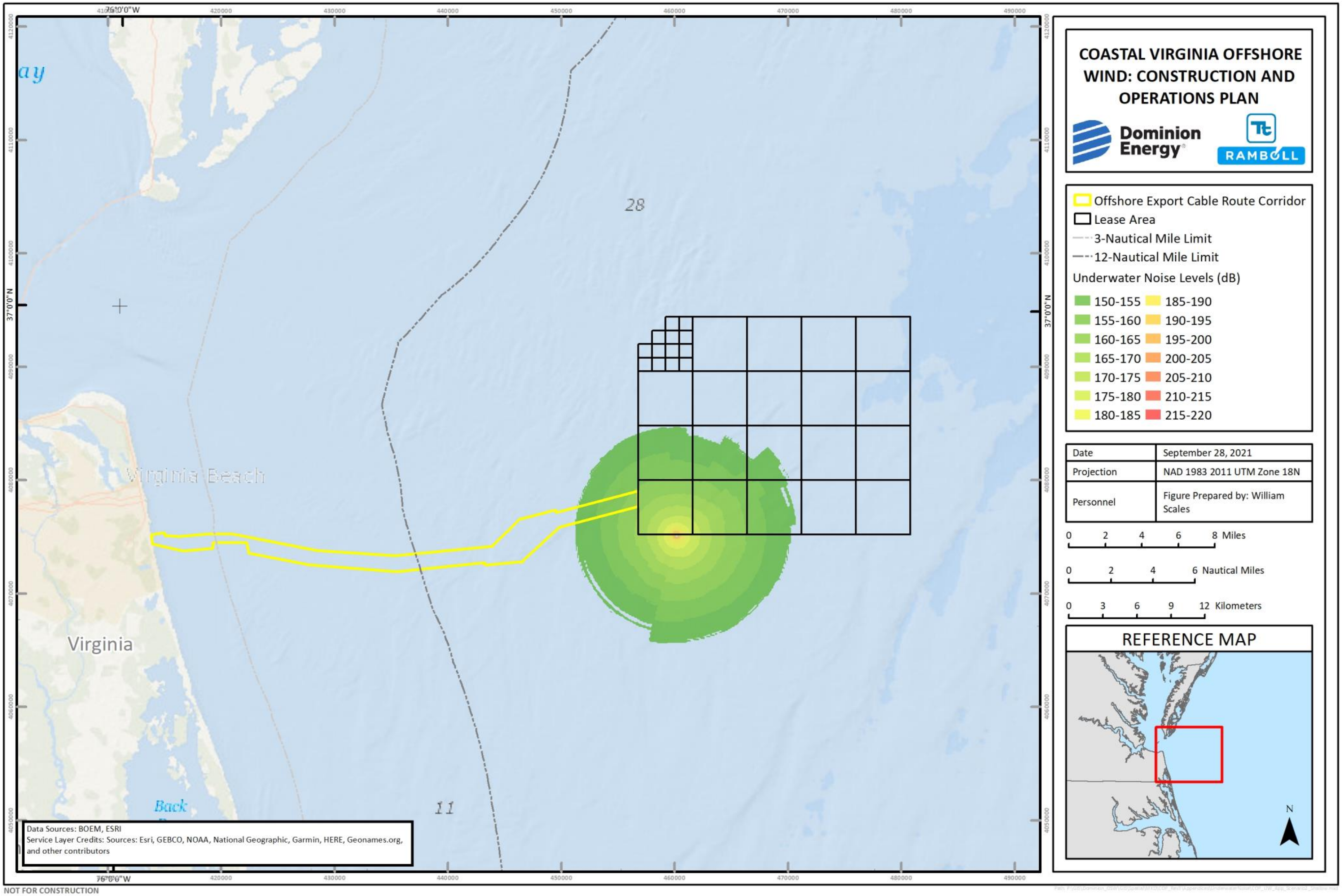


Figure Z-12. **Underwater Received Sound Levels: Scenario 2, Unmitigated, Shallow Location (SPL)**

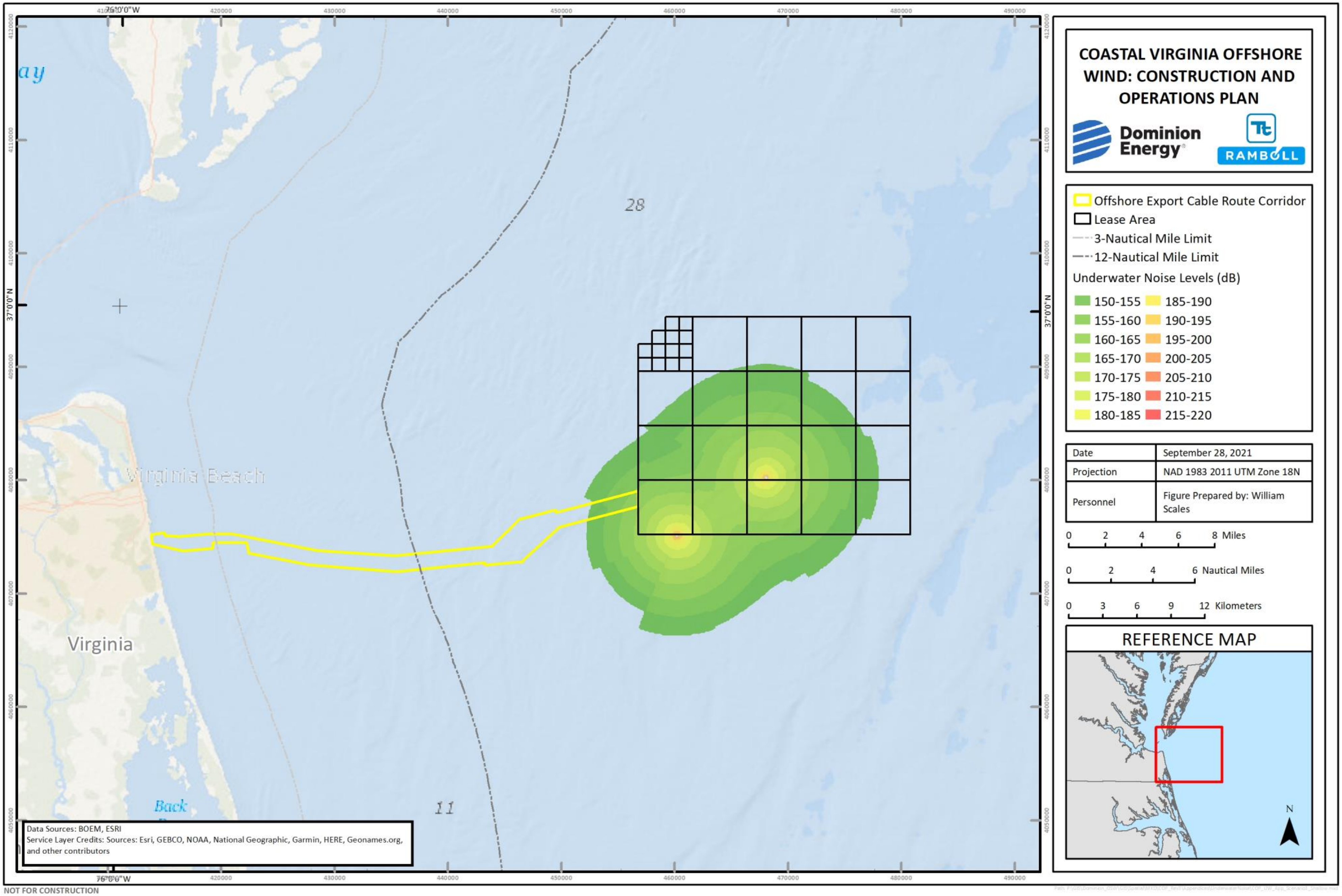
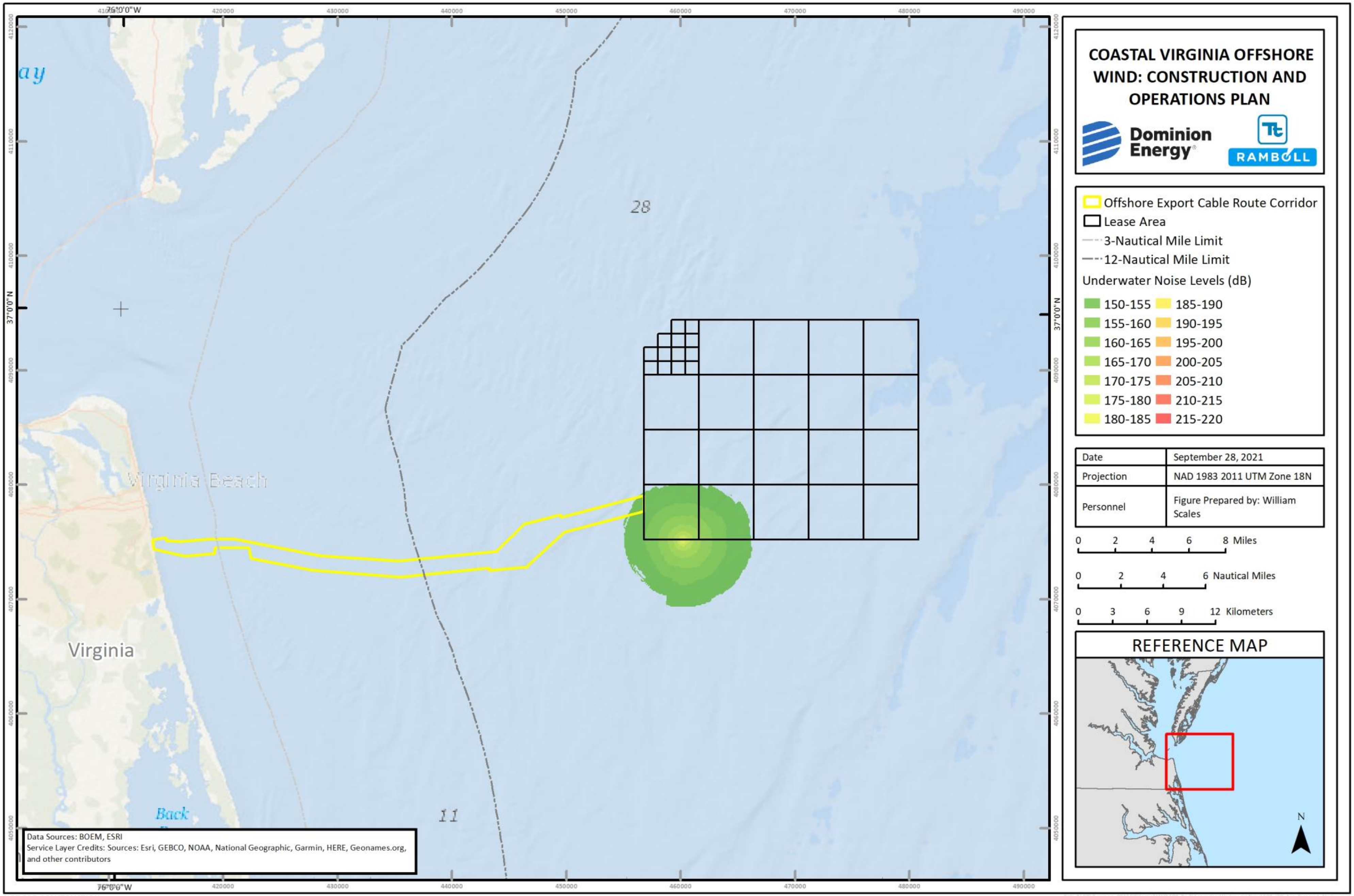


Figure Z-13. Underwater Received Sound Levels: Scenario 3, Unmitigated, Shallow Location (SPL)



Data Sources: BOEM, ESRI
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Figure Z-14. **Underwater Received Sound Levels: Scenario 4, Unmitigated, Shallow Location (SPL)**

Vibratory pile-driving modeling scenarios resulted in distances to applicable acoustic thresholds of less than 82 ft (25 m) with the exception of marine mammal and fish behavioral response thresholds of 120 dB SPL RMS and 150 dB SPL RMS, respectively. Results for the representative vibratory pile-driving location associated with cofferdam installation are given in Table Z-17, Table Z-18, Table Z-19, Table Z-20, and Table Z-21.

Table Z-17. Marine Mammal Permanent Threshold Shift Onset Threshold Distances (meters) for Vibratory Pile-Driving

Location	Hearing Group			
	Low-Frequency Cetaceans	Mid-Frequency cetaceans	High-Frequency cetaceans	Phocid pinnipeds
	199 SEL$_{cum}$	198 SEL$_{cum}$	173 SEL$_{cum}$	201 SEL$_{cum}$
Cofferdam	<1	<1	<1	<1

SEL$_{cum}$ = sound exposure level (dB re 1 μPa^2·s); *L*$_{PK}$ = peak sound pressure (dB re 1 μPa)

Table Z-18. Sea Turtles and Fish Onset of Injury Threshold Distances (meters) for Vibratory Pile-Driving

Location	Hearing Group[1]				
	Fish: No Swim Bladder	Fish: Swim bladder not involved in hearing	Fish: Swim bladder involved in hearing	Eggs and Larvae	Sea Turtle (Injury)
	219 SEL$_{cum}$	210 SEL$_{cum}$	210 SEL$_{cum}$	210 SEL$_{cum}$	200 SEL$_{cum}$
Cofferdam	<1	<1	<1	<1	

Source: Popper et al. 2014
SEL$_{cum}$ = sound exposure level (dB re 1 μPa^2·s); *L*$_{PK}$ = peak sound pressure (dB re 1 μPa)

Table Z-19. Fishes Acoustic Injury Criteria Threshold Distances (meters) for Vibratory Pile-Driving

Location	Hearing Group	
	Small Fish	Large Fish
	183 SEL$_{cum}$	187 SEL$_{cum}$
Cofferdam	15	2

Source: Stadler and Woodbury 2009
SEL$_{cum}$ = sound exposure level (dB re 1 μPa^2·s); *L*$_{PK}$ = peak sound pressure (dB re 1 μPa)

Table Z-20. Sea Turtles in National Marine Fisheries Service Greater Atlantic Region Behavioral and Physiological (Injury) Threshold Distances (meters) for Vibratory Pile-Driving

Location	Species		
	Sea Turtle Behavioral	Sea Turtle Temporary Threshold Shift	Sea Turtle Partial Threshold Shift
	175 SPL RMS	220 SEL$_{cum}$	204 SEL$_{cum}$
Cofferdam	23	<1	<1

Source: GARFO 2019
SPL RMS = root mean square sound pressure (dB re 1 μPa)
SEL$_{cum}$ = sound exposure level (dB re 1 μPa^2·s); *L*$_{PK}$ = peak sound pressure (dB re 1 μPa)

Table Z-21. Marine Mammals and Fish Behavioral Response Threshold Distances (meters) for – Vibratory Pile-Driving

Location	Hearing Group	
	Fish	Marine Mammals
	150 SPL RMS	120 SPL RMS
Cofferdam	645	16,220

Source: GARFO 2019
SPL RMS = root mean square sound pressure (dB re 1 μPa)

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 the Bureau of Ocean Energy Management, 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.

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