Appendix M-2 – Underwater Acoustic Modeling Report

UNDERWATER ACOUSTIC MODELING REPORT

Virginia Offshore Wind Technology Advancement Project

(VOWTAP)

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LIST OF ACRONYMS

Acronym	Definition
CRM	Coastal Relief Model
cSEL	cumulative sound exposure level
dB	decibel
dBA	A-weighted decibel
dBL	linear decibel
Dominion	Virginia Electric and Power Company, a wholly owned subsidiary of Dominion Resources, Inc.
DP	dynamic positioning
ESA	Endangered Species Act
FEED	Front End Engineering Design
GAP	General Activities Plan
GEODAS	Geophysical Data System
GeoRAM	Range-dependent Acoustic Model
Hz	hertz
IBGS	Inward Battered Guide Structure
kHz	kilohertz
kJ	kilojoule
µPa	micropascal
MMPA	Marine Mammal Protection Act
MW	megawatt
m^3	cubic meter
NGDC	National Geophysical Data Center
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
OCS	Outer continental shelf
PE	Parabolic Equation
RMS	root-mean-square
RMS90%	90 percent root mean square sound level
ROV	Remotely Operated Vessel
SEL	sound exposure level
SPL	sound pressure level
SSP	sound speed profile
TL	transmission loss
USGS	United States Geological Survey
VOWTAP	Virginia Offshore Wind Technology Advancement Project
WTG	wind turbine generator

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1 INTRODUCTION

Virginia Electric and Power Company, a wholly owned subsidiary of Dominion Resources, Inc. (Dominion) is proposing the Virginia Offshore Wind Technology Advancement Project (VOWTAP or Project), a 12 megawatt (MW), two turbine offshore wind demonstration project located approximately 24 nautical miles (27 statute miles, 43 kilometers) offshore of the city of Virginia Beach, Virginia (Figure 1). Other offshore Project facilities include a 34.5 kilovolt (kV) Inter-Array Cable that will interconnect the two VOWTAP wind turbine generators (WTGs), and a 34.5 kV Export Cable that will convey electricity from the WTGs to a landfall site located in Virginia Beach, Virginia (Figure 1).

Dominion is aware that construction and operation of the Project has the potential to cause acoustic harassment to marine species, in particular marine mammals, sea turtles, and fish populations. This technical appendix presents the acoustic modeling methodologies, as applied, to estimate the expected underwater noise levels generated during construction and operation of the proposed Project, including pile driving of wind turbine foundations, which is expected to generate the highest underwater sound levels. This acoustic analysis included the following steps completed in accordance with established protocols and best engineering practices:

- **Establish existing conditions** – Review literature and measurement data completed within the study area to help determine the underwater acoustic environment and existing sound sources and activities.
- **Source level development and acoustic modeling** – Determination of representative scenarios to describe the resultant underwater sound levels for specific construction and operational activities. Use of a computer-based model simulation to forecast exclusion zones for marine mammals.
- **Data interpretation** – Results used by marine biologists and fisheries experts to assess potential impacts and determine species-specific mitigation.
- **Noise mitigation analysis** – A top down review of candidate noise mitigation strategies to meet design goals and National Oceanic and Atmospheric Administration National Marine Fisheries Service (NOAA Fisheries) requirements.
- **Compliance assessment** – To provide a demonstration of the feasibility of the Project to be constructed and operated in compliance with all applicable requirements and be adequately protective of aquatic life.

The spatial distribution of received noise has been analyzed encompassing three construction scenarios, four unique cable lay construction locations, four pile driver impact forces, and an estimation of underwater sound levels during future wind turbine operation. These modeling scenarios were developed in direct cooperation with the Project's engineering team to ensure an accurate representation of the activities and construction methods. Underwater noise levels were modeled with the widely-used and publically available Range Dependent Acoustic Model (GeoRAM), which is based on the U.S. Navy's Standard Split-Step Fourier Parabolic Equation. Since the seafloor and its properties are variable based on location, it is necessary to use a range dependent model that is programmed to account for these variations along the propagation path.

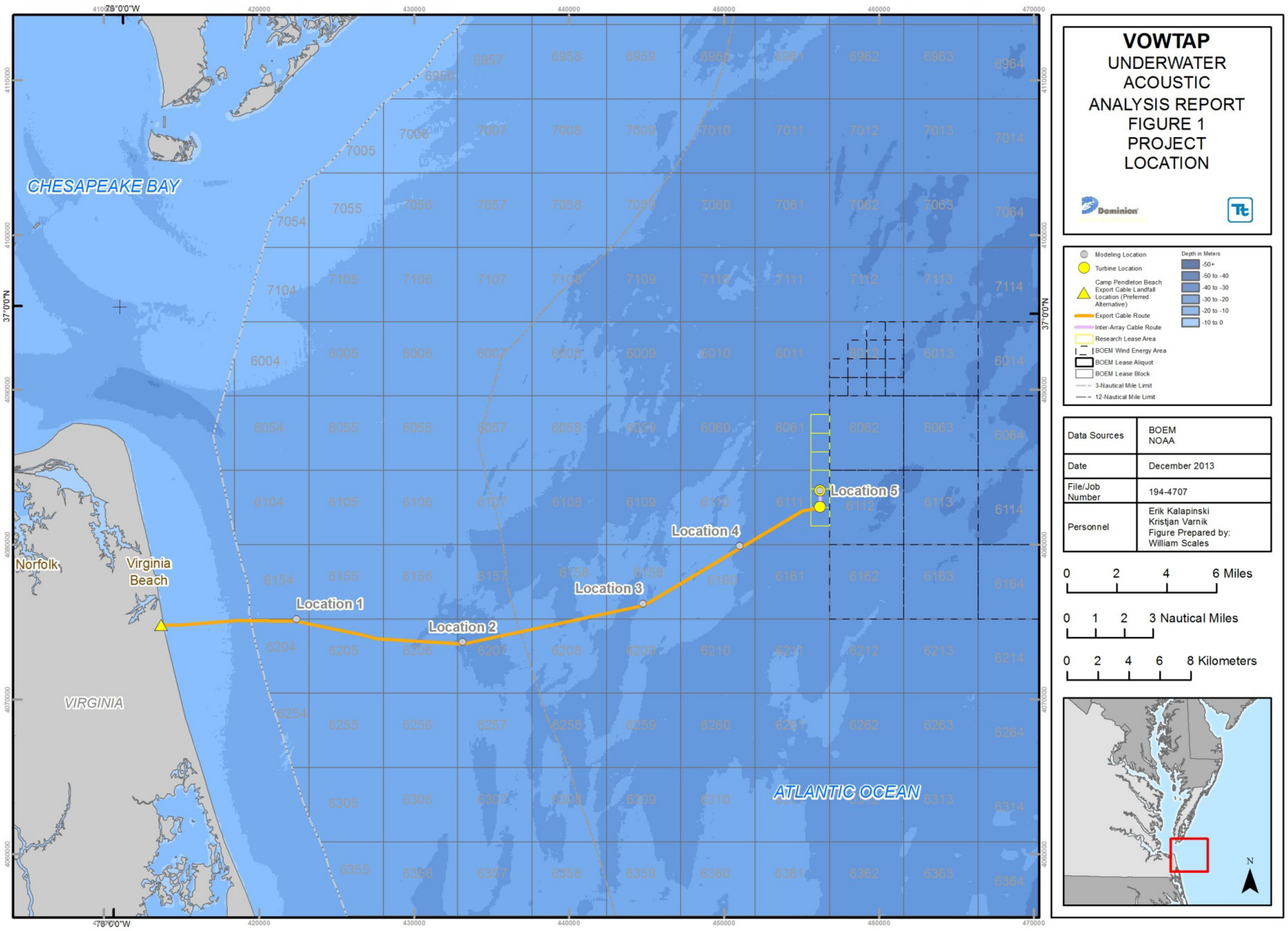


Figure 1. Overview of Project Area

This study also included an extensive background literature review in order to obtain information on similar offshore construction noise source levels, and to incorporate actual measurement data from operational wind farm projects for further model validation purposes. The underwater noise modeling analysis includes an overview of applicable regulatory criteria and scientific based thresholds, and a detailed discussion of the acoustic analysis methodology and the model input parameters incorporated. Modeling results of the underwater acoustic analysis are presented as plots of distances along radial transects. These distances correspond to NOAA Fisheries marine species harassment criteria and interim thresholds for fish and sea turtles. Information provided is intended to form the basis for the assessment of potential biologically significant impacts.

2 EXISTING CONDITIONS

Underwater sounds, if they are intense enough, may cause behavioral responses, injury, or even death from concussion (Richardson et al. 1995). However, actual thresholds for behavioral responses to sounds in the natural environment depend on the range and levels of ambient noise that are persistently present. As is routine when conducting noise surveys in air, the significance of any noise as an annoyance can be related to the extent to which it exceeds background levels. Therefore, the prediction of possible masking effects, and the behavior of marine life, will also be influenced by the anticipated background noise levels. The propagation modeling considers the contribution of the Project in isolation; therefore, existing conditions and potential masking effects are not accounted for. In addition, review of the modeling results alone does not provide an indication of when marine life will acclimatize to certain sound levels.

The existing underwater acoustic environment can be described as a combination of many possible noise sources of both natural and man-made origins. Noise from natural sources is generated by physical or 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. Shallow water has been defined for the purposes of this hydroacoustic analysis as a water column less than 200 m deep. Research has shown that ambient noise is 5-10 dB higher in shallower water, which is linked to the influence of surface agitation and reflection by the bottom and may also be dependent on localized conditions of sea state and wind speed, varying both spatially and temporally. The ambient noise for frequencies above 1 kilohertz (kHz) is due largely to waves, wind, and heavy precipitation; however, it may be evident at frequencies down to 100-300 Hz during otherwise quiet times (Simmonds et al. 2004). Surface ocean wave interaction and breaking waves with spray have been identified as important sources of noise. Wind induced bubble oscillations and cavitation are also near-surface noise sources, major storms can give rise to noise in the 10-50 kHz band which can propagate to long ranges with the same mechanism and directionality as distant shipping. At areas within distances of 8-10 km of the shoreline, surf noise will be prominent in the frequencies ranging up to a few hundred hertz (Richardson et al. 1995), even during calm wind conditions.

Man-made noise sources can consist of contributions related to industrial development, offshore oil industry activities, naval operations, and marine research but the most predominant contributing noise source is generated by commercial ships and recreational watercraft. Noise from such ships dominates coastal waters and emanates from the ships’ propellers and other dynamic positioning propulsion devices such as thrusters. The sound generated from main engines, gearboxes, 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. Other potential ship-related sources include vortex shedding from the hull and noise associated with the wake, noise generated by pipes open to, and discharging into the sea. Most shipping contributes in a frequency range of less than 1 kHz. In general, older vessels produce more noise than newer ones and larger vessels produce more than smaller ones, but this is not always the case. Although, typically, shipping produces frequencies below 1 kHz, small leisure craft may generate sound with frequency components from 1 kHz, up to the 50 kHz range due to propeller cavitation at elevated speeds, which may generate noise at somewhat higher frequencies (Simmonds et al. 2004).

In addition to these sound sources, a considerable amount of background noise may be caused by biological activities. Aquatic animals make sounds for communication, echolocation, prey manipulation, and also 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_{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). With all of the complexities involved, the capacity for acoustic models to estimate background levels is limited, so for that reason the acoustic modeling analysis presented is restricted to future Project construction and operational scenarios only.

2.1 Underwater Acoustic Concepts and Terminology

The sound level estimates presented in this modeling study are expressed in terms of several metrics and applies the use of averaging times 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 to provide further insight into how data and modeling results have been presented in accordance with regulatory reporting requirements and established criteria.

Reference Levels

Sound levels are reported on a logarithmic scale expressed in units of decibels (dB) and are reported in terms of linear (or unweighted) decibels. Linear decibels are referred to as dB or dBL in this report. A decibel is defined as the ratio between a measured value and a reference value of 1 micropascal (µPa). A logarithmic scale is formed by taking 20 times the logarithm (base 10) of the ratio of two pressures: the measured sound pressure divided by a reference sound pressure. When evaluating sound propagation in the underwater environment, in comparison to the in-air environment (see Appendix M-1, In-Air Acoustic Modeling Report), many differences must be noted. The reference for underwater sound pressure is 1 µPa; however, in-air sound uses a reference of 20 µPa. Due to the difference in acoustic impedance, a sound wave that has the same intensity in air and in water will in water have a pressure that is 60 times larger than in air, with a displacement amplitude that will be 60 times less. Assuming pressure is maintained as a constant, the displacement amplitude in water will be 3580 times less than in air. To help demonstrate this relationship, Table 1 provides the corresponding values of sound pressure in air and in water having the same intensities at a frequency of 1 kiloHertz (kHz) as it relates to human-perceived loudness. This somewhat simplistic comparison does not account for the frequency dependent hearing capabilities of various species (e.g., marine species) or individual hearing response mechanisms.

Table 1. Sound Pressure Levels and Comparison to Relative Human Loudness Thresholds

Pressure in Air re 20 µPa/Hz	Pressure in Water re 1µPa/Hz	Relative Loudness (human perception of different reference sound pressure levels in air)
0	62	Threshold of Hearing
58	120	Potentially Audible Depending on the Existing Acoustic Environment
120	182	Uncomfortably Loud
140	202	Threshold of Pain
160	222	Threshold of Direct Damage
Source: Kinsler and Frey 1962		

Sound Level Metrics

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. Statistical levels describe the temporal variation in sound levels. Underwater sound pressure levels may change from moment to moment; some are sharp impulses lasting one second or less, while others may rise and fall over much longer periods of time. Statistical levels provide a percentile distribution of the time-varying sound levels. The statistical sound levels (L_n) provide the sound level exceeded for that percentage of time over the given measurement period. An L_{10} level is often referred to as the intrusive noise level and is the sound level that is exceeded for 10 percent of the time during a specified measurement period. The L_{90} level is the sound level that is exceeded for 90 percent of the time during the measurement time period, or the quietest 10 percent of a given time period. Often referred to as the residual sound level, L_{90} can be an indicator of the potential for acute perceptibility of a new sound source as it will not tend to include sound from transient events (such vessel watercraft passbys), unless they occurred for the entire measurement duration. Statistical levels can be specified as broadband “single number” values and also frequency dependent numbers (i.e., in one-third octave bands).

Underwater sounds are classified according to whether they are transient or continuous. Transient sounds are of short duration and occur singly, irregularly, or as a part of a repeating pattern. For instance, an explosion represents a single transient event, whereas the periodic pulses from a ship’s sonar are patterned transients. Broadband short duration transients are called pulses. Continuous sounds, which occur without pauses, may be further classified as periodic, such as the sound from rotating machinery or pumps, or aperiodic, such as the sound of a ship transiting. Shipping is considered a short-term continuous sound. These sounds normally increase in level with higher engine loads or as vessels approach an observation location and then diminish as they move away. Fixed-location continuous sounds are associated with an operational offshore wind turbine. The intensity of continuous noise is generally given in terms of the root mean square (RMS) sound pressure level (SPL). The RMS SPL (also referred to as the time-averaged level) 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 RMS is also known as the quadratic mean and is a statistical measure of the magnitude of a varying quantity. Exposure to this sound level over the measurement period would result in the same noise dose as being exposed to the actual varying sound levels over that same period. Given a measurement of the time varying sound pressure p(t) from a given noise source at some location, the RMS SPL (L_P) is computed according to the following formula:

$$L_P = 10log_{10}\frac{1}{T}\int_T p(t)^2 dt/P_{ref}^2$$

Where T is the measurement period. Pulses are defined as brief, broadband, atonal, transients. These sounds are all 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. The rapid rise-time characteristic of these sounds ensures that they are also broadband in nature, with the higher-frequency components being related to the rapidity of the rise time. Pile driving using an impact hammer during construction of the jacketed foundations is an example of underwater noise that is characterized as pulsed sound. Impulse sounds may be characterized by L_{peak}, which is the maximum instantaneous sound pressure level attained by an impulse, p(t):

$$L_{peak} = 20log_{10}(max|p(t)|)$$

Where p(t) is the instantaneous pulse pressure as a function of time, measured over the pulse duration $0 \le t \le T$. This metric is very commonly quoted for impulsive sounds but does not take into account the pulse duration or bandwidth of a signal. The peak pressure level of the sound pulse generated by impact piling will decay at a slightly higher rate compared to the energy in the pulse (the SEL is proportional to pulse energy) due to temporal dilation of the pulse that results from multiple reflections from the seabed and the sea surface as the sound pulse propagates. For pulsed noise, the RMS sound pressure level may be measured over the pulse duration according to the following equation:

$$L_P = 10log_{10}\left(\frac{1}{T}\int_T p^2(t)dt/P_{ref}^2\right)$$

The time interval, T, above, is most often taken to be the “90 percent energy pulse duration” rather than a fixed time window when computing pile driving safety radii. The 90 percent energy pulse duration is computed for each seismic shot as the window containing 90 percent of the pulse energy, and RMS SPLs computed in this way are commonly referred to as 90 percent RMS SPLs. In addition, because the window length is used as a divisor, pulses that are more spread out in time have a lower RMS SPL for the same total acoustic energy.

The final sound metric referred to in the following report is the sound exposure level (SEL or LSEL). The SEL is the decibel level of the cumulative sum-of-square pressures over the duration of a sound (e.g., 1 dB μPa^2-s) for sustained nonpulse sounds where the exposure is of a constant nature. However, this measure is also extremely useful for pulses and transient nonpulse sounds because it enables sounds of differing duration to be characterized in terms of total energy over a given time period for purposes of assessing exposure. The SEL metric also allow for integration of sound energy to determine exposure from multiple sources. The SEL for a single pulse is computed using the equation below.

$$L_{SEL} = 10log_{10}\left(\int_{T} p^2(t)dt/P_{ref}^2\right)$$

Unless otherwise stated, sound exposure levels for pulsed noise sources (*i.e.*, impact hammer pile driving) presented in this report refer to a single pulse.

Spectral Levels

Acoustic modeling was completed at one-third octave band center frequencies in the range of 10 Hz to 4 kHz. One-third octaves are a series of electronic filters used to separate sound into discrete frequency bands, making it possible to know how sound energy is distributed as a function of frequency. Corresponding broadband dBL sound levels sum the acoustic energy across all frequencies. These analyses quantitatively describe the frequency dependent sound environment for specific events or activities. The advantage of one-third octave band modeling is that it can resolve the frequency dependent propagation characteristics of a particular environment and can be summed to efficiently compute the overall broadband sound pressure level for any given receiver position within the water column.

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 viscosity of the medium causes sound energy to be converted into heat by internal friction. Some sound energy is converted into heat because sound waves alternately raise and lower the temperatures. Suspended particles are set to oscillating by the sound waves and in this process some of the sound energy is dissipated in the form of heat. This is especially the case if the particles are air bubbles. While each of these factors offers its own unique contribution to the total absorption loss, all of them are caused by the repeated pressure fluctuations in the medium as the sound waves are propagated. In these processes, the area over which the signal is spread remains the same, but the energy in the signal, and therefore the intensity, is decreased.

The absorption of sound energy by water contributes to the attenuation losses 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 10°C, pH of 8.0, and a salinity of 35 practical salinity units [psu]), the equations presented by Francois and Garrison (1982a, b) yield the following values for seawater absorption: 0.001 dB/km at 100 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.

Spatial Effects and Spreading

Transmission loss (TL) underwater is the accumulated decrease in acoustic intensity as an acoustic pressure wave propagates outwards from a source. The intensity of the source is reduced with increasing distance due to spreading. Spreading can be categorized into two models, spherical spreading and cylindrical spreading models. Three fundamental equations can be used to describe spreading losses. The first equation used for noise modeling covers TL for short ranges near the source, where sound energy spreads outward unimpeded by interactions at the sea surface or sea floor until the entire channel depth is insonified. The following equation is used when r, the horizontal separation distance between sound source and receiver, is up to 1 times H, which is sometimes conservatively assumed as the average water depth. The equation also includes a range and frequency dependent absorption term, α.

$$TL = 20\log r + \alpha r$$

The intermediate (or transition zone) is defined as H ≤ r ≤ 8H where modified cylindrical spreading occurs accompanied by mode stripping effects (Richardson et al. 1995). The TL equation representing this intermediate range is given below:

$$TL = 15\log r + \alpha r$$

For underwater transmission in shallow water where the water depth is greater than five-times the sound wavelength, the 15 log r spreading loss factor in the above equation may extend beyond the range of 8H. Long range TL occurs where r > 8H. Due to the boundaries of the sea surface and sea floor, sound energy is not able to propagate uniformly in all directions from a source indefinitely; therefore, long range TL is represented as cylindrical spreading, limited by the channel boundaries. Cylindrical spreading propagation is applied using the equation given below:

$$TL = 10\log r + \alpha r$$

These equations are based on free-field conditions that assume uniform sound spreading in an infinite, homogeneous ocean and neglect specific environmental effects, such as water column refraction and bottom reflections. Such factors are important in consideration of underwater sound propagation carried out over extended calculation distances, and thus strongly affect the accuracy of this methodology. The acoustic far-field is defined as the distance from a source, which is greater than the acoustic wavelength at a frequency of interest. Since the wavelength varies with frequency, the separation distance will vary with frequency with the lower frequencies having the longer wavelength, as measured in meters. The geometric far-field roughly begins at the distance from a source of sound which is greater than roughly four times the largest physical dimension of the area sound source(s). When in the geometric far-field, the sources have all essentially merged into one, so that measurements made even further away will be no different in terms of source contribution. The effects of source geometry and multiple sources operating concurrently, in the geometric far-field, are expected to be negligible. In this report all modeled distances are reported horizontally from the source's acoustic center to determine the average energy flux in a sound field at a given distance.

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 TL 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. It is also very likely that some reflections or refractions may actually overlap others and cause constructive and destructive interference patterns.

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. It may produce locations in the ocean that a sound ray sent out from a particular transducer cannot penetrate. These are called shadow zones. It may also produce sound channels that can trap the sound and allow a signal to travel great distances with minimal loss in energy.

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 is negligible. Also, scattering loss occurring at the surface due to wave action will increase at higher sea states.

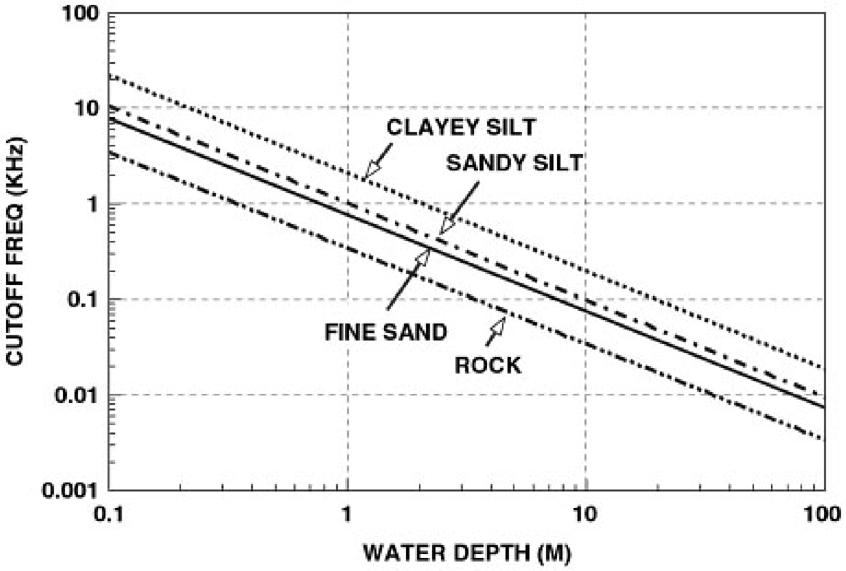
Cut-off Frequency

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 (f_c) can also be calculated if the speed of sound in the sediment ($C_{sediment}$) is known (Hastings 2008) and seasonal temperature variation of the speed of sound of the seawater (C_{water}) is known using the following equation:

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

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

In the Project Area, the speed of sound in the sediment is higher than in water, where it is approximated at 1500 m/s. Values for speed of sound in sediment will range from 1605 m/s in sand-silt sediment to 1750 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 stronger attenuation than sound propagating as opposed to areas with greater water depths. Figure 2 graphically presents the cut-off frequency for different bottom material types. As shown in this plot, at a water depth of 10 m and a bottom condition consisting of predominantly of fine sand, the approximate cutoff frequency would be expected to occur at approximately 100 Hz. Below this frequency, significant parts of sound energy would be cut off, and thus sound sources occurring in shallower water are subject to stronger attenuation than in the deeper regions of the ocean.



Reference: Au, W. and M. Hastings. 2008. Principles of Marine Bioacoustics. Springer Science & Business Media, New York, New York.

Figure 2. Cut-off Frequencies for Different Bottom Materials

3 REGULATORY CRITERIA AND SCIENTIFIC GUIDELINES

The potential harmful effects of high-level underwater sound can be summarized as lethal, physical injury and hearing impairment. In general, biological damage as a result of sound is either related to a large pressure change (barotrauma) or to the total quantity of sound energy received. Other ways in which sound or noise can be detrimental to the marine mammals and fish is by causing behavioral disturbance and auditory masking. A regulatory and literature review was conducted to obtain and summarize the most relevant impact criteria in order to assess the impact on marine mammals, sea turtles and fishery resources.

3.1 MMPA Thresholds for Lethal and/or Injurious Auditory Effects

Under the Marine Mammal Protection Act (MMPA), Level A harassment is statutorily defined as any act of pursuit, torment or annoyance that has the potential to injure a marine mammal or marine mammal stock in the wild. NOAA Fisheries recognizes three kinds of noises that could be potentially harassing to marine mammals: continuous, intermittent, and pulse. NOAA Fisheries defines the zone of injury as the range of received levels from 180 linear decibels (dB or dBL) referenced to 1 μPa RMS, for marine mammals. The MMPA defines Level B harassment as any act of pursuit, torment or annoyance that 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. Current thresholds established for Level B harassment are 160 dB re 1μPa from a non-continuous noise source averaged over the duration of the signal, and 120 dB re 1μPa from a continuous noise source or an intermittent non-pulse source.

These thresholds are based on a limited number of experimental studies on captive odontocetes, a limited number of controlled field studies on wild marine mammals, observations of marine mammal behavior in the wild, and inferences from studies of hearing in terrestrial mammals. In addition, marine mammal responses to sound can be highly variable, depending on the individual hearing sensitivity of the animal, the behavioral or motivational state at the time of exposure, past exposure to the noise which may have caused habituation or sensitization, demographic factors, habitat characteristics, environmental factors that affect sound transmission, and non-acoustic characteristics of the sound source, such as whether it is stationary or moving (NRC 2003).

Criteria levels consider instantaneous sound pressure levels at a given receiver location. Being expressed in RMS units, the criteria account for not only the energy of the signal, but also the length of the pulse. The NOAA Fisheries acoustic guidelines were purposely developed to be protective of all marine mammal species from high sound pressure levels and are assessed from unweighted acoustic signals, so they do not account for the different hearing abilities of marine species at different frequencies. Also, the NMFS (2005) states that such criteria have the disadvantage of not accounting for important attributes of exposure such as duration, sound frequency, or rate of repetition. A summary of the NOAA Fisheries cause and effect noise criteria are summarized in Table 2.

Table 2. Summary of NOAA Fisheries Cause and Effect Noise Criteria

	Criteria Level	Type
Level A Harassment	180 dBL re 1 μPa (RMS)	Absolute
Level B Harassment	160 re 1 μPa (RMS$_{90\%}$) 120 re 1 μPa (RMS)	Impulse Continuous
Reference: Federal Register: January 11, 2005 (Volume 70, Number 7)		

3.2 Fish Species

The hearing capabilities and sensitivities of fish vary from species to species but are believed to form three functional hearing groups, e.g., fishes with swim bladders mechanically linked to the ears, fishes with swim bladders not linked to the ears, and fishes without swim bladders. Fish species with a reduced or no swim bladder tend to have a relatively low auditory sensitivity, fish having a fully functional swim bladder tend to be more sensitive, and fish with a close coupling between the swim bladder and the inner ear are most sensitive. In addition, while some fish are sensitive to sound pressure, all fish are capable of detecting particle motion or the rate of displacement of fluid particles by acoustic pressure. The existing body of literature relating to the impacts of sound on marine species can be divided into three categories: (1) pathological, (2) physiological, and (3) behavioral. Pathological effects include lethal and sub-lethal physical damage; physiological effects include primary and secondary stress responses; and behavioral effects include changes in exhibited behaviors. Behavioral changes might be a direct reaction to a detected sound or a result of anthropogenic sound masking natural sounds that fishes make use of in their normal behavior. Risk of injury or mortality resulting from noise is generally related to the effects of rapid pressure changes, especially on gas-filled spaces in the animal’s body.

While impact pile driving activity has been linked to fish mortality, there are insufficient data to indicate the percentage of fish killed, whether some species are more susceptible to sound than others, and the distance at which fish are killed (Hastings and Popper 2005). It is possible that fish outside a designated zone of influence are damaged and that ultimately this damage would lead to death. Moreover there are numerous complicating factors with pile driving that might impact fish.

An interagency work group, including the U.S. Fish and Wildlife Service (USFWS) and the NMFS, has reviewed the best available scientific information and developed criteria for assessing the potential of pile driving activities to cause injury to fish (FHWG 2008). The workgroup established dual sound criteria for injury, measured 33 feet away from the pile, of 206 dB re 1μPa Peak and 187 dB accumulated sound exposure level (dB cSEL; re: 1μPa^2 sec) (183 dB accumulated SEL for fish less than 2 grams). While this work group is based on the U.S. West coast, species similar to Atlantic sturgeon were considered in developing this guidance (green sturgeon). As these species are biologically similar to the species being considered herein, it is reasonable to use the criteria developed by the FHWG to assess Atlantic sturgeon injury resulting from Project pile driving operations.

The NOAA Fisheries also currently recognizes a 150 dB_{RMS} re 1μPa level as the threshold for disturbance to salmon and bull trout. Based on their assessment, sound pressure levels in excess of 150 dB re 1 μPa are expected to cause temporary behavioral changes, such as elicitation of a startle response or avoidance of an area. Those levels are not expected to cause direct permanent injury. That is not to say that exposure to noise levels of 150 dB_{RMS} re 1μPa will always result in behavioral modifications, but that there is the potential, upon exposure to noise at this level, to experience some behavioral response *(e.g.,* temporary startle to avoidance of an insonified area). In summary, based on the best available information on other fish species, underwater noise at or above the presented in Table 3 have the potential to cause injury or behavioral modification to fish.

Table 3. Interim Fisheries Cause and Effect Guidelines

	Criteria Level	Type
Physiological Effects	206 dBL re 1 μPa	Absolute Peak SPL
	187 dBL re 1 $\mu Pa^2 s$	SEL_{cum}, For fishes above 2 grams (0.07 ounces)
	183 dBL re 1 $\mu Pa^2 s$	SEL_{cum}, For fishes below 2 grams (0.07 ounces)
Behavioral Effects	150 dBL re 1 μPa (RMS)	Absolute
Reference: U.S. Department of the Interior, Bureau of Ocean Energy Management (BOEM). Effects of Noise on Fish, Fisheries, and Invertebrates in the U.S. Atlantic and Arctic from Energy Industry Sound-Generating Activities, Literature Synthesis, 2012		

3.3 Sea Turtles

The hearing capabilities of sea turtles are poorly known and there is very little available information on the effects of noise on sea turtles. Some studies have demonstrated that sea turtles have fairly limited capacity to detect sound, although all results are based on a limited number of individuals and must be interpreted cautiously. Most recently, McCauley et al. (2000) noted that decibel levels of 166 dB_{RMS} re 1μPa were required before any behavioral reaction (e.g., increased swimming speed) was observed, and decibel levels above 175 dB_{RMS} re 1μPa elicited avoidance behavior of sea turtles. The study done by McCauley et al. (2000), as well as other studies done to date, used impulsive sources of noise (e.g., air gun arrays) to ascertain the underwater noise levels that produce behavioral modifications in sea turtles.

As no studies have been done to assess the effects of impulsive and continuous noise sources on sea turtles, McCauley et al.(2000) serves as the best available information on the levels of underwater noise that may produce a startle, avoidance, and/or other behavioral or physiological response in sea turtles. Based on this and the best available information, NOAA Fisheries believes any sea turtles exposed to underwater noise greater than 166 dB_{RMS} re 1µPa may experience behavioral disturbance/modification (e.g., movements away from insonified area). Table 4 summarizes the present NOAA Fisheries interim guidelines on underwater noise level which have the potential to cause injury or behavioral modification of sea turtles.

Table 4. Interim Sea Turtle Cause and Effect Guidelines

	Criteria Level	Type
Behavioral Modification	166 dBL re 1 µPa (RMS)	Absolute
Injury	207 dBL re 1 µPa (RMS)	Absolute

4 ACOUSTIC MODELING METHODOLOGY

Acoustic modeling was conducted for primary-noise generating activities occurring during Project construction and operation. The following subsections describe the modeling program used, the modeling scenarios, and acoustic model input values.

4.1 Sound Propagation Model

Acoustic modeling was completed with the widely-used the Range Dependent Acoustic Model (GeoRAM) which is based on the U.S. Navy's Standard Split-Step Fourier Parabolic Equation (PE). Since the seafloor and its properties are variable based on location, it is necessary to use a range dependent model that is programmed to account for these variations along the propagation path. GeoRAM computes acoustic fields in 3-D by modeling transmission loss along evenly distributed radial traverses covering a 360 º swath from the source (so-called N×2-D modeling). This methodology consists of a set of algorithms that calculates transmission loss based on a number of factors including the distance between the source and receiver along with basic ocean parameters (e.g., depth, bathymetry, geoacoustic properties of sediment type, and the ocean's temperature-depth sound speed profile).

GeoRAM is an extremely efficient PE code that copes naturally with range-dependent environments and overcomes the principle limitation of the PE method; lack of accuracy for energy propagating at large angles to the horizontal (Duncan and Maggi, 2006). Use of the PE method allows for a one-way wave equation that can be solved by a range-marching technique with a proper starting field (i.e., near-field underwater sound pressure level). The forward propagating field is obtained at a given range from the field at a previous range after having also accounted for boundary conditions at the top and bottom of the domain, in other words the solution (i.e., the underwater received sound pressure level) is marched in range.

GeoRAM assumes that outgoing reflected and refracted sound energy dominates scattered sound energy and computes the solution for the outgoing (one-way) wave equation. At low frequencies, the contribution of scattered energy is very small compared to the outgoing sound field. An uncoupled azimuthal approximation is used to provide gridded 2-D TL values in range and depth with a geo-referenced dataset to automatically retrieve the bathymetry and acoustic environment parameters along each propagation transect radiating from the sound source.

The received sound field within each vertical radial plane is sampled at various ranges from the source with a fixed radial step size. At each sampling range along the surface, the sound field is sampled at various depths, with the step size between samples increasing with depth below the surface. The received sound level at a given location along a given transect is taken as the maximum value that occurs over all samples within the water column below. The TL values produced by the model are used to attenuate the spectral acoustic output levels of the sound source to generate received sound levels along a transect. These values are then summed across frequencies to provide broadband received levels at the MMPA level A and B harassment criteria as well as fishery and sea turtle interim guidelines, as described Section 3.

4.2 Modeling Environment

The accuracy of underwater noise modeling results is largely dependent on the referenced sound source data and the accuracy of the intrinsically dynamic data inputs used to describe the medium between the path and receiver including sea surface conditions, water column, and sea bottom. 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. In these instances, the reliance on a simplistic geometric spreading model such as the inverse power law may be inappropriate.

4.2.1 Bathymetry

For geometrically shallow water, sound propagation is dominated by boundary effects. Bathymetry data represent the 3D nature of the subaqueous land surface and was obtained from the National Geophysical Data Center (NGDC) US Coastal Relief Model (NOAA Satellite and Information Service 2005); the horizontal resolution of this data set is 3 arc-seconds. 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 datasets, originally with a horizontal resolution of 20 m, were linearly interpolated on a regular grid. The bathymetric data was 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 both the construction and operation of the Project, with each radial centered on the given Project sound source or activity. Figure 1 presents the bathymetries within the Project Area.

4.2.2 Sediment

Sediment type (e.g., hard rock, sand, mud) directly impacts the speed of sound as it is a part of the medium in which the sound propagates. The propagation efficiency of the seabed is far less than that of the water column because the intrinsic absorption of the bottom is typically about 1,000 times that in seawater. Because of variations in water depth and in ocean bottom properties, noise in shallow water can be highly variable from one location to another. Sediment information for the Project study area was obtained from the U.S. Geological Survey (USGS) Continental Margin Mapping Program, which includes an extensive east coast sediment study. Geoacoustic properties were defined up to a maximum depth of 81 ft, which was the maximum depth of the available geological data.

The geoacoustic properties of these materials include compressional speed (cp), density (ρ), P-attenuation (αp), shear speed (cs) and S-attenuation (αs), and vary with depth (z). Bottom loss is a complex and only partly understood phenomenon. Table 5 presents order of magnitude acoustic parameters for common sediments and seafloor conditions, with the bottom type in the Project Area being predominantly sand.

Table 5. Geoacoustic Parameters for Sediments[1]

Sediment Type	M (Φ)	N (%)	P (kgm^{-3})	c_r	c(m/s)	V(0°) (dB)	αs (dB/λ)	c_3 (m/s)	Ω_0 (cm^4)	h(cm)	δ {°}
Clay	9	80	1,200	0.98	1,470	-21.8	0.08	-	5 x 10^{-4}	0.5	1.2
Silty clay	8	75	1,300	0.99	1,485	-18.0	0.10	-	5 x 10^{-4}	0.5	1.5
Clayey silt	7	70	1,500	1.01	1,515	-13.8	0.15	125	5 x 10^{-4}	0.6	1.3
Sand-silt-clay	6	65	1,600	1.04	1,560	-12.1	0.20	290	5 x 10^{-4}	0.6	2
Sand-silt	5	60	1,700	1.07	1,605	-10.7	1.00	340	5 x 10^{-4}	0.7	2.5
Silty sand	4	55	1,800	1.10	1,650	-9.7	1.10	390	1 x 10^{-3}	0.7	3
Very fine sand	3	50	1,900	1.12	1,680	-8.9	1.00	410	2 x 10^{-3}	1.0	4
Fine sand	2	45	1,950	1.15	1,725	-8.3	0.80	430	3 x 10^{-3}	1.2	5
Coarse sand	1	40	2,000	1.20	1,800	-7.7	0.90	470	7 x 10^{-3}	1.8	6
Source: Hamilton 1976, Hamilton 1982, Hamilton and Bachman 1982, APL 1994.											

4.2.3 Seasonal Sound Speed Profiles

The speed of sound in sea water depends on the temperature T [°C], salinity S [ppt], and depth D [m] and can be characterized using sound speed profiles (SSPs). The SSP of an underwater environment has a significant effect on sound attenuation. 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 predominantly present in the winter season, sound speed increases with depth and the sound is, therefore,

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[1] Hamilton, E.L. 'Compressional Waves in marine sediments', Geophysics, 37 620-646, 1982.
Hamilton, E.L. 'Geoacoustic modeling of the sea floor', Journal of the Acoustical Society of America, 68, 1313-1340, 1976.
Hamilton, E.L. and Bachman, R.T., 'Sound velocity and related properties of marine sediments', Journal of the Acoustical Society of America, 72, 1891-1904, 1982
APL, APL-UW High-Frequency Ocean Environmental Acoustic Models Handbook (APL-UW TR 9407). Seattle, WA: Applied Physics Laboratory, University of Washington, 1994.

refracted upwards, which can aid in long distance sound propagation. The construction timeframe is expected to start in May and completion by mid July. For the majority of construction modeling scenarios the May SSP (Figure 3) was chosen due to it exhibiting worst case characteristics in terms of long range propagation effects. For the wind turbine operational scenario, the February SSP (Figure 4) was considered worst case on an annual basis, with May temperatures colder at the bottom and February temperatures colder at the surface, as shown on the corresponding plots.

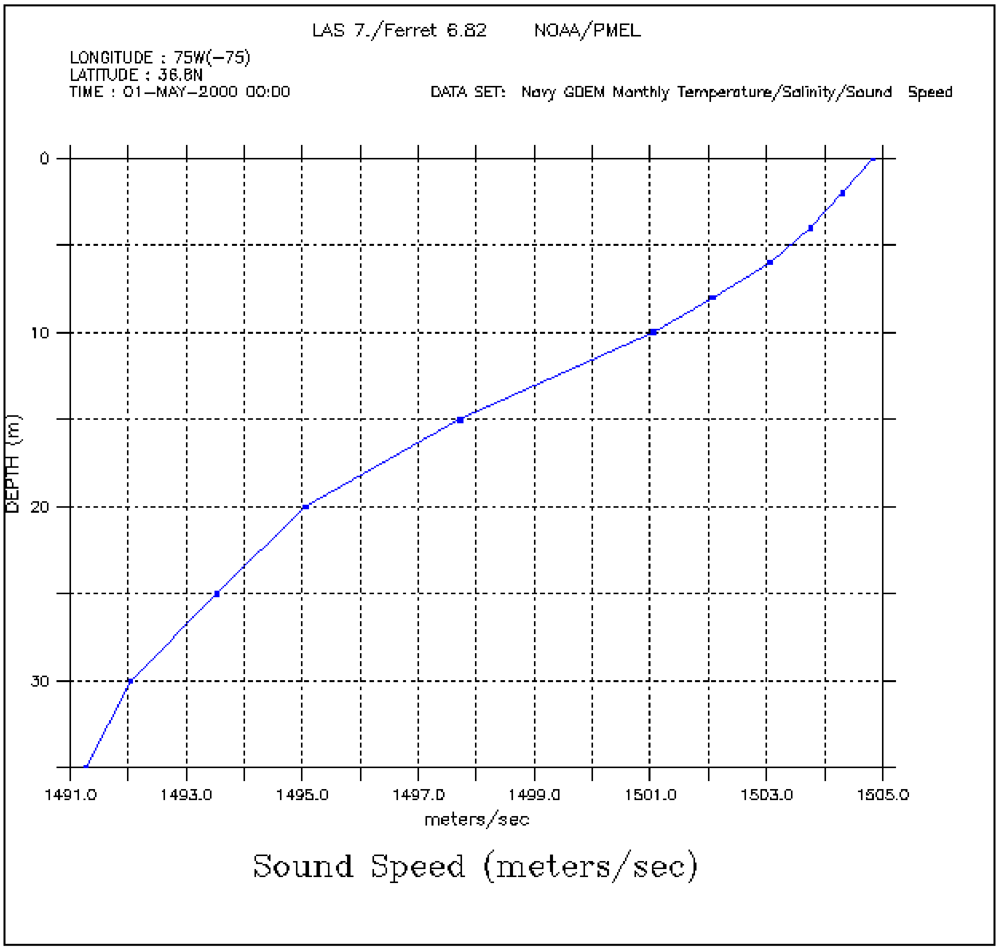

Figure 3. Average May Sound Speed Profile as a Function of Depth

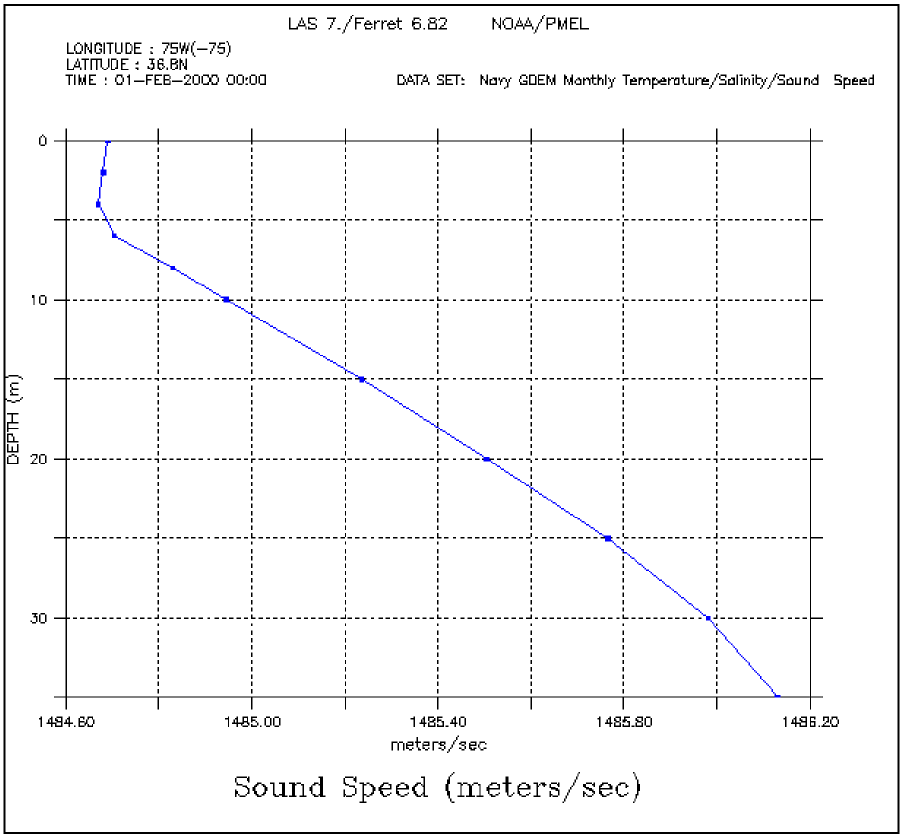

Figure 4. Average February Sound Speed Profile as a Function of Depth

4.3 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 subsections that follow provide more detailed information about the parameters used to model the noise sources associated with each scenario. Sound source level data were unavailable for several vessels and activities identified at the time of writing. Therefore, a literature review was conducted in order to identify source level measurements from comparable equipment performing similar activities. Proxy source levels for each of the modeling scenarios presented in this report were derived from literature, engineering guidelines, and underwater source measurements of similar equipment and activities. Actual source levels may vary and will be validated by Dominion during future construction and operation of the Project.

The following four modeling scenarios were considered in the current study:

- Scenario 1: Dynamic Positioning (DP) thruster use during cable lay operations
- Scenario 2: Vessel activities associated with WTG installation
- Scenario 3: Impact pile driving during wind turbine foundation installation
- Scenario 4: Wind turbine operation

Reasonable and appropriate source level information was derived for wind turbine operation, impact pile driving, cable lay operations and DP vessels expected to be used in support of the WTG installations. The source level descriptions and source depth assumptions are key inputs to the acoustic propagation model. The source level is stated as a spectral level as a function of frequency – e.g. in one-third octave bands and summed as an overall broadband level. The level of an acoustic source is a measure of the acoustic output of that source. It is related to the radiant intensity and acoustic power of the source, but it is rarely described in these terms. By convention in the United States, underwater acoustic source levels are defined as the acoustic pressure at 1m distance from idealized point source, i.e. dB re 1 μPa at 1m by extrapolating back to a reference range of one meter from the source using a version of the simplified free field modeling (see Section 2.1). Most European nations have generally opted for a less error prone strategy of stating the level at the given measurement distance from the source, or a normalized distance for comparative purposes. Extrapolating back to 1 meter, as is done for many of the early US data to derive an apparent sound source level, is particularly prone to error due to the fact that the assumptions used in this derivation are not typically stated. However, since most of the data from proxy sources are derived in this way, this format has been maintained here, with the calculation of the apparent source normalized to the VOWTAP project site based on far-field measurements. A summary of apparent source levels incorporated into the underwater acoustic modeling analysis is provided in Table 6.

Table 6 Apparent Sound Source Levels (dB re 1 μPa)

Frequency (Hz)	Impact Pile Driver 60 kJ / 600 kJ Force 1.4 m pile	Impact Pile Driver 100 kJ /1000 kJ Force 2.4 m pile	WTG Installation Vessels	Cable Lay Operations	Operational Wind Turbine
12.5	175 / 186	181 / 193	167	159	-
16	174 / 185	180 / 192	167	159	127
20	174 / 185	180 / 192	167	159	126
25	176 / 187	182 / 194	167	159	128
31.25	176 / 188	182 / 194	167	159	135
40	175 / 186	182 / 193	167	159	130
50	178 / 189	184 / 196	167	159	144
62.5	183 / 195	189 / 202	167	159	140
80	181 / 193	188 / 200	167	159	130
100	184 / 196	199 / 203	167	159	132
125	196 / 209	203 / 216	168	160	134
160	193 / 206	200 / 213	170	161	146
200	198 / 211	205 / 218	171	163	143
250	201 / 214	208 / 221	172	163	132
315	197 / 210	204 / 217	173	164	127
400	196 / 209	203 / 216	174	165	131
500	196 / 208	203 / 215	174	165	136
630	196 / 209	203 / 216	174	166	134
800	194 / 207	201 / 214	175	166	134
1000	193 / 206	200 / 212	175	166	129
1250	191 / 204	198 / 210	175	166	127
1600	186 / 198	193 / 205	174	165	-
2000	183 / 196	190 / 202	174	165	-
2500	183 / 195	189 / 202	174	165	-
3150	181 / 193	187 / 199	173	164	-
4000	179 / 191	186 / 197	173	164	-

Table 6 Apparent Sound Source Levels (dB re 1 µPa) (continued)

Frequency (Hz)	Impact Pile Driver 60 kJ / 600 kJ Force 1.4 m pile	Impact Pile Driver 100 kJ /1000 kJ Force 2.4 m pile	WTG Installation Vessels	Cable Lay Operations	Operational Wind Turbine
5000	175 / 186	181 / 193	167	159	-
6300	174 / 185	180 / 192	167	159	-
8000	174 / 185	180 / 192	167	159	-
10000	175 / 186	181 / 193	167	159	-
12000	175 / 181	181 / 193	167	159	-
16000	175 / 186	181 / 193	167	159	-
20000	178 / 189	188 / 200	167	159	-
Broadband Summation	207 / 220	214 / 227	186	177	151

4.3.1 Cable Lay Operations

Specialist vessels specifically designed for laying and burying cables on the seabed will be used. The cable will be buried along the cable route by the use of a jet plow. Throughout 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. Contractors have not yet been identified for Project construction; therefore, data on any vessel specific thrusters is not available at this time. The sound source level assumption employed in the underwater acoustic analysis was 177 dBL re 1 µPa at 1 meter and a vessel draft of 2.5 meters for placing source depth. For the purposes of the underwater acoustic modeling analysis it was assumed that cable laying activities will be continuous and may occur on a 24-hour schedule. Table 6 provides octave band spectrum data for the modeled DP vessel to describe frequency characteristics. Thruster noise is generated by cavitation and has a relatively flat spectrum shape due to the large number of random bursts caused by various sized bubbles collapsing. The discrete spectral "blade rate" component occurs at multiples of the rate at which any irregularity in the flow pattern or in the impeller itself is intercepted by the impeller blades (Fischer 2000).

4.3.2 WTG Installation

Supply and service vessels (tugboats, barges, etc.) of various sizes will operate in proximity to the wind turbine installation site, many of which are equipped with thrusters. Thrusters are propellers located below the water line and may either be mounted in tunnels running crosswise through the vessel's hull or hung below the vessel's hull. Thrusters can generate elevated underwater noise and are used intermittently for anchor handling and maneuvering. Broadband linear source values were estimated to range from 177 to 183 dB re 1 µPa assuming full engine loads occurring during short term pushing or pulling operations. For the purposes of providing the acoustic modeling analysis, the apparent sound source level was adjusted up to 186 dB re 1µPa at 1m to account for cumulative effects of multiple support vessels facilitating the wind turbine installation activities.

4.3.3 Pile Driving

In most cases, foundations for massive offshore structures such as wind turbines are formed by driving piles into the seabed with hydraulic hammers. Predicting underwater noise levels during offshore pile driving is therefore of great interest to installation contractors who must comply with stringent noise emission thresholds. The VOWTAP Inward Battered Guide Structure (IBGS) structure will have three 1.4 m diameter inward battered piles of similar length to that of a four legged jacket. It will also have a 2.4 m caisson which is of much shorter length. Impact pile driving will be needed to secure the piles and it has been assumed that only one pile will be driven at a time.

Impact pile driving involves weight hammers that pile into the seafloor. Different methods for lifting the weight include hydraulic, steam or diesel. The acoustic energy is created upon impact; 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 travelling 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, travelling through the ground and radiating back into the water. Near the pile, acoustic energy arrives from different paths with different associated phase and time lags which creates a pattern of destructive and constructive interference. Further away from the pile, the water and seafloor borne energy are the dominant pathways. The underwater noise generated by a pile-driving strike depends primarily on the following factors:

1. The impact energy and type of pile driving hammer,
2. The size and type of the pile
3. Water depth, and
4. Subsurface hardness in which the pile is being driven.

The acoustic energy radiated into the aquatic environment by a struck pile is directly correlated to the kinetic energy that the impact hammer imparts to it. Engineering considerations about pile penetration and load bearing capacity dictate that the impact hammer energy must be matched to the pile and to the resistance of the underlying substrate (Parola 1970). Greater hammer impact energy is required for larger diameter piles to achieve the desired load bearing capacity. The water depth also has a strong influence. As more of the surface area is exposed at deeper depths, a greater percentage of sound energy is introduced into the aquatic environment.

Tables 7a and 7b presents underwater sound measurement data collected for impact pile driving of cylindrical steel piles with similar diameter, water column depths, seafloor characteristics, and impact forces, in the context of an offshore oceanic environment. Table 7a reports measurement results for piles sizes ranging from 1 to 2 meters and Table 7b from 2 to 4 meters in diameter. Research has shown that that the noise level increases by 13 $\log_{10}(E_2/E_1)$ as the blow energy is increased from E_1 to E_2 (Schultz-von et al. 2006; Stephen P. Robinson et al. 2007). The normalization methodology also accounts for variations in depth and distance and is described by the following equation for the expected maximum impact force necessary to seat the 1.4 meter diameter pile:

$$L_{normalized} = L_{measured} + 10\log_{10}\left(\frac{25}{H_1}\right) + 15\log_{10}\left(\frac{R_1}{500}\right) + 13\log_{10}\left(\frac{600}{E_1}\right)$$

Where: L = sound pressure level
H_1= depth at which the original pile driving measurement was completed
R_1 = distance at which the original measurement was taken
E_1 = impact hammer force for the original measurement
E_2 = estimated maximum hammer force 600 kJ (1.4 meter diameter raked piles)

The last three columns of Table 7a and 7b presents the key sound metrics that are used in the determination of biological significance, normalized to a distance of 500 meters including the one second sound exposure level (SEL) and the instantaneous 90 percent root mean square sound level ($RMS_{90\%}$). Pile driving sound is characterized as impulsive, which has somewhat unique features in comparison to other sounds. Impulsive sounds can have moderate average, but very high instantaneous pressure peaks, which might be harmful to the auditory system. For the purposes of assessing compliance with the NOAA Fisheries cause and effect for impulsive sound, the reporting of sound generated during impact pile driving must employ a RMS sound pressure “averaged over the duration of the pulse”. A typical pile driving impulse lasts approximately 125 milliseconds with principal energy contained within the first 30 to 40 milliseconds. The measured peak sound level represents the maximum of these high instantaneous pressure peaks. An integration period (T90) of the RMS signal inclusive of 90 percent of the sound energy has been calculated to result in a net 9 dBL increase relative to the reported SEL values shown in Table 7, when approximated as a 3 dB increase of each halving of the 1-second SEL signal duration. This semi-empirical relationship between SEL and $RMS_{90\%}$ is expected to hold for relatively short ranges; however, at increasing ranges from the source, distortion of the pulse duration will occur, especially in shallow water environments similar to that of the Project Area. For the one to two meter diameter piles, the normalized $RMS_{90\%}$ range from 177 to 182 dB re 1µPa at a distance of 500 meters at a maximum expected impact force of 600 kJ. For the two to four diameter piles and a higher impact force of 1000 kJ, the normalized $RMS_{90\%}$ range from 185 to 190 dB re 1µPa at a distance of 500 meters.

The SEL is the level of a sound energy averaged over a stated 1-second duration with the same sound energy as occurring at the during the pressure pulse. The SEL may be more appropriate for assessing masking effects at larger distances from the source and is used in assessing a cumulative sound exposure (cSEL). For the one to two meter diameter piles, the normalized SELs range from 168 to 173 dB re 1µPa at a distance of 500 meters at a maximum expected impact force of 600 kJ. For the two to four diameter piles requiring a higher impact force of 1000 kJ, the normalized SELs range from 176 to 181 dB re 1µPa at a distance of 500 meters. If the strikes are all equal force, the cSEL can be computed from the single-strike SEL based on the total number of strikes using the following equation:

Cumulative SEL (cSEL) = Received SEL + 10 * log(# number of strokes)

That is, the cSEL increases by 10 dB with every tenfold increase of the number of strikes. In actuality, the pile driving would initially start at the lower range of impact force, and ramp up to a maximum impact force to reach final design penetration and seat the piles. To be conservative in the calculation of the cSEL, the Project has assumed this maximum impact force would occur over the full piling sequence.

Table 7a. Normalized Underwater Pile Driving Measurement Results for 1 to 2 Meter Diameter Piles

Measurement Site	Pile Diameter m	Measured Depth H1 m	Measured Distance R1 m	Impact Energy E1 kJ	MEASURED SPLs dB re 1 µPa			SEL re 1 µPa^{2}s NORMALIZED TO 500 m		RMS$_{90\%}$ re 1 µPa NORMALIZED TO 500 m	
					PEAK re 1 µPa	SEL re 1 µPa^{2}s	RMS$_{90\%}$ re 1 µPa	Impact Force 60 kJ	Impact Force 600 kJ	Impact Force 60 kJ	Impact Force 600kJ
Jade Port Construction Works, Germany, 2005	0.9	11.0	340	135	188	162	171*	158	171	167	180
Jade Port Construction Works, Germany, 2005	1.0	11.0	340	135	190	164	173*	160	173	169	182
FINO 1, Germany, 2003	1.6	30.0	400	140	192	162	171*	155	168	164	177
Moray Firth, Scotland, 2010	1.8	44	100	200	187	166	176*	159	172	169	182
Cape Wind MDCF, 2002	1.0	13.5	500	200	n/a	161	170	157	170	166	179

* Data reported in terms of SEL only. RMS$_{90\%}$ values estimated assuming a 125 millisecond pulse.

Table 7b. Normalized Underwater Pile Driving Measurement Results for 2 to 4 Meter Diameter Piles

Measurement Site	Pile Diameter m	Measured Depth H1 m	Measured Distance R1 m	Impact Energy E1 kJ	MEASURED SPLs dB re 1 µPa			SEL re 1 µPa^{2}s NORMALIZED TO 500 m		RMS$_{90\%}$ re 1 µPa NORMALIZED TO 500 m	
					PEAK re 1 µPa	SEL re 1 µPa^{2}s	RMS$_{90\%}$ re 1 µPa	Impact Force 100 kJ	Impact Force 1000 kJ	Impact Force 100 kJ	Impact Force 1000 kJ
Alpha Ventus, 2008	2.7	28.0	1100	250	197	167	176*	166	179	175	188
Utgrunden, 2000	3.0	10.0	720	250	n/a	166	175*	167	180	176	189
SKY 2000, Germany, 2002	3.0	21.0	260	200	196	170	179*	163	176	172	185
FINO 2, Germany, 2006	3.3	24.0	530	300	190	170	179*	164	177	173	186
Amrumbank West, Germany, 2005	3.5	23.0	850	550	196	174	183*	168	181	177	190

* Data reported in terms of SEL only. RMS$_{90\%}$ values estimated assuming a 125 millisecond pulse.

4.3.4 WTG Operation

When the WTGs 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). There is a limited amount of published data on wind turbines of this size with the IBGS type foundation. The wind turbine project Alpha Ventus in Germany was chosen as a proxy source with measurement data at varying distances presented in Table 8.

Table 8. Summary of Offshore WTG Underwater Sound Measurement Data of Similar Foundation Type

Measurement Site	Foundation	Power Rating (MW)	Depth (m)	Distance from WTG (m)	SPLRMS re 1 µPa
Alpha Ventus	Jacketed	5	30	800	105
Alpha Ventus	Jacketed	5	30	100	118
Alpha Ventus	Jacketed	5	30	75 - 135	127

A review of other published studies indicate 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 may range up to 153 dB re 1µPa at 1m (Nedwell et al. 2004), which is slightly higher when compared to normalized measurements results as documented by the Alpha Ventus Project with the jacketed type foundation. Similar measurements by Nedwell indicate that the steady state background in an offshore oceanic environment ocean 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.

5 ACOUSTIC MODELING RESULTS

By employing field verified underwater measurement data, resultant sound levels are representative of vessels and equipment that are likely to be employed during Project activities. Acoustic modeling algorithms were applied to estimate received sound levels from various Project construction and operational phases to determine distances at biologically significant threshold levels as defined by NOAA Fisheries. Analysis methods accounted for the Project's shallow water environment, considering both spatial and seasonal factors in conjunction with estimations of source levels. This is a recommended approach for underwater acoustic modeling of effects on marine mammals and aquatic life, and the model results closely fit underwater sound measurements from the existing wind farms and sites with similar water depths to that for this Project. The modeling methodologies were presented and accepted by NOAA Fisheries in a meeting conducted on October 31, 2013.

Acoustic modeling was conducted for the scenarios described in Section 4.3 and the results of those analyses are presented in the subsequent subsections. The results of the hydroacoustic modeling calculations are presented in two different formats. Table 9 presents a summary of the critical distances to

NOAA Fisheries threshold values. Maximum distances to harassment thresholds will be used as a conservative approach to determine zones of influence for marine mammal, sea turtle, and fish species. The critical distances to the MMPA criteria and interim sea turtle and fisheries resources are also visually displayed in Attachment A on georeferenced bathymetry mapping along each major directional transect from the sound source being evaluated and provides key information in determining potential zones of impact during Project activities. These data may be used to estimate how many marine mammals and other species of concern would receive a specified amount of sound energy in a given time period and for use in developing monitoring and/or mitigation programs, as necessary. The results are not inclusive of the existing acoustic underwater ambient noise conditions.

Table 9. Distances to MMPA Thresholds and Interim Guideline for Sea Turtles and Fish Species

Regulatory Threshold	Criteria Level	Pile Driving 1.4 meter pile 60 kJ / 600 kJ	Pile Driving 2.4 meter pile 100 kJ / 1000 kJ	Cable Lay Operations	Wind Turbine Installation	Operational WTGs
Marine Mammal Level A Harassment	180 dBL re 1 μPa (RMS)	32 m / 625m	140 m / 0.9 to 1.7 km	-	-	-
Marine Mammal Level B Harassment	160 dBL re 1 μPa (RMS_{90})	0.9 to 1.7 km / 3 to 7.2 km	1.8 to 3.4 km / 5.6 to 12.2 km	5m or less	20m or less	-
Marine Mammal Level B Harassment	120 dBL re 1 μPa (RMS)	11.7 to 34 km / 15 to 64 km	13 to 47 km / 17.5 to 89.5 km	1.4 to 3.2 km	5.6 km to 13.5 km	100m or less
Sea Turtle Injury	207 dBL re 1 μPa (RMS)	5m or less /	5 m or less / 15m or less	-	-	-
Sea Turtle Behavioral Modification	166 dBL re 1 μPa (RMS)	400 to 650 m / 1.8 to 3.4 km	1.4 to 2.8 km / 3 to 8.2 km	-	10m or less	-
Fish Behavioral Modification	150 dBL re 1 μPa (RMS)	2.2 to 5.1 km / 5.9 to 13.5 km	3.5 to 9.3 km / 9.1 to 17.7 km	20m or less	100 m or less	-

5.1 Cable Lay Operations

The use of DP thrusters and trenching activities were modeled at four locations along the cable lay route. The locations were chosen to provide analysis on different water depths and bathymetry profiles affect the area of impact. Cable lay procedures and DP thrusters were modeled to determine the distances to assess the potential for adverse impacts to aquatic life. For the Level A Harassment marine mammal 180 dB_{RMS} threshold and the 166 dB_{RMS} behavioral for sea turtles, it was concluded that the distance will be negligible.

The distances to the 150 dB_{RMS} behavior threshold for the fish would range be 20 meters or less from a DP vessel with thrusters operating at full power. The variation of these distances is due to changing bathymetries and water depths present at the four different cable lay positions reviewed. Additionally, if we assume that the a fish remains near the construction area, and that the vessels operate for a continuous 24-hour period, then the distance to the fisheries interim guideline of 187 dB cSEL accumulated sound exposure level ranges from 125 to 300 meters. However, this assumes that the fish species would remain within the insonified zone in proximity to the DP vessel resulting in a continuous exposure. The real-time received noise that could potentially result in a cumulative exposure of 187 dB re 1µPa cSEL is approximately equivalent to 1-sescond SEL of 137 dB_{RMS} for 24 hours, well below the known threshold for physiological effects for fish of 206 dB re 1µPa Peak or even a potential behavioral impacts for fish species which has been established at 150 dB re 1µPa dB RMS.

5.2 Wind Turbine Installation

Vessels associated with WTG installation were also evaluated in terms of potential impacts to marine species. For the marine mammal 180 dB_{RMS} threshold, distances will be no more than one meter from the vessel. Therefore, the distance to the 166 dB_{RMS} physiological effect for sea turtles will be even closer to the vessel. Noise impacts to distances further out will vary based on differences in the bathymetry.

For the screening level analysis, the distances to the 150 dB_{RMS} behavior limit for fish would be between 100 meters or less. Additionally, if we assume that the a fish remains near the construction area, and that multiple thrusters are continually in use over a 24-hour period, then the distance reached for the 187 dB cSEL accumulated sound exposure level would be 1.6 kilometers. However, at this worst case distance and assuming continuous exposure of a stationary fish, the real-time received noise that would potentially result in a cumulative exceedances of 187 dB cSEL are approximately equivalent to 1-sescond SEL of 137 to 138 dB_{RMS}, well below the known thresholds which cause physiological or even a potential behavioral impacts for fish.

5.3 Pile Driving

Pile driving activities will occur during daylight hours starting approximately 30 minutes after dawn and 30 ending minute prior to dusk unless a situation arises where ceasing the pile driving activity would compromise safety (both human health and environmental) and/or the integrity of the Project. Each foundation is anticipated to require up to 7 days to complete the installation.

A soft-start procedure of at least 30 minutes, will be used starting at 60 kJ (1.4 meter raked piles) and 100 kJ (2.4 meter center caisson pile). This procedure will reduce the initial range over which instantaneous injury may occur and be effective in deterring aquatic life to a safe distance before the full energy piling is reached. Impact pile driving included the analysis for the maximum 600 kJ (1.4 meter raked piles) and 1000 kJ (2.4 meter center caisson pile) impact forces, thereby describing the full range of sound levels expected to be experienced throughout an entire piling sequence. The resultant distances to the Level B Harassment of marine mammals threshold of 160 dB_{RMS90} threshold is ranges from 0.9 km and 7.2 km for the rake piles and 1.8 km and 12.2 km for the center caisson pile. The distance to the 166dB_{RMS} threshold will be even closer to the construction area ranging from 0.4 km to 3.4 km for the rake piles and 1.4 km to 8.2 km for the center caisson pile. The variation in distance to thresholds is mostly due to changes in bathymetry and impact force.

The calculation of cSEL only considers the noise dose received from a single pile installation, the increased dose from all three inward battered piles and the center caisson of the IBGS foundation would not be significant assuming that the animal swims away. Given the zone over which piling is expected to occur, the movement of the marine mammal or sea turtle away from the source of noise should be sufficient to minimize the risk of auditory injury during longer installation operations. Hearing recovery time would be expected during significant gaps in piling. The 12 hour period represents the daylight time window that pile driving is in operation and accounts for overnight recovery time for the fish during the day after pile driving has stopped. The distances to the 150 dB_{RMS} limit for fisheries resources are 2.2 km to 5.1 km for the initial 60 kJ impact force and up to 5.9 km to 13.5 km for the worst case 600 kJ impact force. For the larger center caisson pile, the distances to the 150 dB_{RMS} limit are 3.5 km to 9.3 km for the initial 100 kJ impact force and up to 9.1 km to 17.7 km for the maximum expected impact force necessary to seat the pile at 1000 kJ.

To evaluate the 187 dB accumulated sound exposure level, it is assumed that the that the fish remain stationary. To achieve the necessary penetration depth, the pile driving will requir an estimated 2000 blows per pile for the rake piles and 500 strikes for the larger diameter caisson pile. The lower number of strikes for the caisson pile is due to the fact that the target depth is approximately 20 meters to reach full penetration into the sea bed, yielding a shorter duration of pile hammering, as compared with the longer raked piles.

The resulting distance for determining the accumulated 187 dB cSEL is 1.7 km to 10.0 km for the rake piles and 1.7 km to 12.1 km for the center caisson pile. However, at this worst case distance and assuming continuous exposure at maximum impact force, the real-time received noise levels that would potentially result a cumulative exceedances of the 187 dB cSEL are approximately equivalent to a 1-second SEL of 153 to 154 $dB_{RMS,}$ for the pile and 160 and 161dB_{RMS} for the center caisson. At these distances, the received sound levels are below established thresholds of 206 dB re 1µPa Peak, which may cause physiological effects for fish, but may result in short term behavioral changes.

5.4 Wind Turbine Operation

Possible noise from the operation of the wind farm has also been modeled based on actual measurement data and shows that noise levels within the boundary of the Project are not likely to be significantly above ambient noise, but may increase the ambient noise slightly during periods of calm seas and low shipping traffic. It should be noted that a major contribution to the ambient noise would result from sea-state, which would be expected to increase as the turbines rotational speed increases with wind speed.

Acoustic modeling of underwater operational sound was performed for the design wind condition during normal operations. The predicted sound level from operation of a wind turbine has been estimated at only 130 dBL at 20 m from the wind turbine foundation and attenuates to the 120 dB re 1 µPa threshold level at a relatively short distance of 100 m. These levels are very close to the expected regularly reoccurring ambient noise levels. The VOWTAP WTGs are located approximately 3,450 ft (1,050 m) apart from one another; so no cumulative effects above 120 dB_{RMS} re 1 µPa threshold will occur.

The operational effects of the Project are anticipated to be minimal, with no adverse effect to marine mammals and aquatic life. Underwater noise levels in this range may be perceptible to marine mammals that swim close to an operating wind turbine, but would not likely adversely affect them or their prey. Although the effect on fish response is more difficult to establish given the lack of information available in the scientific literature, there is indicative evidence that fish would be unlikely to show significant avoidance to the noise levels radiating from the turbine and received sound levels will be below the 150 dB_{RMS} behavioral threshold set for listed species. Vessels servicing the Project site will produce underwater sounds typical of existing vessel traffic in the area; therefore, the Project poses no unique or special risk to marine life.

To evaluate the 187 dB accumulated sound exposure level, a 24 hour wind of operation was assumed and that the fish remain stationary. The distance for measuring the accumulated 187 dB cSEL is less than 5 meters. However, at this worst case distance and assuming continuous exposure, the real-time received noise levels that would potentially result in a cumulative exceedance of the 187 dB cSEL are approximately equivalent to a 1-second SEL of 137 to 138 dB_{RMS} , well below the threshold level to cause a physiological or even a potential behavioral response for fish species.

6 CONCLUSION

Underwater sound levels produced during Project construction are not expected to be of sufficient duration to cause long term effects on marine mammals, sea turtles and fisheries within the Project Area. Temporary avoidance behavior from Project related noise and vessel activity is likely to occur during the construction period. In addition, the implementation of mitigation and monitoring techniques such as observation of time-of-year windows, the use of protected species observers during project construction activities that are known to generate high-intensity sound levels, and the establishment of exclusion and monitoring zones as well as ramp-up and shut-down procedures for noise producing equipment have proven to minimize impacts on marine species should they occur in the Project Area. Monitoring of the area within the proposed safety exclusion zone effectively eliminates the potential for harassment, injurious, or lethal takes of marine mammal and sea turtle species. In addition, Dominion will conduct field verifications of actual impact pile driving and DP vessel thruster noise during installation of the VOWTAP IBGS foundations, and the Inter-Array and Export Cables for model validation purposes.

The assessment of underwater noise levels associated with the operation of the VOWTAP WTGs are also expected to be too low to cause injury to marine species; however there are limited data on impact thresholds for fish and other marine species exposed to continuous noise. As part of the goal of this demonstration project, underwater noise will be monitored and observed during a 2-week real-time monitoring period to collect data on the full range of wind turbine operational conditions and wind speeds.

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Attachment A – Figures

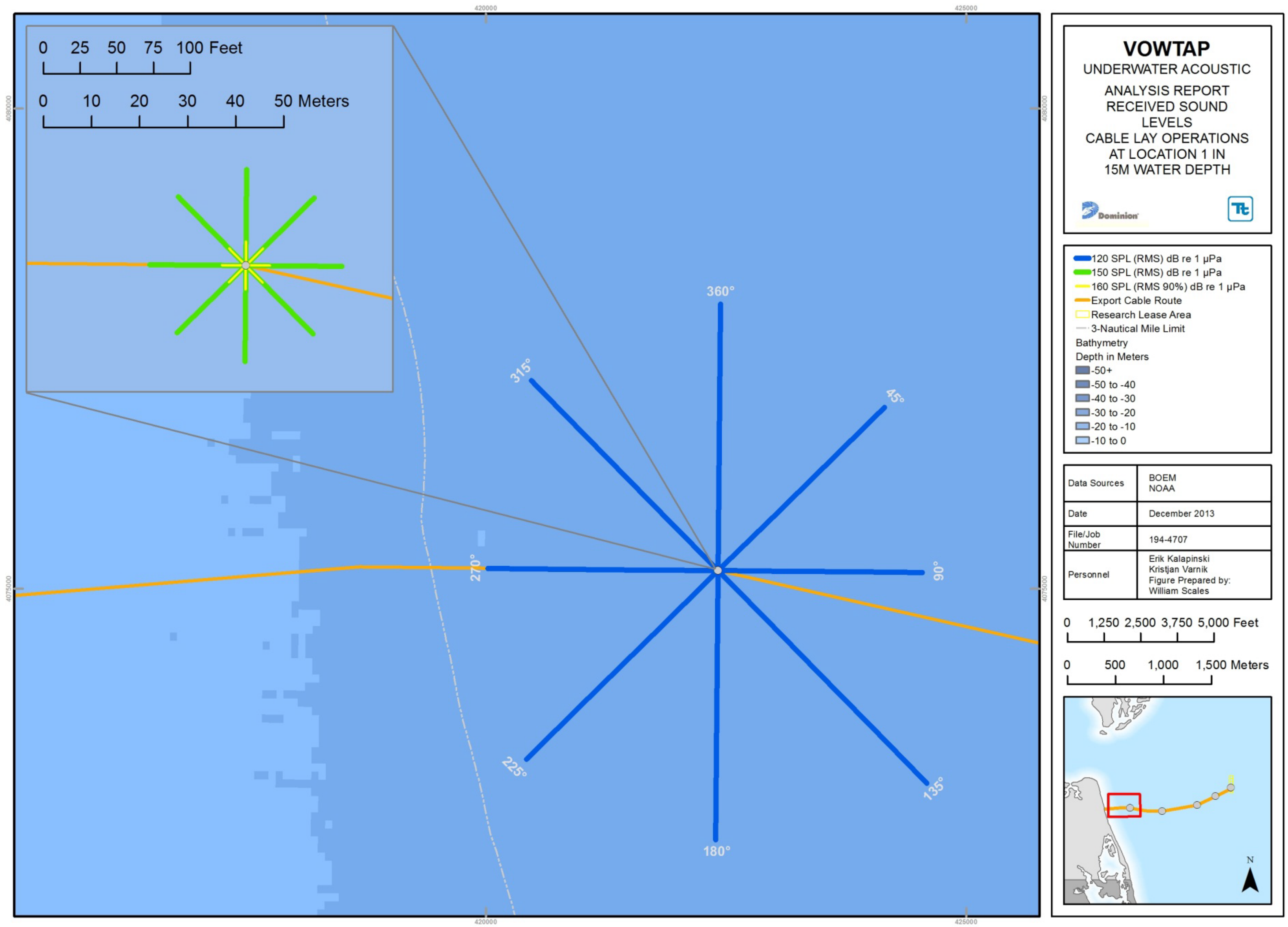


Figure A-1. Received Sound Levels, Cable Lay Operations at Location 1 in 15m water depth

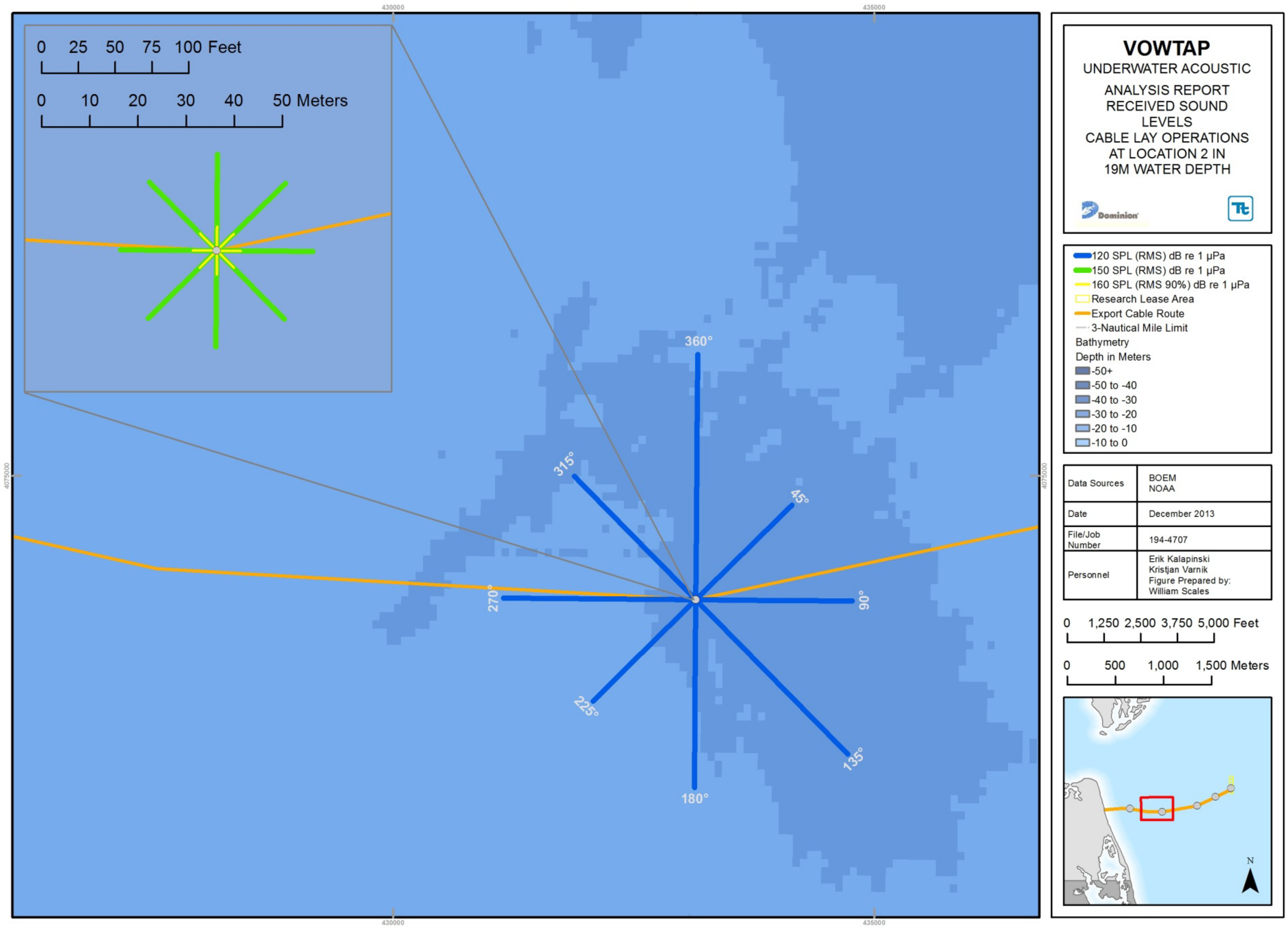
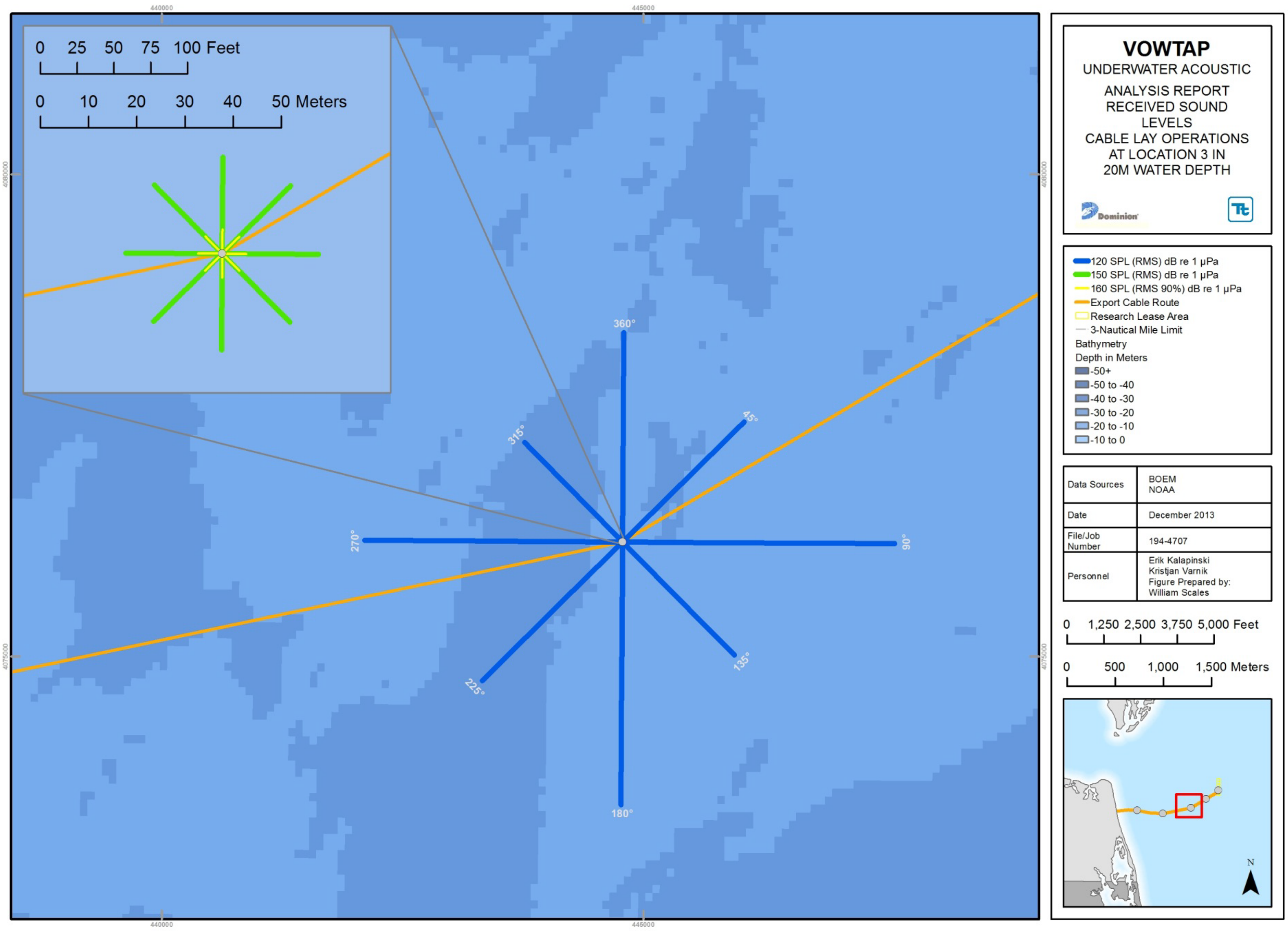


Figure A-2. Received Sound Levels, Cable Lay Operations at Location 2 in 19m water depth



Data Sources	BOEM NOAA
Date	December 2013
File/Job Number	194-4707
Personnel	Erik Kalapinski Kristjan Varnik Figure Prepared by: William Scales

Figure A-3. Received Sound Levels, Cable Lay Operations at Location 3 in 20m water depth

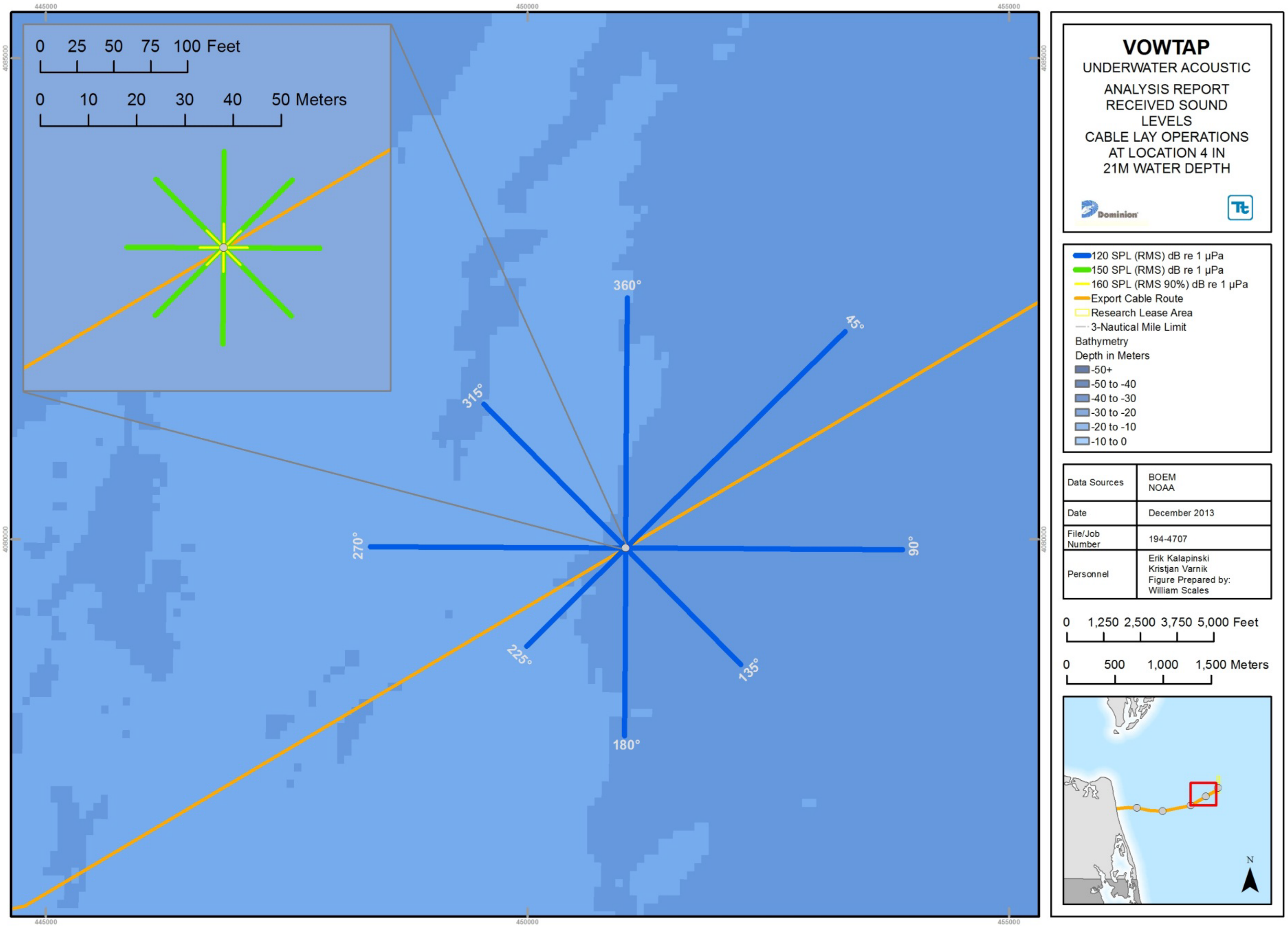
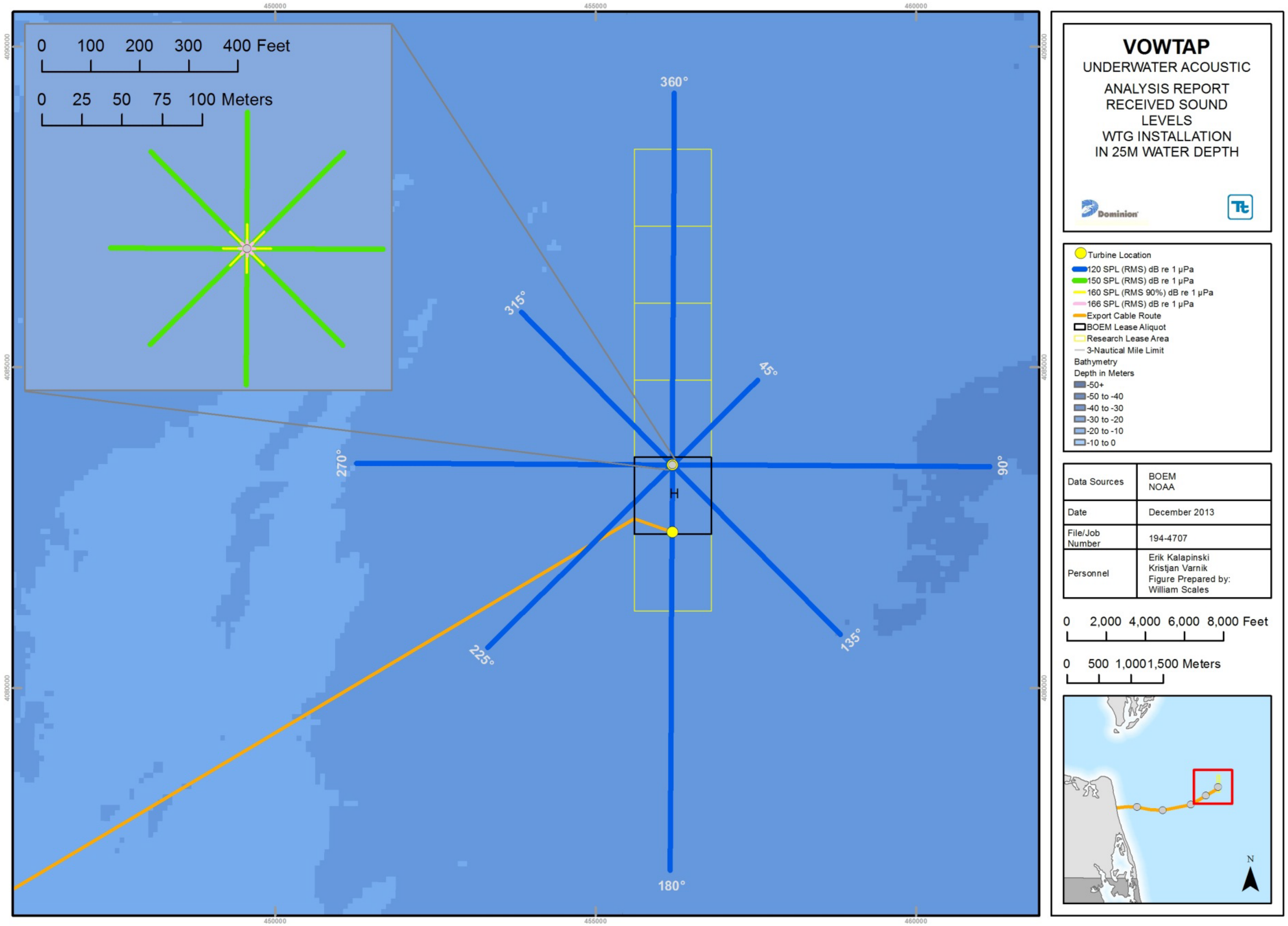


Figure A-4. Received Sound Levels, Cable Lay Operations at Location 4 in 21m water depth



Data Sources	BOEM NOAA
Date	December 2013
File/Job Number	194-4707
Personnel	Erik Kalapinski Kristjan Varnik Figure Prepared by: William Scales

Figure A-5. Received Sound Levels, Wind Turbine Installation at Project Site in 25m water depth

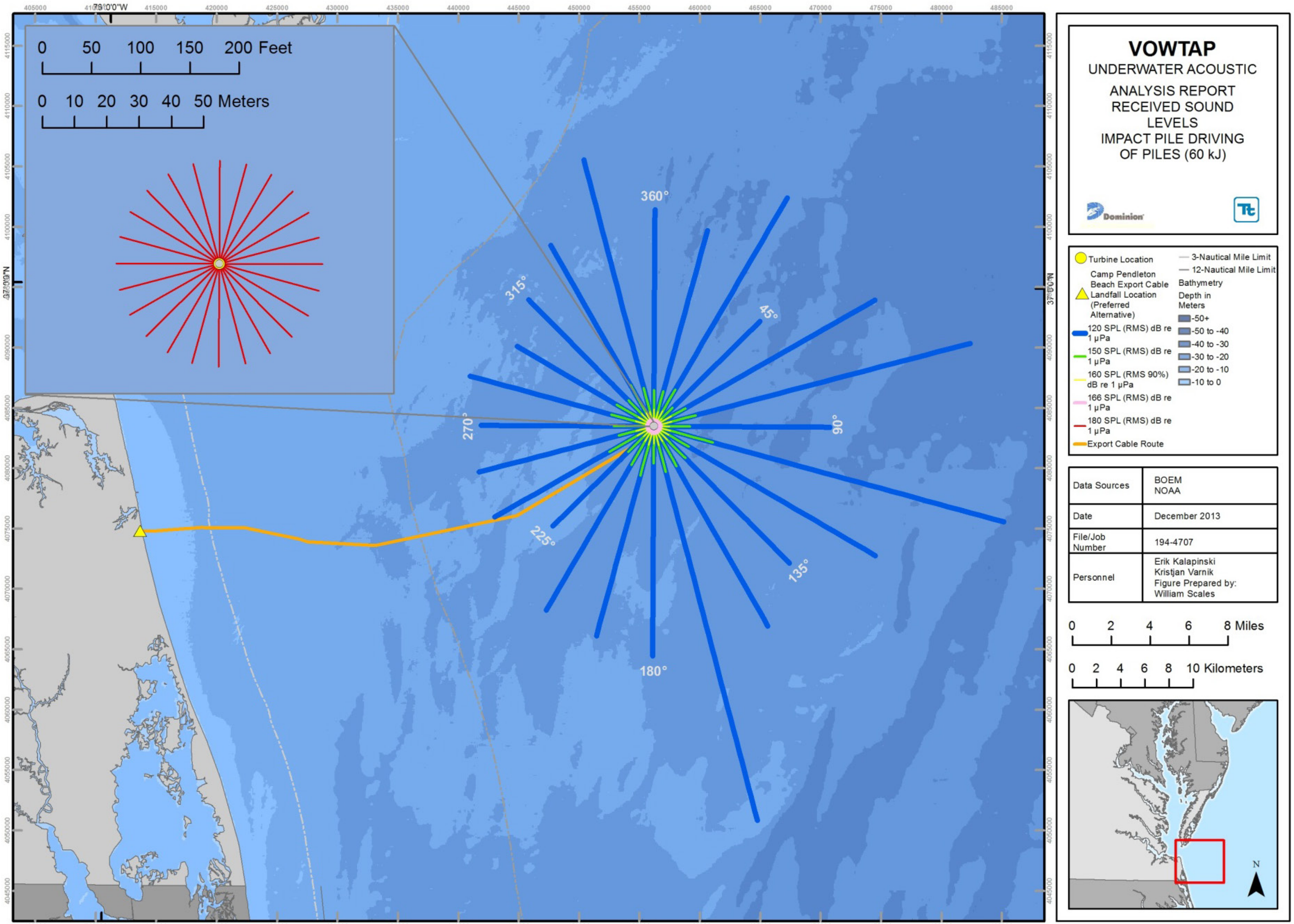


Figure A-6. **Received Sound Levels, Impact Pile Driving of 1.4 Meter Diameter Raked Pile during Soft Start (60 kJ)**

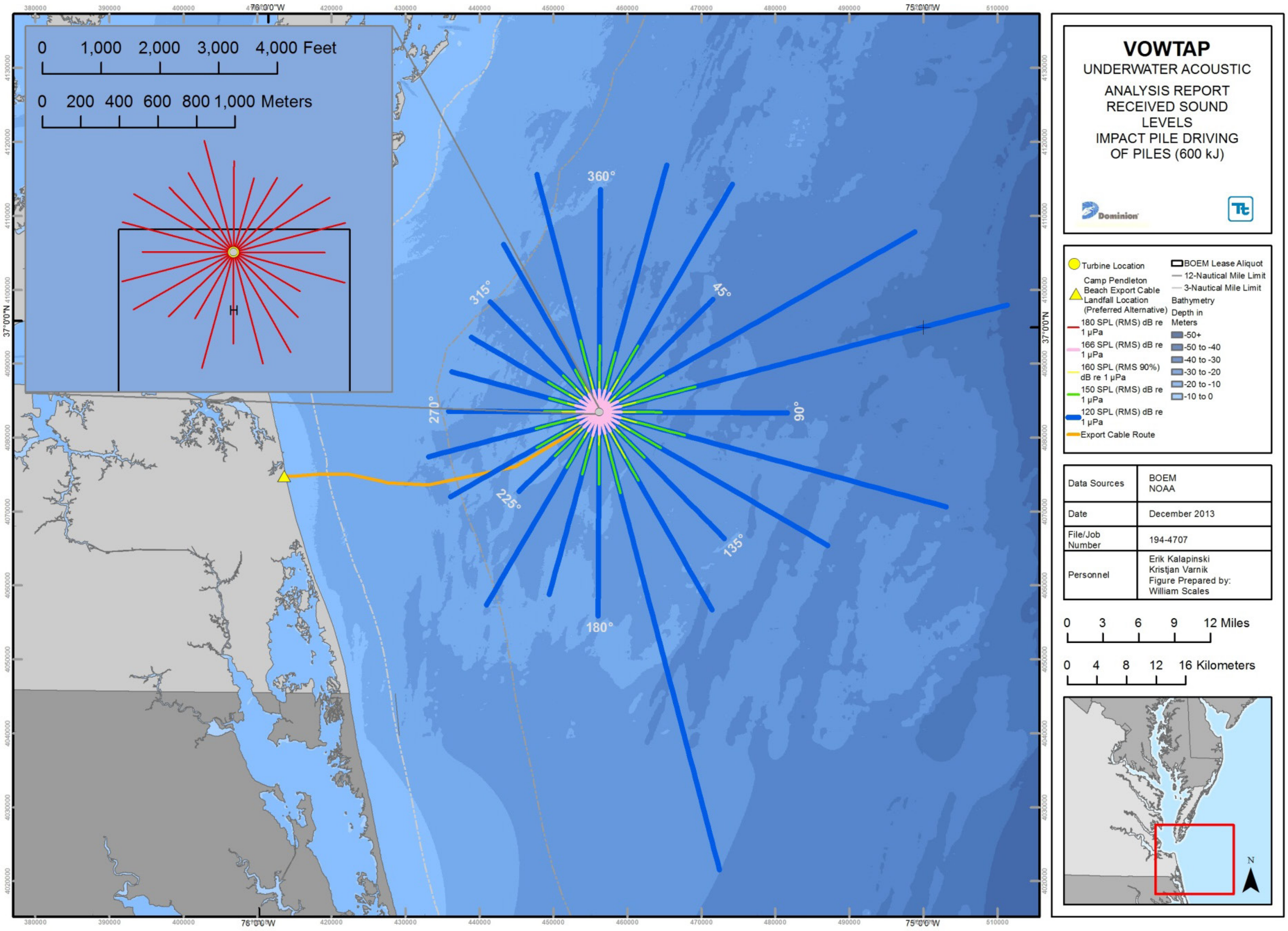


Figure A-7. Received Sound Levels, Impact Pile Driving of 1.4 Meter Diameter Raked Pile at Maximum Impact Force (600 kJ)

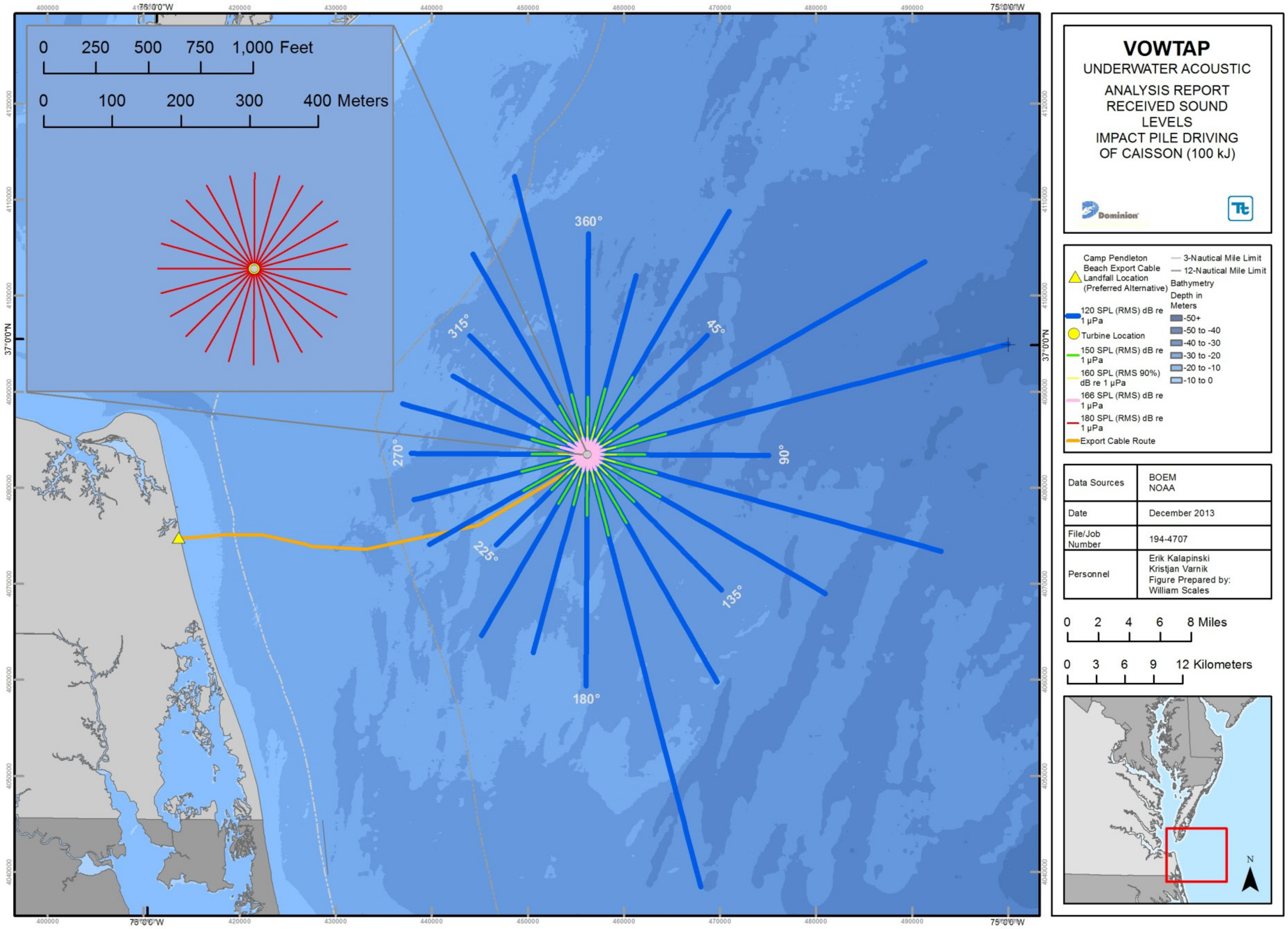


Figure A-8. Received Sound Levels, Impact Pile Driving of 2.4 Meter Diameter Center Caisson Raked Pile during Soft-Start (100 kJ)

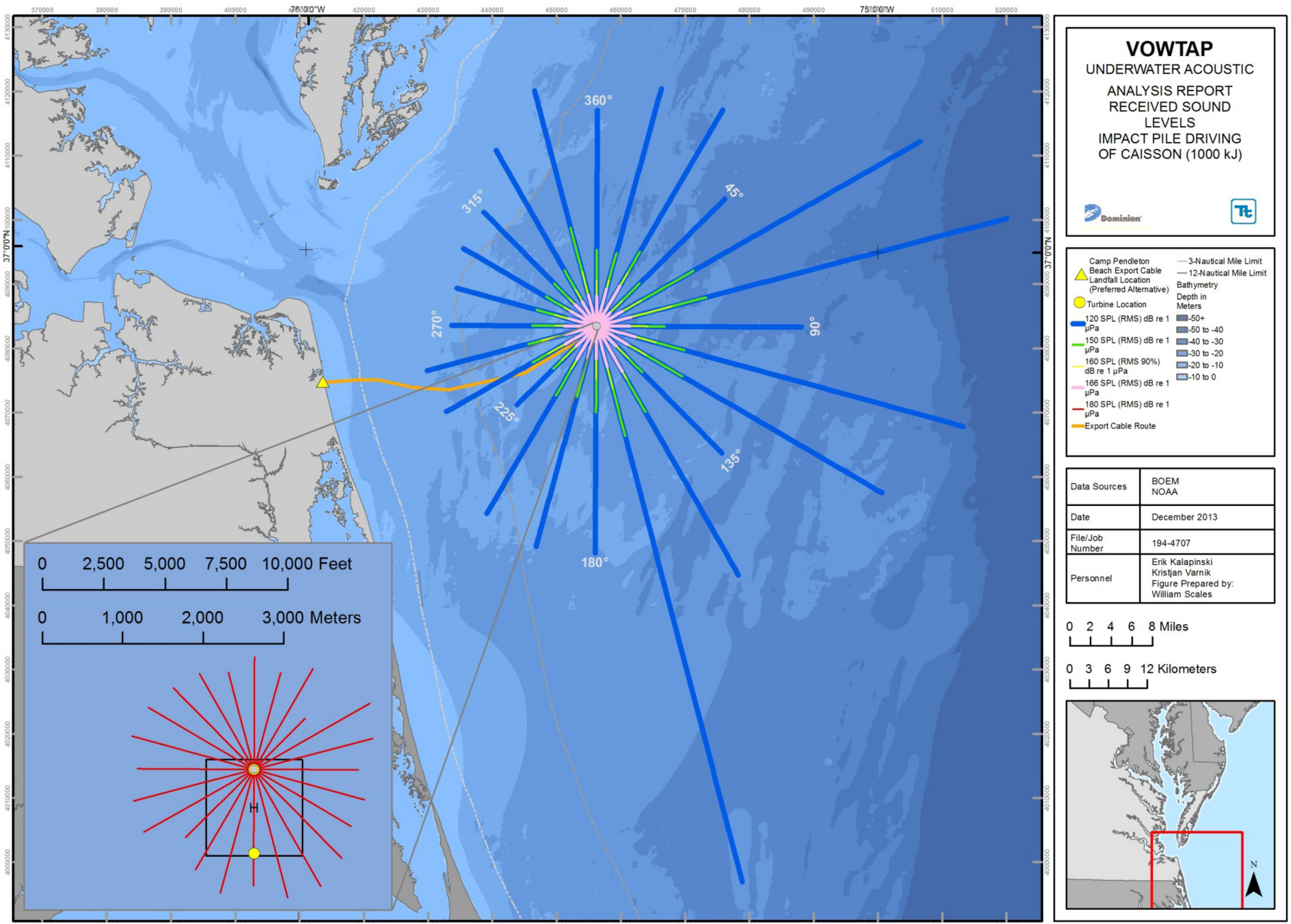


Figure A-9. Received Sound Levels, Impact Pile Driving of 2.4 Meter Diameter Center Caisson Raked Pile at Maximum Impact Force (1000 kJ)

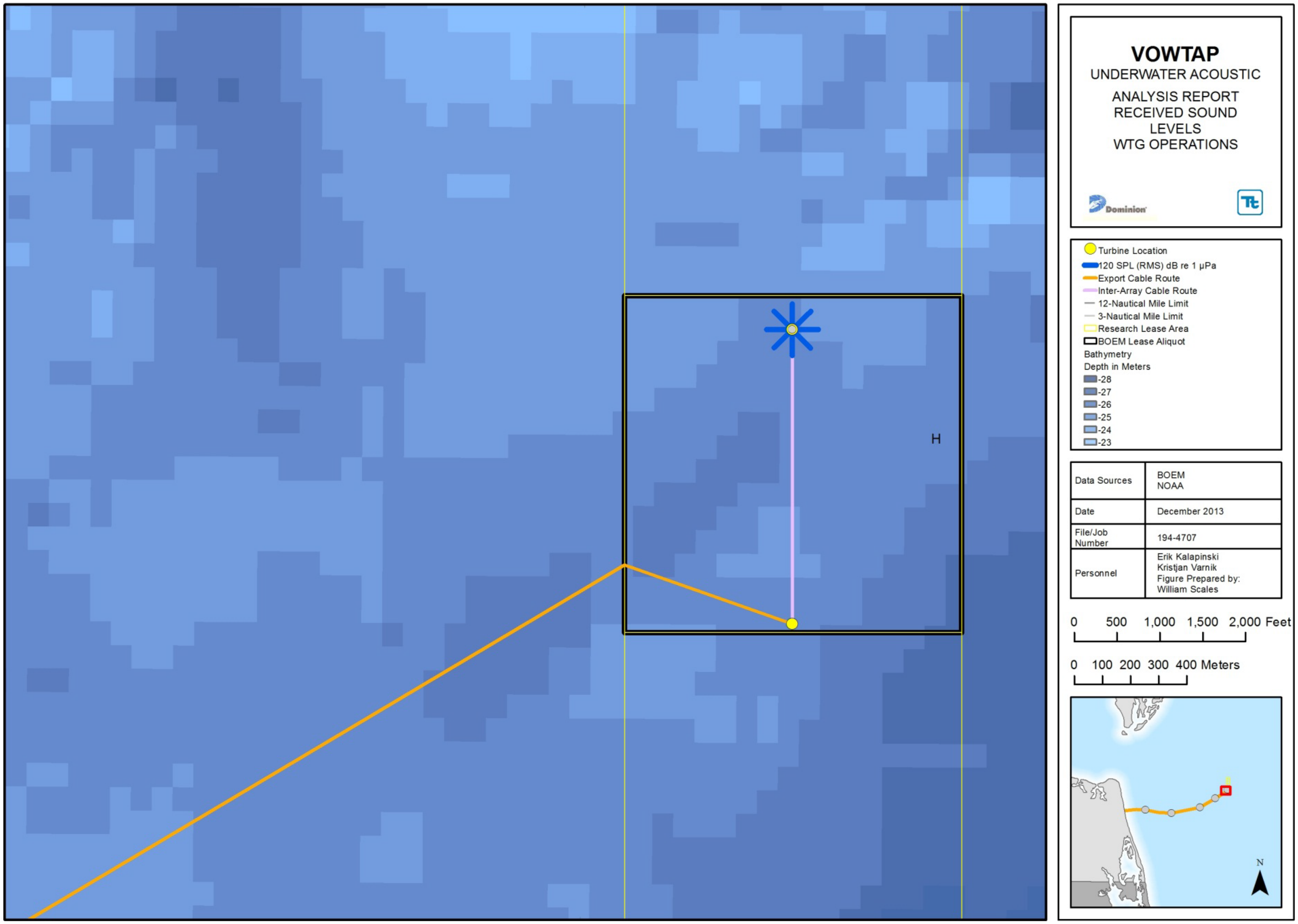


Figure A-10. Received Sound Levels, Wind Turbine Operations