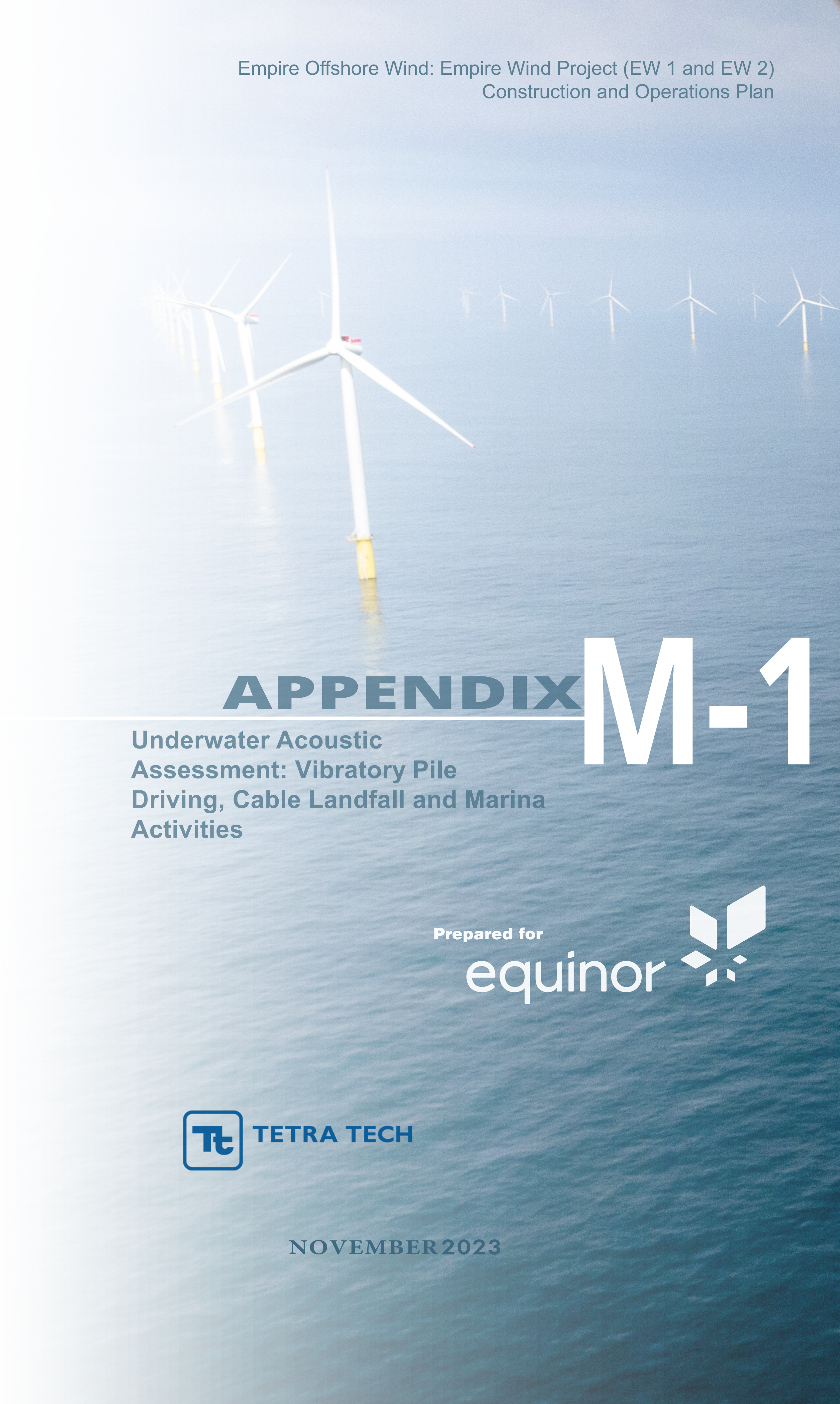
The latest revision date of Appendix M-1 to the Empire Offshore Wind COP is September 2023. This appendix was not revised as part of the November 2023 submittal; therefore, the date on the Appendix M-1 cover sheet remains as September 2023.

Empire Offshore Wind: Empire Wind Project (EW 1 and EW 2)
Construction and Operations Plan



APPENDIX M-1

Underwater Acoustic Assessment: Vibratory Pile Driving, Cable Landfall and Marina Activities

Prepared for
equinor

TETRA TECH

NOVEMBER 2023

Construction and Operations Plan

Empire Offshore Wind: Empire Wind Project (EW 1 and EW 2)

Appendix M-1

Underwater Acoustic Assessment:

Vibratory Pile Driving, Cable Landfall and Marina Activities

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September 2023

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ACRONYMS AND ABBREVIATIONS

°C	Celsius
C	Speed of sound
$C_{sediments}$	Speed of sound in the sediment
C_{water}	Speed of sound in the seawater
COP	Construction and Operations Plan
CRM	Coastal Relief model
dB	decibels
dB_{Peak}	Peak sound pressure
DP	dynamic positioning
Empire	Empire Offshore Wind LLC
ESA	Endangered Species Act
EW	Empire Wind
F_c	Critical frequency
ft	foot
GARFO	Greater Atlantic Regional Fisheries Office
GEODAS	Geophysical Data System
HDD	horizontal directional drilling
HF	High-frequency
Hz	Hertz
I	intensity
I^{ref}	Reference intensity
kHz	kilohertz
km	kilometer
Lease Area	designated Renewable Energy Lease Area OCS-A 0512
LF	Low-frequency
L_{PK} or $L_{p,pk}$	Peak sound pressure
µPa	microPascal
m	meter
m/s	meters per second
MF	Mid-frequency
mi	mile
MMPA	Marine Mammal Protection Act
mph	miles per hour
NGDC	National Geophysical Data Center
nm	nautical mile
NOAA	National Oceanic and Atmospheric Administration
NOAA Fisheries	NOAA National Marine Fisheries Service
OW	Otariids Underwater
P	pressure

Project	The offshore wind project for OCS A-0512 proposed by Empire Offshore Wind LLC consisting of Empire Wind 1 (EW 1) and Empire Wind 2 (EW 2).
Project Area	The area associated with the build out of the Lease Area, submarine export cable routes, and onshore project facility locations including the onshore export and interconnection cables, onshore substations, and O&M Base
psu	Practical salinity units
ppt	Parts per thousand
PTS	Permanent threshold shift
PW	Phocids Underwater
re 1 μPa	referenced to 1 micropascal
RMS	Root mean squared
s	second(s)
SEL or L_E	Sound exposure level
SEL_{cum}	Cumulative sound exposure level
SPL or L_p	Sound pressure level
SSP	Sound speed profile
TTS	Temporary threshold shift

INTRODUCTION

Empire Offshore Wind LLC (Empire) proposes to construct and operate an offshore wind facility located in the designated Renewable Energy Lease Area OCS-A 0512 (Lease Area). The Lease Area covers approximately 79,350 acres (32,112 hectares) and is located approximately 14 statute miles (mi) (12 nautical miles [nm], 22 kilometers [km])[1] south of Long Island, New York and 19.5 mi (16.9 nm, 31.4 km) east of Long Branch, New Jersey (**Figure M-1-1**).

Empire proposes to develop the Lease Area in two wind farms, known as Empire Wind 1 (EW 1) and Empire Wind 2 (EW 2) (collectively referred to hereafter as the Project). Both EW 1 and EW 2 are covered in this Construction and Operations Plan (COP). EW 1 and EW 2 will be independent from each other. Each wind farm will connect via offshore substations to separate Points of Interconnection (POIs) at onshore locations by way of export cable routes and onshore substations. In this respect, the Project includes two onshore locations in New York where the renewable electricity generated will be transmitted to the electric grid.

This Underwater Acoustic Assessment report has been prepared in support of the Project's COP. As discussed in the COP, construction and operations of the Project have the potential to cause acoustic harassment to marine species, in particular, marine mammals, sea turtles, and fishes. This report presents the acoustic modeling methodologies, as applied, to estimate the expected underwater noise levels generated during construction activities associated with the proposed Project. The objective of this modeling study was to predict the ranges to acoustic thresholds that could result in injury or behavioral disruption of marine mammals, sea turtles, and fishes during construction activities associated with the Project. Primary noise-generating activities during construction have been identified as impact pile driving during wind turbine foundation installation, vibratory pile driving during cofferdam installation and bulkhead repair, and impact pile driving of small piles used for bridge foundations and for temporary HDD "goal posts". Vibratory pile driving of the cofferdam and bulkhead and impact pile driving of smaller piles in the nearshore areas is discussed in this report, while impact pile driving of foundations within the Lease Area is discussed separately (**Appendix M-2**). Noise associated with vessel activity related to cable laying and wind turbine operation is also qualitatively discussed. During the decommissioning phase of the Project, all activities are anticipated to be similar to or less than those described for construction; therefore, impacts from decommissioning are anticipated to be similar to or less than those expected during construction and are not addressed specifically in this report.

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.

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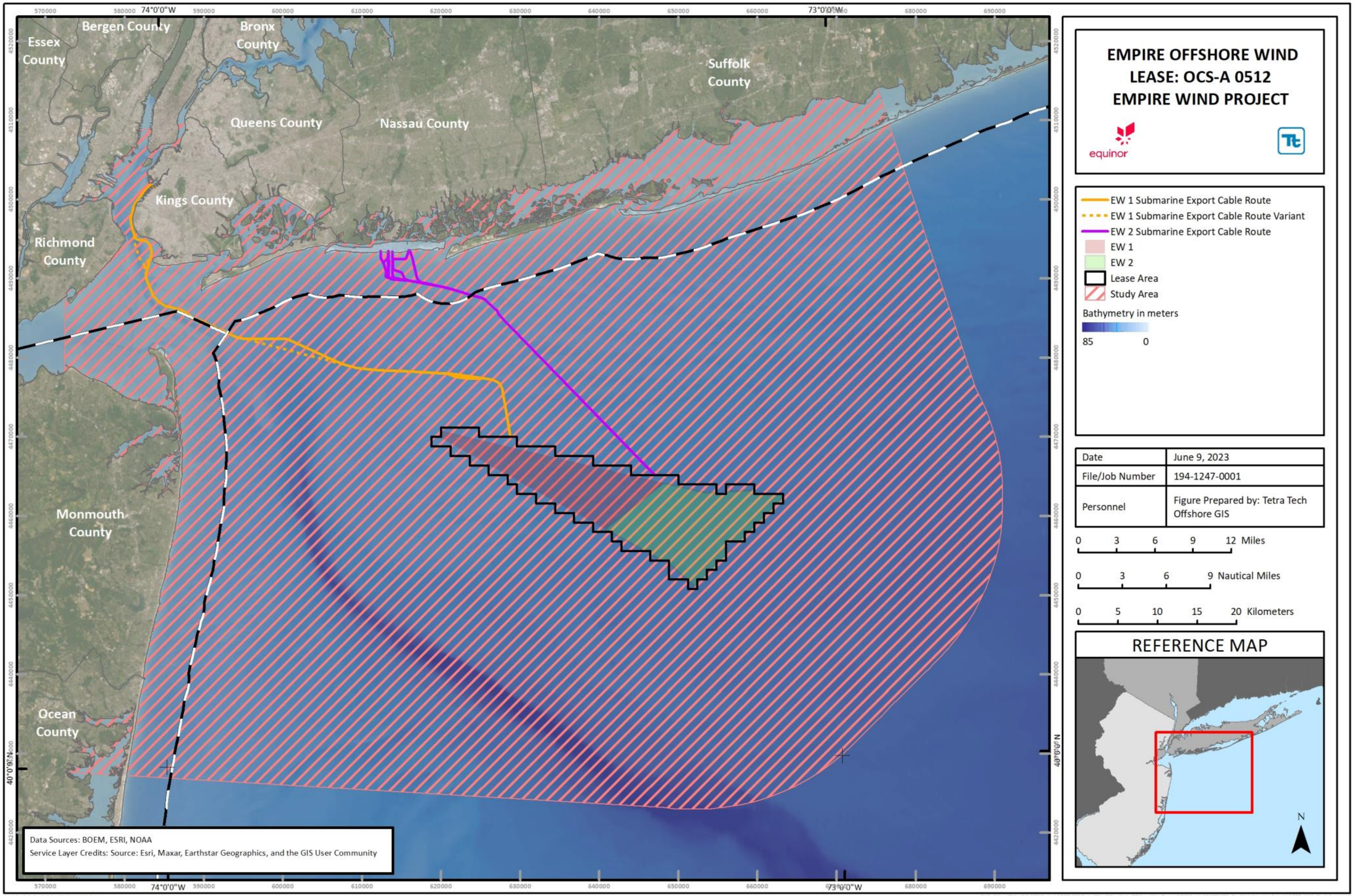
[1] Distances throughout the COP are provided as miles or nautical miles as appropriate, with kilometers in parentheses. For reference, 1 mi equals approximately 0.87 nm or 1.6 km.



NOT FOR CONSTRUCTION

Figure M-1-1 Project Area

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 (e.g., 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. The National Oceanic and Atmospheric Administration's National Marine Fisheries Service (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 M-1-1** provides a summary of the relevant metrics from both NOAA Fisheries (2018) and ISO (2017) that are used within this report.

Table M-1-1 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	L_{PK}	$L_{p,pk}$	dB re 1 µPa
Cumulative Sound Exposure Level	SEL_{cum} a/	SEL	L_E	dB re 1 µPa^2·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 (L_{PK} 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 L_{PK} 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 L_{PK} 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.

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

Sound pressure level (SPL or Lp; 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 $0 \leq t \leq T$.

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

Sound exposure level (SEL or L_E; dB re 1 μPa^2·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}):

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

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 μPa^2·s) can be computed by summing (in linear units) the SEL of the N individual events:

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

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°F (10°C), pH of 8.0, and a salinity of 35 practical salinity units [psu]), 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 (SSP) 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.

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, sound attenuation will mostly occur 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.

Geotechnical reports were reviewed for the 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. Further details pertaining to sediment characteristics are given in Section M-1.4.2.2.

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 (fc) 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:

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

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 3,355 miles per hour (mph, 1,500 meters per second [m/s]). Values for speed of sound in sediment will range from 3,590 mph (1,605 m/s) in sand-silt sediment to 3,915 mph (1,750 m/s) in predominantly sandy areas. Sound traveling in shallower regions of the Project Area will be subject to a higher cutoff frequency and a greater attenuation rate than sound propagating in deeper regions.

Figure M-1-2 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 cutoff frequency would be expected to occur at approximately 30 Hz. Greater low-frequency attenuation rates would occur at shallower locations within the Lease Area. Significant sound energy would attenuate more rapidly as sound sources occurring in shallower water are subject to much stronger attenuation below this cut-off frequency than what would occur in deeper ocean regions. 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.

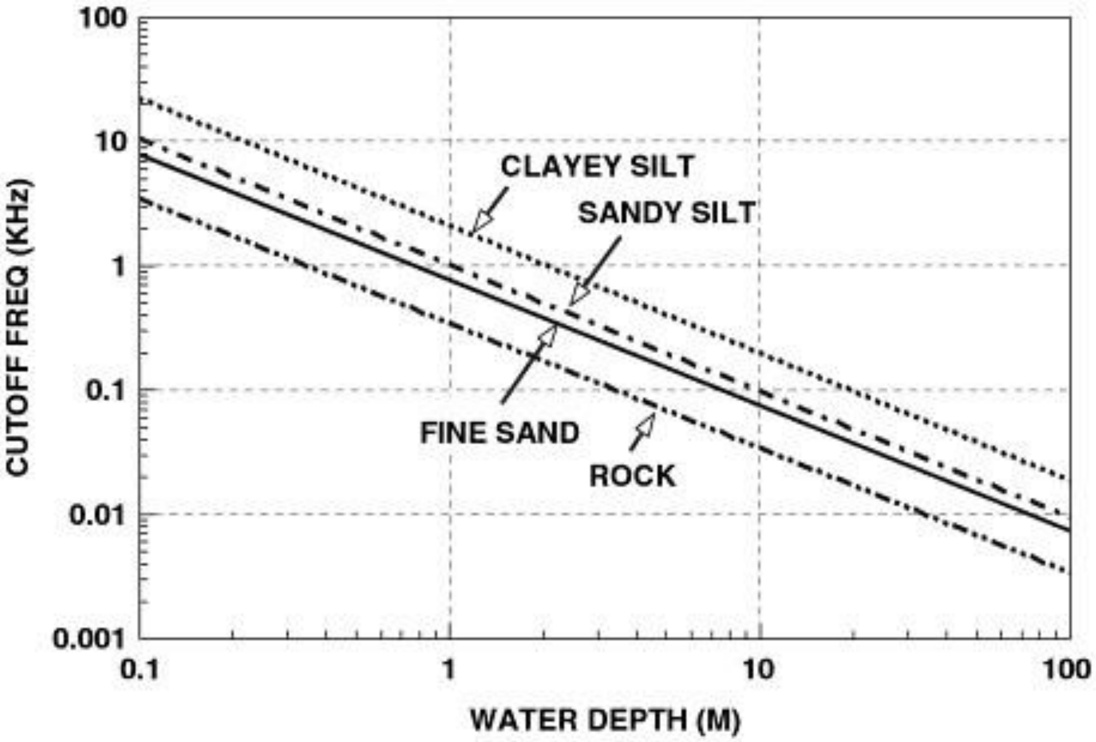


Figure M-1-2 Cut-off Frequencies for Different Bottom Materials (Au and Hastings 2008)

REGULATORY CRITERIA AND SCIENTIFIC GUIDELINES

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. NOAA and the U.S. Fish and Wildlife Service both share jurisdiction for overseeing the MMPA regulations; however, NOAA 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 term "take," as defined in Section 3 (16 United States Code § 1362 [13]) of the MMPA, means "to harass, hunt, capture, or kill, or attempt to harass, hunt, capture, or kill any marine mammal". "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 SPL 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, seals, and sea lions, which was updated in 2018 (NOAA Fisheries 2018) from the previous 2016 guidance. 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: peak sound pressure levels (L_{PK}) may cause damage to the inner ear (this is discussed further below), and the accumulated sound energy the animal is exposed to (cumulative sound exposure levels, SEL) over the entire duration of a discrete or repeated noise exposure, which has the potential to induce auditory damage if it exceeds distinct 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 Hz to 35 kHz.
- Mid-frequency (MF) Cetaceans—this group 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— this group 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 (PW)— this group 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]).
- Otariids Underwater (OW)— this group 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 M-1-3)**.

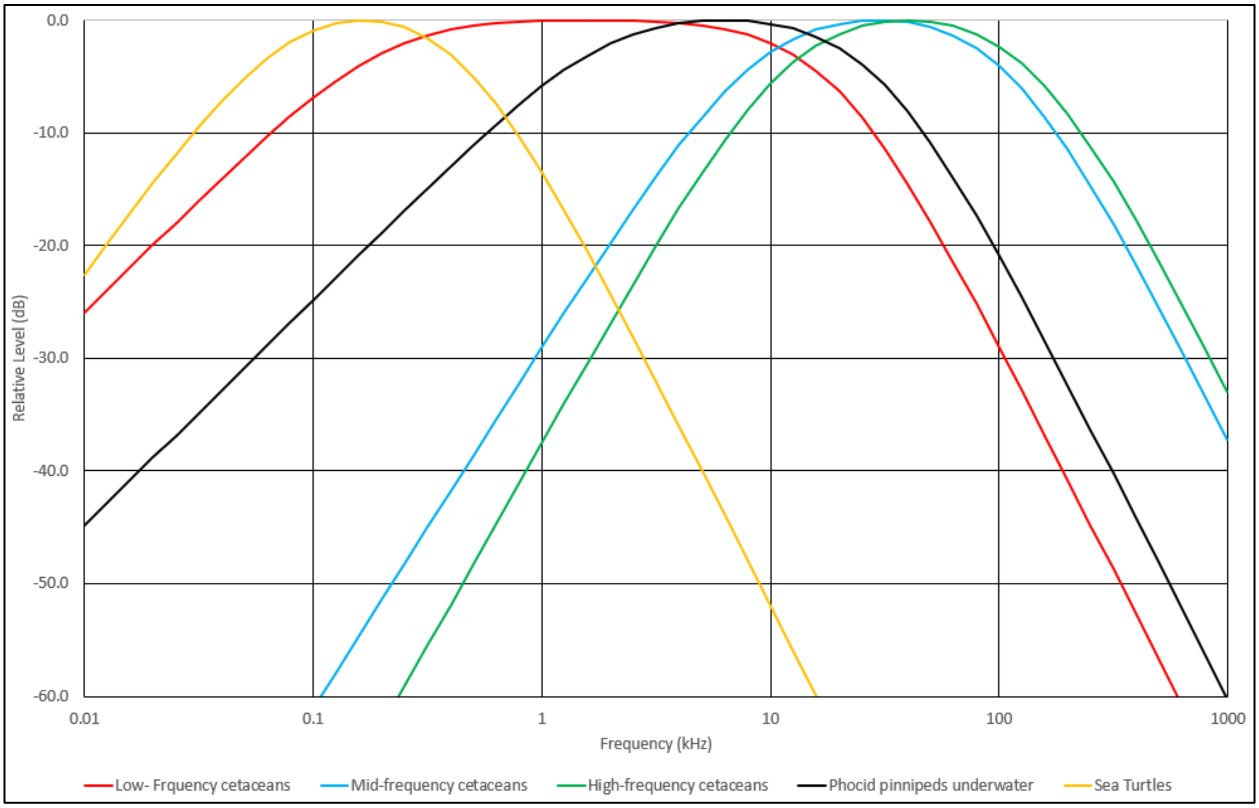


Figure M-1-3 Auditory Weighting Functions for Cetaceans (Low-frequency, Mid-frequency, and High-frequency Species), Pinnipeds in water (PW), and Sea Turtles (NOAA Fisheries 2018, Department of the Navy 2017)

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 M-1-2**), which are presented in terms of dual metrics; SEL_{cum} and L_{PK}. The Level B harassment thresholds are also provided in **Table M-1-2**.

NOAA Fisheries anticipates behavioral response for sea turtles from impulsive sources such as impact pile-driving to occur at 175 dB SPL re 1µPa, which has elicited avoidance behavior of sea turtles (**Table M-1-3**; Blackstock et al. 2018). 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 re 1 $\mu\text{Pa}^2\cdot\text{s}$), impulsive criterion for TTS (189 dB SEL re 1 $\mu\text{Pa}^2\text{s}$), and non-impulsive criteria for TTS (200 dB SEL re 1 $\mu\text{Pa}^2\text{s}$ and 226 dB L_{PK} re 1 µPa) and PTS (220 dB SEL re 1 $\mu\text{Pa}^2\text{s}$ and 232 dB L_{PK} re 1 µPa). The weighting for sea turtles is presented in **Figure M-1-3**.

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 (FHWG), 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 Endangered Species Act (ESA)-listed fish species and sea turtles exposed to elevated levels of underwater sound produced during pile driving, which were just recently updated (NOAA Fisheries 2019). These noise thresholds are based on sound levels that have the potential to produce injury or illicit a behavioral response from fishes (**Table M-1-3**).

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 M-1-4**; 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., dab and other flatfish); 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).

EXISTING AMBIENT CONDITIONS

Noise in the ocean associated with natural sources is generated by physical and biological processes. 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. At areas within distances of 4 to 5 mi (8 to10 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 by-products 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 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).

Table M-1-2 Acoustic Threshold Levels for Marine Mammals

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

Sources: NOAA Fisheries 2018; Southall et al. 2019

Table M-1-3 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 (mass ≥ 2 g)	206 ($L_{p,pk}$) 187 ($L_{E, 24h}$)	--	--	--	150 (L_p)
Fishes (mass < 2 g)	206 ($L_{p,pk}$) 183 ($L_{E, 24h}$)	--	--	--	150 (L_p)
Sea turtles	232 ($L_{p,pk}$) 204 ($L_{E, TUW, 24h}$)	226 ($L_{p,pk}$) 189 ($L_{E, TUW, 24h}$)	220 ($L_{E, TUW, 24h}$)	200 ($L_{E, TUW, 24h}$)	175 (L_p)

Sources: Stadler and Woodbury 2009; NOAA Fisheries 2019; Blackstock et al. 2017; Department of the Navy 2017

Note:
-- = not applicable; TUW = turtle weighting

Table M-1-4 Acoustic Threshold Levels for Fishes and Sea Turtles for Onset of Mortality, Potential Mortal Injury, Recovery Injury, and TTS

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 ($L_{p,pk}$) > 219 ($L_{E,\ 24h}$)	> 213 ($L_{p,pk}$) > 216 ($L_{E,\ 24h}$)	> 186 ($L_{E,\ 24h}$)	--	--
Fishes with swim bladder not involved in hearing	207 ($L_{p,pk}$) 210 ($L_{E,\ 24h}$)	207 ($L_{p,pk}$) 203 ($L_{E,\ 24h}$)	>186 ($L_{E,\ 24h}$)	--	--
Fishes with swim bladder involved in hearing	207 ($L_{p,pk}$) 207 ($L_{E,\ 24h}$)	207 ($L_{p,pk}$) 203 ($L_{E,\ 24h}$)	186 ($L_{E,\ 24h}$)	170 (L_p)	158 (L_p)
Sea turtles	207 ($L_{p,pk}$) 210 ($L_{E,\ 24h}$) 232 ($L_{p,pk}$) PTS	(N) High (I) Low (F) Low	226 ($L_{p,pk}$)	--	--
Eggs and larvae	207 ($L_{p,pk}$) 210 ($L_{E,\ 24h}$)	(N) Moderate (I) Low (F) Low	(N) Moderate (I) Low (F) Low	--	--

Source: Popper et al. 2014

Note:
N = near (10s of meters); I = intermediate (100s of meters); F = far (1000s of meters); -- = not applicable

A study contracted by the New York State Department of Environmental Conservation to conduct passive acoustic monitoring within the New York Bight to assess marine mammal occurrence and patterns of ambient noise in the region was completed from October 2017 to July 2018 (Estabrook et al. 2019). For this study, 15 archival autonomous recording devices were deployed along two lines paralleling the major shipping lanes of the New York Bight to record ambient noise and marine mammal vocalizations for six whale species: the blue whale (*Balaenoptera musculus*), fin whale (*B. physalus*), humpback whale (*Megaptera novaeangliae*), minke whale (*B. acutorostrata*), North Atlantic right whale (*Eubalaena glacialis*), and sei whales (*B. borealis*). A goal of the study was to determine the ambient noise levels at the frequency ranges that corresponded to the hearing ranges of the whales. Therefore, the ambient noise levels presented in the study were limited to those frequency bands associated with the different target whale species. **Table M-1-5** summarizes the ambient noise level ranges observed based on whale species evaluated in the study.

Table M-1-5 New York Bight Underwater Ambient Noise Levels

Species with Hearing Range Corresponding to Measured Frequency Range	Measured Frequency Range (Hz)	Ambient Noise Level Recorded In-Band Frequency Levels (dB re 1 μPa)
North Atlantic Right Whale	70 – 224	84 to 143
Humpback Whale	28 – 708	90 to 152
Minke Whale	44 – 355	86 to 147
Sei Whale	28 – 89	83 to 149
Fin Whale	17 – 28	82 to 148
Blue Whale	14 – 22	74 to 146

Source: Estabrook et al. 2019

The study found that the highest noise levels were associated with a monitoring location nearest to the harbor, which experiences the greatest volume of shipping traffic. The study concluded that the ambient noise levels at each of the monitoring sites were relatively consistent throughout the survey period, with the exception of several loud shipping events.

ACOUSTIC MODELING METHODOLOGY

Underwater acoustic model simulations were conducted for primary noise generating activities occurring during Project construction and operations. The following subsections describe the modeling calculations approach, modeled scenarios, and model input values.

Sound Propagation Model

Underwater sound propagation modeling for vibratory cofferdam installation was completed using dBSea, a powerful 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 SSP, temperature, salinity, and current. Noise levels are calculated throughout the entire Project 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. For the purposes of the Project acoustic analysis, two different solvers for the low and high-frequency ranges:

- dBSeaPE (Parabolic Equation Method): The dBSeaPE solver makes use of the range-dependent acoustic model 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.

The underwater acoustic modeling analysis calculated sound levels in 1/3 octave band center frequencies using a split solver, with dBSeaPE evaluating the 12.5 Hz to 800 Hz with the 1/3 octave bands centered at 800 Hz and dBSeaRay addressing 1,000 Hz to 20,000 Hz with the 1/3 octave bands centered at 1,000 Hz. The specific parameters used in the modeling are described in the following sections. The underwater acoustic modeling analysis was designed using conservative assumptions. If necessary, further review will be conducted as permitting progresses, for instance for the purposes of preparation of an Incidental Harassment Authorization or Letter of Authorizaton application.

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 as well as consulting empirical data. Modeling incorporates the best available Project-specific information and unknown Project details are typically addressed through the use of technical resources such as empirical models, scientific literature, and field measurement data, if available. Model input variables incorporated into the calculations are further described as follows.

Bathymetry

Bathymetry data represent the 3D nature of the subaqueous land surface and were obtained from the National Geophysical Data Center (NGDC) and a US Coastal Relief Model (NOAA 2005); the horizontal resolution of this dataset is 3 arc seconds (90 meters). NGDC's 3 arc-second U.S. Coastal Relief Model (CRM) 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 CRM 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 (GEODAS) is an interactive database management system developed by the NGDC for use in the assimilation, storage and retrieval of geophysical data. GEODAS 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 radials transects were used for modeling acoustic impacts during both the construction and operations of the Project, with each radial centered on the given Project sound source or activity.

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 Project Area encompassing the 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 performed by Empire in 2018 (Gardline 2019) The sediment layers used in the modeling and the main geoacoustic properties are defined in **Table M-1-6**. 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 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 M-1-6 Geoacoustic Properties of Sub-bottom Sediments as a Function of Depth

Seabed Layer (m)	Material	Geoacoustic Properties
0 to 6	Sand and silt	Cp = 1575 m/s αs (dB/λ) = 1.0 dB/ λ ρ = 1700 kg/m^3
5 to 18.5	Sand (dense to very dense)	Cp = 1650 m/s αs (dB/λ) = 0.8 dB/ λ ρ = 1900 kg/m^3
18 to 50	Clay	Cp = 1560 m/s αs (dB/λ) = 0.2 dB/ λ ρ = 1560 kg/m^3

Seasonal Sound Speed Profiles

The speed of sound in sea water depends on the temperature T [°C], salinity S [parts per thousand (ppt)], and depth D [m] and can be described using SSPs. 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 downwards which may result in increased bottom losses with distance from the source. In a positive sound gradient, as is predominantly present in the winter season, sound speed increases with depth and the sound is, therefore, refracted upwards, which can aid in long distance sound propagation. The construction timeframe is expected to run year-round. Speed of sound profile information was obtained using the NOAA Sound Speed Manager software incorporating the World Ocean Atlas 2009 extension algorithms (World Ocean Atlas 2009). For the construction modeling scenarios, the December SSP was selected after having completed a sensitivity analysis whereby all of the monthly SSPs were input directly into the Project dBSea modeling environment and resulting underwater received sound levels were compared. The December SSP was determined to result in the most favorable sound propagation during the proposed construction period and would therefore correlate with maximum underwater noise impacts. **Figure M-1-4** displays the monthly SSPs for the Project Area.

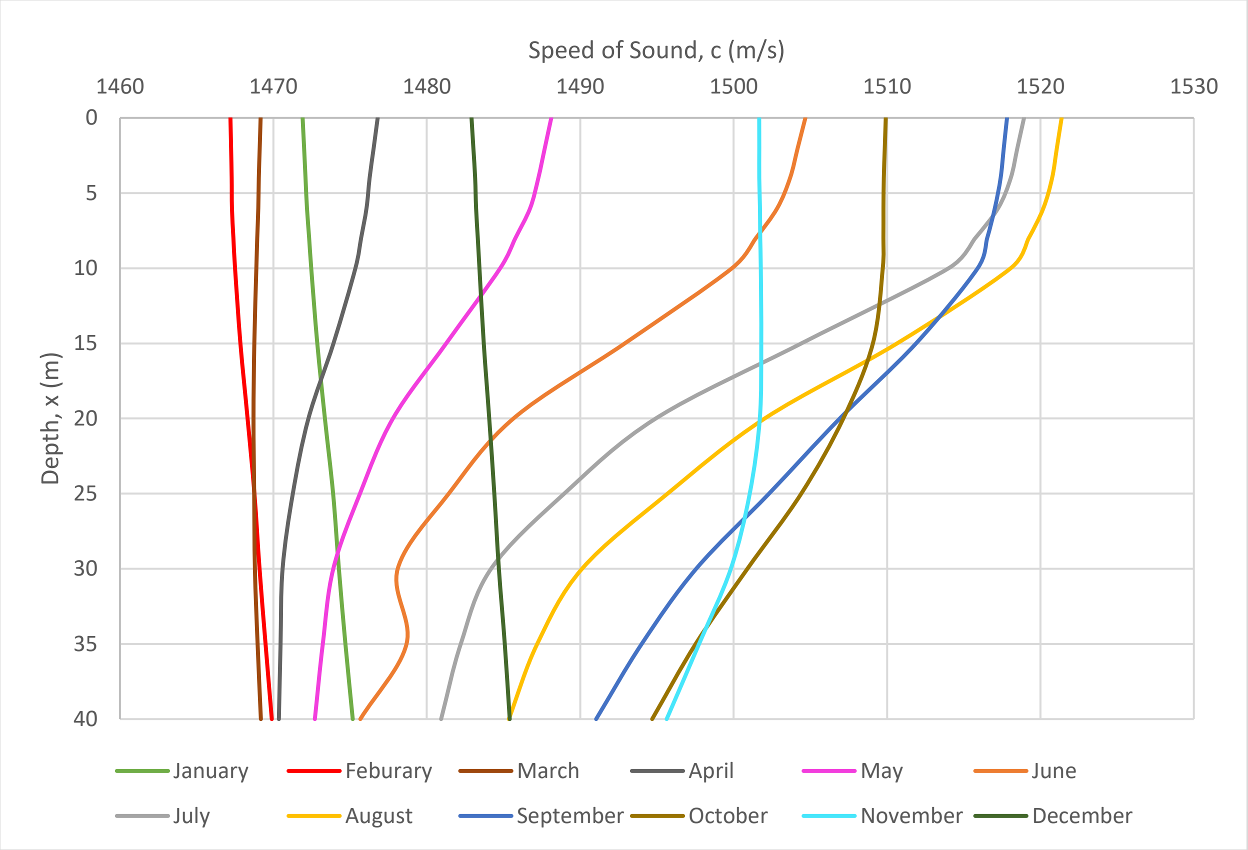


Figure M-1-4 Monthly Sound Speed Profile as a Function of Depth

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 sampling 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 five 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 area that would be exposed to sound at or above the specified level. All distances to injury thresholds presented in the Underwater Acoustic Assessment Report are presented in terms of the $R_{95\%}$ range.

Calculation Methodology for Installation of Goal Posts, Marina, Berthing Pile and Bulkhead Activities

Modeling of goal posts and marina activities, berthing pile and the bulkhead, was conducted 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 adjustment factors in the spreadsheets allow for the calculation of SEL_{cum} and PK 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:

$$SPL(r) = SL - PL(r) \tag{6}$$

Where:

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

Propagation loss is calculated using:

$$PL(r) = F\ Log_{10}(r) \tag{7}$$

Where:

F = Transmission loss coefficient, and

To determine the transmission loss coefficient to apply, a review of underwater noise measurement studies for pile installations was completed. This review included multiple studies collecting data in shallow water environments from impact and vibratory hammers (Blackwell 2005, Burgess 2005, CALTRANS 2020, Denes et al 2016, and NAVFAC 2017). These studies show that the average transmission loss coefficient is greater than 20 for large distances. The data in these studies also show that the transmission loss coefficient increases with distance. Therefore, a conservative transmission loss coefficient of 15 was used to calculate all Level B thresholds with the exception of the 120 dB SPL. For the 120 dB SPL threshold, a transmission loss coefficient of 20 was used since the distance to the 120 dB SPL threshold was large, where we expect greater attenuation.

Note that the calculation methodologies do not allow for inclusion of site-specific environmental parameters.

ACOUSTIC MODELING SCENARIOS

The representative acoustic modeling scenarios analyzed for the Project were derived from descriptions of the expected construction activities and operational conditions developed in consultation with the Project design and engineering teams. This report specifically addresses potential underwater acoustic impacts associated vibratory pile driving needed for cofferdam installation. Underwater acoustic modeling scenarios associated with impact pile driving at the wind turbine locations are described in **Appendix M-2**.

Maximum design parameters were considered in order to develop a conservative assessment and evaluate potential worst case underwater noise impacts. **Table M-1-7** summarizes the activities, locations, and sound source levels used for the underwater acoustic modeling scenarios. Empire is in the process of finalizing the export cable landfall for EW 2; therefore, to demonstrate the potential range of underwater noise impacts associated with cofferdam installation, three representative locations were modeled. Cofferdam location EW 2-1 is representative of EW 2 Landfall A, EW 2 Landfall B, and EW 2 Landfall E. Cofferdam location EW 2-2 is representative of a shallow water option for the EW 2 Landfall C, while EW 2-3 is representative of a deep water option for the EW 2 Landfall C. EW 2-4 is representative of the western approach to EW 2 Landfall C.

In addition to the cofferdam installation, **Table M-1-7** details the modeling scenarios evaluated for goal post installation, marina bulkhead work and marina berthing pile removal.

Table M-1-7 Underwater Acoustic Modeling Scenario

Scenario	Description	Location (UTM Coordinates)	Sound Source Level b/	Modeling Program/Method Used
Scenario 1: Cofferdam Installation	Vibratory Pile Driving	EW 1: 583452 m, 4501772 m EW 2-1: 613965 m,4492769 m EW 2-2: 617063 m, 4493259 m EW 2-3: 616467 m, 4492268 m EW 2-4: 615730 m, 4492964 m	165 $L_{E,\ 1sec}$ c/	dBSea
Scenario 2: Goal Post Installation	Impact Pile Driving	Representative Location	200 $L_{p,pk}$ 174 $L_{E\ (ss)}$ c/ 184 L_p	NOAA Fisheries User Spreadsheet and *F* log R a/
Scenario 3: EW 2 Onshore Substation C Marina Bulkhead Work (Sheetpile installation)	Vibratory Pile Driving	Representative Location	160 $L_{E,\ 1sec}$ c/	NOAA Fisheries User Spreadsheet and *F* log R a/
Scenario 4: EW 2 Onshore Substation C Marina Berthing Pile Removal	Vibratory Pile Driving	Representative Location	165 $L_{E,\ 1sec}$ d/	NOAA Fisheries User Spreadsheet and F log R a/
Impact Pile Driving Scenarios (Fully Detailed in Appendix M-2)				
Monopile (Pile Diameter = 9.6 m)	Impact Pile Driving (Typical)	L01, L02, L03	222, 221, 221 $L_{p,pk}$ 200, 199, 199 $L_{E,\ 0.125sec}$ 209, 208, 208 L_p	Full Waveform Range-dependent Acoustic Model (FWRAM)
Monopile (Pile Diameter = 9.6 m)	Impact Pile Driving (Difficult to Drive)	L01, L02, L03	221, 221, 221 $L_{p,pk}$ 200, 199, 199 $L_{E,\ 0.125sec}$ 209, 208, 208 L_p	Full Waveform Range-dependent Acoustic Model (FWRAM)
Monopile (Pile Diameter = 11 m)	Impact Pile Driving	R3-L04, T1-L05, U3-L06, R3-L07, T1-L08, U3-L09	221, 222, 219, $L_{p,pk}$ 221, 222, 219 $L_{p,pk}$ 199, 201, 198, $L_{E,\ 0.125sec}$ 199, 200, 197 $L_{E,\ 0.125sec}$ 208, 210, 207, L_p 208, 209, 206 L_p	Full Waveform Range-dependent Acoustic Model (FWRAM)
Jacket (Pile Diameter = 2.5 m), 2 piles/day	Impact Pile Driving	OSS1, OSS2	211, 209 $L_{p,pk}$ 191, 188 $L_{E,\ 0.125sec}$ 197. 194 L_p	Full Waveform Range-dependent Acoustic Model (FWRAM)

Scenario	Description	Location (UTM Coordinates)	Sound Source Level b/	Modeling Program/Method Used
Jacket (Pile Diameter = 2.5 m), 3 piles/day	Impact Pile Driving	OSS1, OSS2	211, 209 $L_{p,pk}$ 193, 190 $L_{E,\ 0.125sec}$ 197. 194 L_p	Full Waveform Range-dependent Acoustic Model (FWRAM)

Notes:
$L_{E,\ (ss)}$ = cumulative sound exposure from a single strike.
a/ Refer to Equation 7 for definition of *F*.
b/ Sound source levels are at a distance of 1 meter unless specified otherwise.
c/ Sound pressure level measured at a distance of 10 meters from the sound source.
d/ Sound pressure level measured at a distance of 9 meters from the sound source.

Vibratory Pile Driving Associated with Cofferdam Installation

The exit point of the long-distance horizontal directional drilling (HDD) will be 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 by 50 ft (6.1 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 a good deal of 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. The one-third-octave band vibratory pile driving source levels cited for similar vibratory pile driving activities planned for the Block Island Wind Farm (Tetra Tech 2012) were incorporated into the analysis. The one-third-octave band levels cited in the Block Island Wind Farm report are shown in **Figure M-1-5**..

The broadband sound source level was obtained from measurements of vibratory driving of steel sheet piles conducted at Berth 30, Port of Oakland, California (CALTRANS 2020). These measurements showed a maximum 165 dB re 1 $\mu Pa^2 \cdot s$ at 10 meters, which is conservative compared to the other vibratory driving of steel sheet pile measurements presented in the CALTRANS report. For the Project, a duration of 1 hour was assumed for the vibratory hammer activities.

The SPL was derived assuming a relationship between the SEL and SPL as 10 times the common logarithm of the duration of the source (see equation 8).

$$SPL=SEL-10Log_{10}(T) \tag{8}$$

Where:

T = duration of event in seconds

The one-third octave band levels shown in Figure M-1-5 were then equally scaled to align with the broadband sound pressure level of 165 dB re 1 µPa at 10 meters.

Goal Post Pile Driving

As an alternative to use of cofferdams for the cable landfall, goal posts may be used to assist in the installation of a casing pipe for cable landfall. For the goal post installation process, a barge with necessary support equipment is first mobilized and anchored into position. The support equipment on the barge will include at least one crane, a hydraulic hammer mounted at the end of the crane hook or load block, and the piles to be driven. An additional crane, trackhoe, or similar equipment may also be located on the support barge to aid in the handling of the goal post piles. For each HDD of Direct Pipe installation, it is estimated that three to five goal posts will need to be installed to support the casing pipe. For each goal post, a total of two 12-inch steel piles must be driven to complete a single goal post installation. Each 12-inch steel pile will require a total of 2,000 blows assuming 20 blows per minute for approximately 2 hours. A total of two 12-inch steel piles are expected to be installed per day; therefore, the total number of blows and time spent hammering per day would be 4,000 blows over approximately 4 hours; including setup and associated preparatory activities. The piles are installed by attaching the hydraulic hammer to the end of the pile, and lifting the hydraulic hammer with the crane, and swinging the pile into place for the goal post installation. The hydraulic hammer then drives the pile into the subsea floor by repeated percussive blows until the pile reaches a sufficient depth where enough strength to support the casing pipe is achieved. This process is repeated until all piles necessary for the goal post are installed.

Figure M-1-5 Vibratory Pile Driving Sound (SPL at 1 meter) (Tetra Tech 2012)

Modeling of goal posts was conducted 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 adjustment factors in the spreadsheets allow for the calculation of cumulative sound exposure level (SELcum) distances and peak sound exposure (PK) 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.

Marina Activities

Marina activities will also be completed along the EW 2 Onshore Substation C location along inshore Long Island on the Wreck Lead Channel. These activities consist of bulkhead repairs and the removal of berthing piles. Up to 130 12-inch diameter timber berthing piles would be removed using a combination of a crane and vibratory hammer, depending on the condition of the piles. Two piles would be removed each hour. Up to 15 piles a day would be removed over the course of two weeks, noting that due to the use of the crane when applicable, overall noise generation would be kept to a minimum. Vibratory installation of 24-inch z-type steel sheet piles would also occur at the marina bulkheads, consisting of 20 piles per day, with vibratory installation occurring for 1 hour per pile installed. Marine pile vibratory installation is expected to occur over a total of 35 days.

Modeling of marina activities, berthing piles and the bulkhead, was conducted 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 adjustment factors in the spreadsheets allow for the calculation of cumulative sound exposure level (SELcum) distances and peak sound exposure (PK) 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.

Cable Lay Operations

Specialist vessels specifically designed for laying and burying cables on the seabed will be used. The submarine export and interarray cables will most likely be buried by the use of a jet plow or plow (see Section 3.4.1.4 and Section 3.4.1.5 of the COP for a complete list of potential cable lay and burial methods and equipment). For part of the cable lay process, 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 thruster noise is non-impulsive and continuous in nature and is not expected to result in harassment and therefore a detailed acoustic modeling analysis was not conducted.

Wind Turbine Operation

When the wind turbines are operational, the main source of underwater noise will be from the working of the gears in the nacelle at the top of the tower (Nedwell et al. 2004). This noise/vibration is transmitted into the sea by the structure of the tower itself, and manifests as low-frequency noise. Other transmission pathways are via the tower 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 tower (Nedwell et al. 2004). A review of other published studies indicate that source levels from operating offshore wind turbines 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 1µPa at 1m (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 and size of turbine, the noise level relative to background noise (i.e., from wave action, entrained bubbles) remained relatively constant (Stöber and Thomsen 2021).

NOISE MITIGATION

Sound levels can be greatly reduced during pile driving activities using sound attenuation devices. There are several types of sound attenuation devices including bubble curtains, cofferdams, and isolation casings (also called temporary noise attenuation piles), and cushion blocks. 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 ~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. High current conditions can limit the effectiveness of bubble curtains by sweeping the air bubbles away from the pile (Elmer et al. 2007). 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).

For vibratory pile driving activities, impact driving of goal post piles, and marina removal activities, implementation of noise mitigation strategies (e.g., bubble curtains) are not anticipated and were not accounted for in the modeling results.

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 M-1.2.1. The modeling scenarios analyzed are described in **Table M-1-7**. Vibratory pile driving, if used, would occur at the proposed cofferdam locations at the export cable landfalls.

SPL results for the vibratory pile driving scenarios for cofferdam installation along the EW 1 and EW 2 export cable HDD exit points correspond to distances that are generally less than 328 ft (100 m). There are only a select few scenarios where potential sound impacts are expected to extend beyond 328 ft (100 m); distances to response thresholds for various taxa are shown in **Table M-1-8** through **Table M-1-11**. Based on the average marine mammal densities in the ensonified areas, the potential numbers of marine mammals exposed to harassment from the sound of cofferdam pile driving is shown in **Table M-1-12**.

Table M-1-8 Marine Mammal PTS Onset Criteria Threshold Distances (meters) for Vibratory Pile Driving – Cofferdam Installation

Location	Hearing Group			
	LF cetaceans	MF cetaceans	HF cetaceans	Phocid pinnipeds
	199 $L_{E, 24hr}$	198 $L_{E, 24hr}$	173 $L_{E, 24hr}$	201 $L_{E, 24hr}$
EW 1	122	0	44	62
EW 2-1	75	0	43	0
EW 2-2	32	0	20	0
EW 2-3	81	0	52	0
EW 2-4	13	0	12	11

Acoustic Threshold Source: NOAA Fisheries 2018

Table M-1-9 Fishes Acoustic Injury Threshold Distances (meters) for Vibratory Pile Driving – Cofferdam Installation

Location	Hearing Group	
	Small Fish	Large Fish
	183 $L_{E, 24hr}$	187 $L_{E, 24hr}$
EW 1	304	260
EW 2-1	155	97
EW 2-2	162	105
EW 2-3	156	99
EW 2-4	96	15

Acoustic Threshold Source: Stadler and Woodbury 2009

Table M-1-10 Sea Turtles Behavioral and Acoustic Injury Criteria Threshold Distances (meters) for Vibratory Pile Driving – Cofferdam Installation

	Species		
	Sea Turtle Behavioral	Sea Turtle TTS	Sea Turtle PTS
Location	175 L_P	200 $L_{E, TUW, 24hr}$	220 $L_{E, TUW, 24hr}$
EW 1	53	174	0
EW 2-1	15	11	0
EW 2-2	13	12	0
EW 2-3	10	10	0
EW 2-4	10	8	0
Acoustic Threshold Source: NOAA Fisheries 2019			

Table M-1-11 Marine Mammals and Fish Behavioral Response Criteria Threshold Distances (meters) for Vibratory Pile Driving – Cofferdam Installation

	Hearing Group	
	Fish	Marine Mammals
Location	150 L_p	120 L_p
EW 1	268	1,985
EW 2-1	77	2,083
EW 2-2	72	2,044
EW 2-3	66	2,191
EW 2-4	16	1,535
Acoustic Threshold Source: NOAA Fisheries 2019		

Table M-1-12 Average Marine Mammal Densities Used in Exposure Estimates and Estimates of Potential Takes by Level B Harassment from Vibratory Pile Driving – Cofferdam Installation

Species	EW 1 Cofferdams		EW 2 Cofferdams	
	Average Seasonal Density a/ (No./100 km²)	Calculated Exposure Estimates by Level B Harassment	Average Seasonal Density a/ (No./100 km²)	Calculated Exposure Estimates by Level B Harassment
North Atlantic Right Whale	0.073	0.020 (0)	0.073	0.020 (0)
Humpback Whale	0.099	0.030 (0)	0.099	0.030 (0)
Fin Whale	0.097	0.030 (0)	0.097	0.030 (0)
Sei Whale	0.030	0.010 (0)	0.030	0.010 (0)
Sperm Whale	0.006	0.000 (0)	0.006	0.000 (0)
Minke Whale	0.526	0.170 (0)	0.526	0.160 (0)
Bottlenose Dolphin (Western North Atlantic Northern Migratory Coastal Stock) b/	6.299	2.030 (180)	6.299	1.900 (270)
Atlantic Spotted Dolphin	0.058	0.020 (0)	0.058	0.020 (0)
Short-Beaked Common Dolphin c/	2.837	0.910 (360)	2.837	0.850 (540)
Atlantic White-sided Dolphin	0.469	0.150 (0)	0.469	0.140 (0)
Risso’s Dolphin	0.035	0.010 (0)	0.035	0.010 (0)
Pilot Whale *spp.* d	0.019	0.010 (0)	0.019	0.010 (0)
Harbor Porpoise	3.177	1.020 (1)	3.177	0.960 (1)
Harbor Seal e/	13.673	2.200 (60)	13.673	2.060 (90)
Gray Seal e/	13.673	2.200 (60)	13.673	2.060 (90)

Notes: *For additional details, please refer to Section 6 of the Request for Rulemaking and Letter of Authorization for Taking of Marine Mammals Incidental to Construction Activities on the Outer Continental Shelf (OCS) within Lease OCS-A 0512 and Associated Submarine Export Cable Routes; this table corresponds to* ***Table 34****.*

a/ Cetacean density values from Duke University (Roberts and Halpin 2022). Maximum monthly densities as reported by Roberts and Halpin (2022) were averaged by season over the duration of cofferdam installation/removal (spring [March through May], summer [June through August], fall [September through November], and winter [December through February]). To be conservative, the maximum average seasonal density for each species was then carried forward into the take calculations.

b/ Bottlenose dolphin density values from Duke University (Roberts and Halpin 2022) reported as “bottlenose” and not identified to stock. Given the noise from cofferdam installation would not extend beyond the 20 m isobath, where the coastal stock predominates, it is expected that all estimated takes by Level B harassment of bottlenose dolphins from cofferdam installation will accrue to the coastal stock. As Roberts and Halpin does not account for group size, the requested take was adjusted to account for one group size, 15 individual (Jefferson et al. 2015) per day of bottlenose.

c/ As Roberts et al. does not account for group size, the estimated take was adjusted to account for one group size, 30 individuals (Reeves et al. 2002) per day of each common dolphins.

d/ Pilot whale density values from Duke University (Roberts and Halpin 2022) reported as "Globicephala *spp.*" and not species-specific.

e/ Pinniped density values from Duke University (Roberts and Halpin 2022) are reported as “seals” and are not species-specific, therefore, 50% of expected takes by Level B harassment are expected to accrue to harbor seals and 50% to gray seals. Due to the presence of several seal haul outs in the area, requested level B seal takes were calculated by estimating 10 individuals per day (Woo and Biolsi 2018), divided evenly between harbor seals and gray seals.

The modeling results associated with the goal post installation are given in **Table M-1-13** to **Table M-1-16**. Results for the marina bulkhead work are given in **Table M-1-17** to **Table M-1-20** and results for the marina removal are given in **Table M-1-21** to **Table M-1-24**.

Table M-1-13 Marine Mammal Permanent Threshold Shift Onset Criteria Threshold Distances (meters) for Impact Pile-Driving – Goal Post Installation

Type of Pile	Mitigation (dB)	Hammer Type	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 $L_{E, 24hr}$
12-inch Steel Pile	0	Impact	0	632	0	23	7	753	0	338
	6	Impact	0	252	0	9	3	300	0	135
	10	Impact	0	136	0	5	2	162	0	73

Acoustic Threshold Source: NOAA Fisheries 2018

Table M-1-14 Fishes Acoustic Injury Threshold Distances (meters) and Behavioral Response Criteria for Impact Pile Driving – Goal Post Installation

Type of Pile	Mitigation (dB)	Hammer Type	Fish 206 $L_{p,pk}$	Small Fish 183 $L_{E, 24hr}$	Large Fish 187 $L_{E, 24hr}$	Fish 150 L_p
12-inch Steel Pile	0	Impact	4	631	342	1848
	6	Impact	2	251	136	736
	10	Impact	1	136	74	398

Acoustic Threshold Source: Stadler and Woodbury 2009

Table M-1-15 Sea Turtles Behavioral and Acoustic Injury Criteria Threshold Distances (meters) for Impact Pile Driving – Goal Post Installation

Type Pile	Mitigation (dB)	Hammer Type	Sea Turtle TTS 189 $L_{E, TUW, 24hr}$	Distance (m) to Sea Turtle TTS (Peak SPL) 226 dB_{Peak}	Sea Turtle PTS 204 $L_{E, TUW, 24hr}$	Distance (m) to Sea Turtle PTS (Peak SPL) 232 dB_{Peak}	Sea Turtle Behavioral 175 L_P
12-inch Steel Pile	0	Impact	183	0	18	0	40
	6	Impact	73	0	7	0	16
	10	Impact	39	0	4	0	9

Acoustic Threshold Source: NOAA Fisheries 2019

Table M-1-16 Marine Mammals and Fish Behavioral Response Criteria Threshold Distances (meters) for Impact Pile Driving – Goal Post Installation

Type Pile	Mitigation (dB)	Hammer Type	160 L_p	120 L_p
12-inch Steel Pile	0	Impact	398	15849
	6	Impact	159	7943
	10	Impact	86	5012

Acoustic Threshold Source: NOAA Fisheries 2019

Table M-1-17 Marine Mammal PTS Onset Criteria Threshold Distances (meters) for Vibratory Hammer – Marina Bulkhead Work

Type of Pile	Hammer Type	Low-Frequency cetaceans	Mid-Frequency cetaceans	High-Frequency cetaceans	Phocid pinnipeds
		199 $L_{E, 24hr}$	198 $L_{E, 24hr}$	173 $L_{E, 24hr}$	201 $L_{E, 24hr}$
EW 2 Onshore Substation C Bulkhead Work Steel Sheet pile	Vibratory	43	4	64	26

Acoustic Threshold Source: NOAA Fisheries 2018

Table M-1-18 Fishes Acoustic Injury Threshold Distances (meters) and Behavioral Response Criteria for Vibratory Pile Driving – Marina Bulkhead Work

Type of Pile	Hammer Type	Small Fish 183 $L_{E, 24hr}$	Large Fish 187 $L_{E, 24hr}$	Fish 150 L_p
EW 2 Onshore Substation C Bulkhead Work Steel Sheet pile	Vibratory	507	274	46

Acoustic Threshold Source: Stadler and Woodbury 2009

Table M-1-19 Sea Turtles Behavioral and Acoustic Injury Criteria Threshold Distances (meters) for Vibratory Pile Driving – Marina Bulkhead Work

Type Pile	Hammer Type	Sea Turtle TTS 189 $L_{E, TUW, 24hr}$	Sea Turtle PTS 204 $L_{E, TUW, 24hr}$	Sea Turtle Behavioral 175 L_P
EW 2 Onshore Substation C Bulkhead Work Steel Sheet pile	Vibratory	147	15	1

Acoustic Threshold Source: NOAA Fisheries 2019

Table M-1-20 Marine Mammals and Fish Behavioral Response Criteria Threshold Distances (meters) for Vibratory Pile Driving – Marina Bulkhead Work

Type Pile	Hammer Type	160 L_p	120 L_p
EW 2 Onshore Substation C Bulkhead Work Steel Sheet pile	Vibratory	10	1000

Acoustic Threshold Source: NOAA Fisheries 2019

Table M-1-21 Marine Mammal PTS Onset Criteria Threshold Distances (meters) for Vibratory Pile Driving – Marina Removal

Type of Pile	Hammer Type	Low-Frequency cetaceans	Mid-Frequency cetaceans	High-Frequency cetaceans	Phocid pinnipeds
		199 $L_{E, 24hr}$	198 $L_{E, 24hr}$	173 $L_{E, 24hr}$	201 $L_{E, 24hr}$
EW 2 Onshore Substation C Marina Removal 12" Timber pile	Vibratory	44	4	64	27

Acoustic Threshold Source: NOAA Fisheries 2018

Table M-1-22 Fishes Acoustic Injury Threshold Distances (meters) and Behavioral Response Criteria for Vibratory Pile Driving – Marina Removal

Type of Pile	Hammer Type	Small Fish 183 $L_{E, 24hr}$	Large Fish 187 $L_{E, 24hr}$	Fish 150 L_p
EW 2 Onshore Substation C Marina Removal 12" Timber pile	Vibratory	511	277	90

Acoustic Threshold Source: Stadler and Woodbury 2009

Table M-1-23 Sea Turtles Behavioral and Acoustic Injury Criteria Threshold Distances (meters) for Vibratory Pile Driving – Marina Removal

Type Pile	Hammer Type	Sea Turtle TTS 189 $L_{E, TUW, 24hr}$	Sea Turtle PTS 204 $L_{E, TUW, 24hr}$	Sea Turtle Behavioral 175 L_P
EW 2 Onshore Substation C Marina Removal 12" Timber pile	Vibratory	148	15	2

Acoustic Threshold Source: NOAA Fisheries 2019

Table M-1-24 Marine Mammals and Fish Behavioral Response Criteria Threshold Distances (meters) for Vibratory Pile Driving – Marina Removal

Type Pile	Hammer Type	160 L_p	120 L_p
EW 2 Onshore Substation C Marina Removal 12" Timber pile	Vibratory	19	1600

Acoustic Threshold Source: NOAA Fisheries 2019

The results of the analysis will be used to inform development of evaluation and mitigation measures that may be applied during construction of the Project, in consultation with the Bureau of Ocean Energy Management and NOAA Fisheries. 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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