APPENDIX L

UNDERWATER ACOUSTIC ASSESSMENT

Prepared for

Beacon Wind LLC

Photo credit: Matt Goldsmith, Equinor

June 2023

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Memo

DATE: 03 June 2023

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TO: Heather Brewster (AECOM)

Subject: Acoustic ranges to regulatory thresholds and exposure estimates for installation of goal posts and casing pipes by impact pile driving and pipe ramming

1. Introduction

To support horizontal directional drilling (HDD) at the potential export cable landfall location at Queens, New York (Figure 1), and at Waterford, Connecticut (Figure 2) the temporary installation of casing pipes by pneumatic pipe ramming and the temporary installation of goal posts by impact pile driving may be required. Each temporary goal post would require the installation of two 12-inch diameter cylindrical steel piles driven via impact pile driving. The casing pipes would be 42-inches in diameter and driven by a pneumatic pipe ramming tool. Table 1 shows the expected location. Goal post installation may occur between July and November.

Impact pile driving and pneumatic pipe ramming produce underwater sounds that have the potential to exceed regulatory thresholds for auditory injury and behavioral disruption in marine mammals, sea turtles, and fish. Distances for potential injury and behavioral disruption were computed using the GRLWEA Dynamics 2010) and JASCO's Pile Driving Source Model (PDSM), a computational model of pile vibration and near-field sound radiation (MacGillivray 2014) to predict source signatures levels associated with impact pile driving activities.

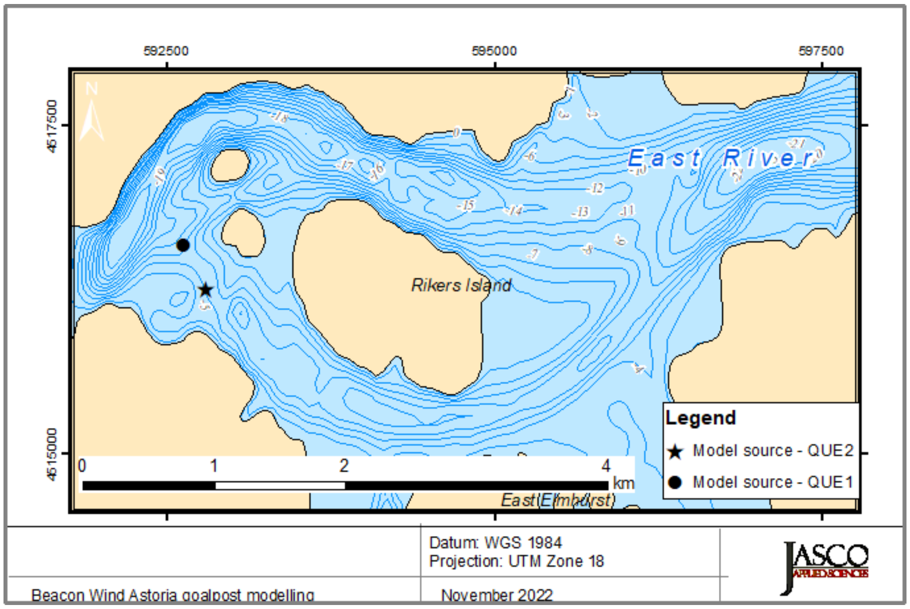

Figure 1. Goal post and casing pipe modeling locations (QUE1 and QUE2) for impact pile driving. Contours are expressed in meters.

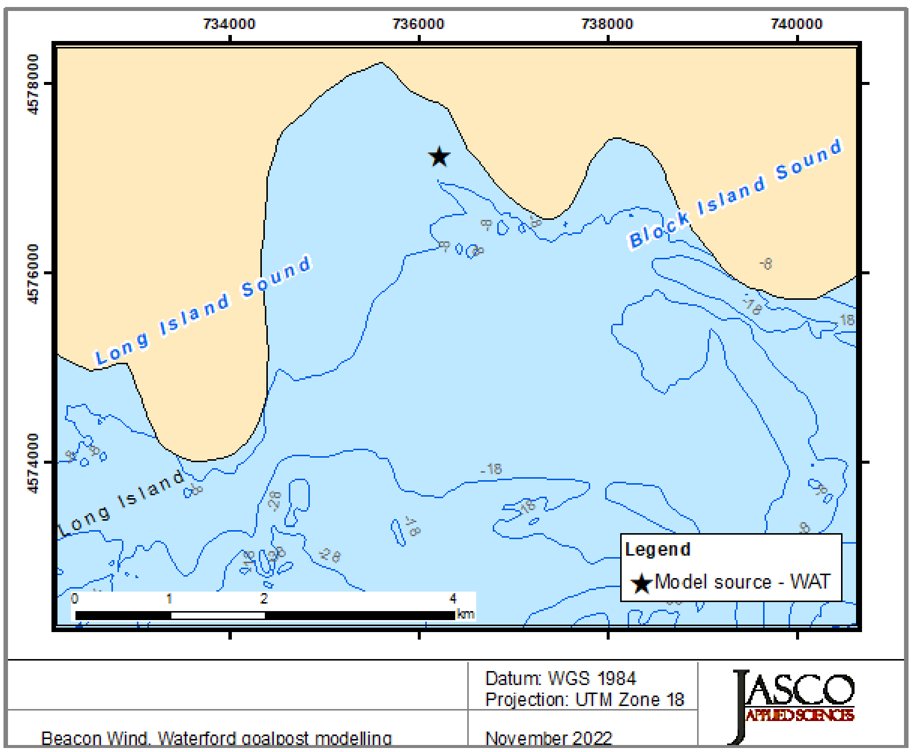

Figure 2. Goal post and casing pipe modeling location for Waterford. WAT refers to the location modeled for pile driving. Contours are expressed in meters.

Table 1. Acoustic modeling locations for goal posts and casing pipes.

Modeling site	Latitude	Longitude	Easting (UTM 18)	Northing (UTM 18)	Depth (m)
QUE1	40.795	-73.902	592629.84	4516580.46	8.362
QUE2	40.792	-73.900	592802.75	4516249.55	6.720
Waterford - WAT	41.312	-72.178	736237.96	4577232	4.101

2. Methods

2.1. Evaluation Criteria

2.1.1. Marine Mammals

To assess the potential impacts of the underwater sound during goal post and casing pipe installation, it is necessary to first establish acoustic exposure criteria to evaluate potential injury or behavioral disruption to animals from exposure to sounds.

Hearing loss, a permanent threshold shift (PTS), may result from exposure to short loud sounds or longer-duration fatiguing sounds. For this reason, dual criteria -- the instantaneous peak sound pressure level, PK, and the sound exposure level, SEL – are used to evaluate the potential for sounds to cause injurious hearing loss (PTS). For marine mammals, there are no direct data on received sound levels that may result in PTS. There are, however, data on the received sound levels at which temporary threshold shift (TTS) occurs, and PTS onset may be extrapolated from TTS onset levels assuming growth functions (Southall et al. 2007).

In 2016, National Oceanographic and Atmospheric Administration (NOAA) Fisheries issued a Technical Guidance document that provides acoustic criteria and thresholds for onset of PTS in marine mammals, which was re-released in 2018 (NMFS 2016, 2018). The Technical Guidance (NMFS 2018) uses dual criterion for assessing the potential for PTS: unweighted PK and frequency-weighted SEL. SEL is calculated using frequency weighting functions applied to received sounds and are specific to functional hearing groups (Table 2). The NMFS (2018) thresholds for evaluating potential PTS are shown in Table 3.

Based on observations of mysticetes (Malme et al. 1983, 1984, Richardson et al. 1986, 1990), sound levels thought to elicit disruptive behavioral response are described using the SPL metric (NMFS and NOAA 2005). NOAA Fisheries (NMFS) currently uses a behavioral response threshold of SPL 160 dB re 1 μPa for marine mammals exposed to intermittent sounds and a threshold of 120 dB re 1 μPa for continuous sounds (NOAA 2005). Alternative thresholds used in acoustic assessments include a graded probability of response approach and take into account the frequency-dependence of animal hearing sensitivity (Wood et al. 2012). The 160 dB threshold is used in this assessment as per NOAA guidance (2019).

Table 2. Marine mammal hearing groups and frequency ranges (Sills et al. 2014, NMFS 2018).

Faunal group	Generalized hearing range[a]
Low-frequency cetaceans (LFC) (mysticetes or baleen whales)	7 Hz to 35 kHz
Mid-frequency cetaceans(MFC) (odontocetes: delphinids, beaked whales)	150 Hz to 160 kHz
High-frequency cetaceans (HFC) (other odontocetes)	275 Hz to 160 kHz
Phocid pinnipeds in water (PPW)	50 Hz to 86 kHz

[a] The generalized hearing range is for all species within a group. Individual hearing will vary.

Table 3. Summary of relevant permanent threshold shift (PTS) onset acoustic thresholds (NMFS 2018) and acoustic sound pressure level (SPL) thresholds used to evaluate potential behavioral impacts (SPL, NOAA 2005) for marine mammal hearing groups.

<table>
<tr><th>Faunal Groups</th><th>Unweighted L_{pk} (dB re 1 µPa)</th><th>Frequency-weighted $L_{E,24h}$ (dB re 1 µPa^2·s)</th><th>Unweighted L_p (dB re 1 µPa^2·s)</th></tr>
<tr><td>Low-frequency cetaceans (LFC)</td><td>219</td><td>183</td><td rowspan="4">160</td></tr>
<tr><td>Mid-frequency (MF) cetaceans (MFC)</td><td>230</td><td>185</td></tr>
<tr><td>High-frequency cetaceans (HFC)</td><td>202</td><td>155</td></tr>
<tr><td>Phocid seals in water (PW)</td><td>218</td><td>185</td></tr>
</table>

[a] Dual-metric acoustic thresholds for impulsive sounds: Of these two metrics, the one with the larger acoustic isopleth or the larger exposure effect is used to assess PTS onset.

2.1.2. Fish and Sea Turtles

In a cooperative effort between Federal and State transportation and resource agencies, interim criteria were developed to assess the potential for injury to fish exposed to pile driving sounds (Stadler and Woodbury 2009) and described by the Fisheries Hydroacoustic Working Group (FHWG 2008). Injury and behavioral response levels for fish were based on past literature that was compiled and listed in the NOAA Fisheries Greater Atlantic Regional Fisheries Office acoustics tool (GARFO 2020) for assessing the potential effects to Endangered Species Act (ESA) listed animals exposed to elevated levels of underwater sound from pile driving. Dual acoustic thresholds for physiological injury to fish included in the tool are 206 dB re 1 µPa PK and either 187 dB re 1 µPa^2·s SEL (>2 grams [g] fish weight) or 183 dB SEL (<2 g fish weight) (FHWG 2008, Stadler and Woodbury 2009) (Table 4). The behavioral threshold for fish is >150 dB SPL (Andersson et al. 2007, Wysocki et al. 2007, Mueller-Blenkle et al. 2010, Purser and Radford 2011).

A technical report by an American National Standards Institute (ANSI) registered committee (Popper et al. 2014) reviewed available data and suggested metrics and methods for estimating acoustic impacts for fish. Their report includes thresholds for potential injury but does not define sound levels that may result in behavioral response, though does indicate a high likelihood of response near impact pile driving (tens of meters), moderate response at intermediate distances (hundreds of meters), and low response far (thousands of meters) from the pile (Popper et al. 2014).

Injury, impairment, and behavioral thresholds for sea turtles were developed for use by the US Navy (Finneran et al. 2017) based on exposure studies (e.g., McCauley et al. 2000a). Dual criteria (PK and SEL) have been suggested for PTS and TTS, along with auditory weighting functions published by Finneran et al. (2017) used in conjunction with SEL thresholds for PTS and TTS . The behavioral threshold recommended in the GARFO acoustic tool (GARFO 2020) is an SPL of 175 dB re 1 µPa (McCauley et al. 2000a, Finneran et al. 2017) (Table 4).

Table 4. Acoustic metrics and thresholds for fish and sea turtles currently used by NMFS and Bureau of Ocean Energy Management (BOEM) for impulsive pile driving.

Faunal group	Injury		Impairment		Behavior
	PTS		TTS		
	L_{pk}	L_E	L_{pk}	L_E	L_p
Fish equal to or greater than 2 g[a,b]	206	187	-	-	150
Fish less than 2 g[a,b]		183	-	-	
Fish without swim bladder[c]	213	216	-	-	-
Fish with swim bladder not involved in hearing[c]	207	203	-	-	-
Fish with swim bladder involved in hearing[c]	207	203	-	-	-
Sea turtles[d,e]	232	204	226	189	175

Lpk – peak sound pressure (dB re 1 µPa), LE – sound exposure level (dB re 1 µPa2·s),
Lp – root mean square sound pressure (dB re 1 µPa).
A dash indicates that a threshold is not available.
PTS = permanent threshold shift; TTS = temporary threshold shift, which are recoverable hearing effects.
a NMFS recommended criteria adopted from the Fisheries Hydroacoustic Working Group (FHWG 2008).
b Andersson et al. (2007), Mueller-Blenkle et al. (2010), Purser and Radford (2011), Wysocki et al. (2007).
c Popper et al. (2014).
d Finneran et al. (2017).
e McCauley et al. (2000)

2.2. Source and Propagation Modeling

The goal post is modeled as a vertical pile and the casing pipe as a pile angled at 12 degrees from horizontal. Piles deform when driven with impact hammers, creating a bulge that travels down the pile radiating sound into the surrounding air, water, and seabed. This sound may be received as a direct transmission from the sound source to biological receivers (such as marine mammals, sea turtles, and fish) through the water or as the result of reflected paths from the surface or re-radiated into the water from the seabed.

Sound transmission depends on environmental parameters, such as the sound speeds in water and substrates. It also depends on the sound production parameters of the pile and how it is driven, including the pile material, size (length, diameter, and thickness) and the make and energy of the hammer.

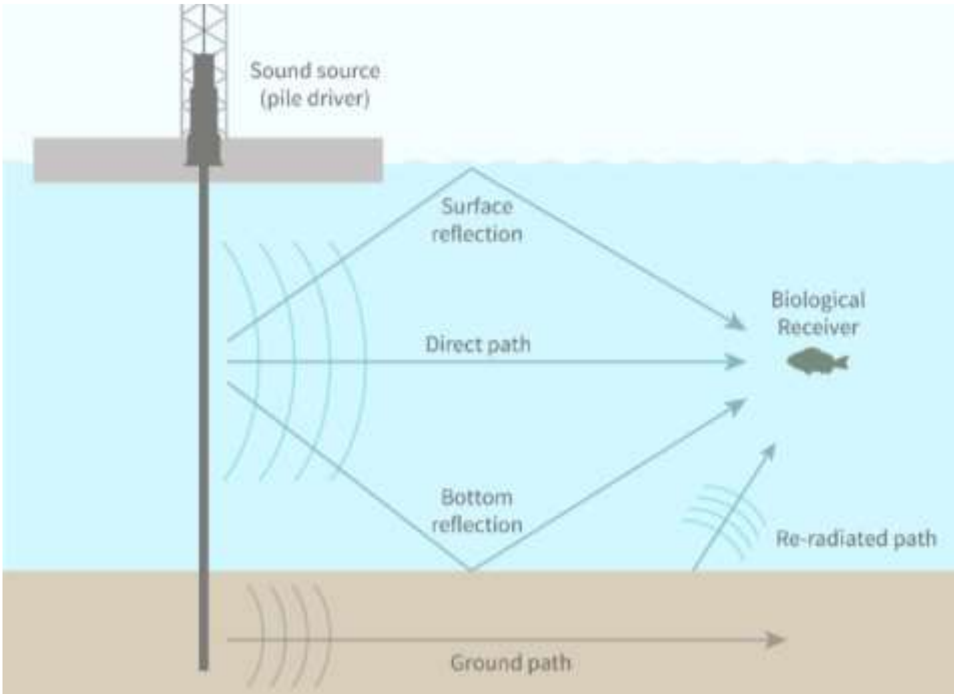

Figure 3. Sound propagation paths associated with pile driving (adapted from Buehler et al. 2015).

JASCO's Pile Driving Source Model (PDSM), a computional model of pile vibration and near-field sound radiation (MacGillivray 2014), was used in conjunction with the GRLWEAP 2010 wave equation model (GRLWEAP, Pile Dynamics 2010) to predict source signatures associated with impact pile driving activities. Goal post piles are modeled as a vertical installation using a finite-difference structural model of pile vibration based on thin-shell theory. The sound radiating from the pile itself was simulated using a vertical array of discrete point sources. In the casing pipe modeling, discrete point sources are simulated along the inclined pile.These models account for several parameters that describe the operation—pile type, material, size, and length—the pile driving equipment, and approximate pile penetration depth.

Forcing functions were computed for the goal posts and the casing pipe, using GRLWEAP 2010 (GRLWEAP, Pile Dynamics 2010). The model assumed direct contact between the representative hammers, helmets, and piles (i.e., no cushion material, which provides a more conservative estimate). The modeling of forcing functions assumed a hammer with average energy of 40.5 kJ (for the goal post) and 40.7 kJ (for the casing pipe). The forcing functions at the top of the pile were used as inputs to estimate propagated acoustic source characteristics.

For this study, synthetic pressure waveforms were computed using FWRAM, a full-wave acoustic propagation model based on the wide-angle parabolic equation (PE) algorithm (Collins 1993). FWRAM computes pressure waveforms as a function of range and depth via Fourier synthesis of transfer functions in closely-spaced frequency bands in range-varying marine acoustic environments. FWRAM employs an array starter method to accurately model sound propagation from a spatially distributed source (MacGillivray and Chapman 2012).

Synthetic pressure waveforms were modeled over the frequency range 10–1024 Hz, inside a 1 s window for the 12 inch goal post and 42 inch casing pipe. The synthetic pressure waveforms were post-processed, after applying a travel time correction, to calculate standard SPL and SEL metrics versus range and depth from the source. The acoustic field is extended to higher frequencies (up to 25,000 Hz) by applying a 20 dB/decade decay rate to match acoustic measurements of impact pile driving (Illingworth & Rodkin 2007, Matuschek and Betke 2009).

Acoustic fields in three dimensions are generated by modeling propagation loss within two-dimensional (2-D) vertical planes aligned along radials covering a 360° swath from the source, an approach commonly referred to as N×2-D. These vertical radial planes are separated by an angular step size of $\Delta\theta$, yielding N = 360°/$\Delta\theta$ planes. A total of N = 144 radial planes along with a range step size Δr = 10 m and a depth step size Δz = 1 m and 0.5 m for goal post and casing pipe, respectively, were used in the calculations. The source array used for modeling the propagation loss for the casing pipe is aligned relative to the source azimuth. The source azimuths (relative to the North) used for the casing pipe are ~0^{o} for the Queens sites and ~243.5^{o} for the Waterford site based on the alignment of the casing pipe. Pile assumptions and input parameters used in the source modeling and sound propagation modeling at the two locations considered (Queens and Waterford) are listed in Table 5. Table 6 describes the environmental parameters used as input to the propagation modeling.

Table 5. Major assumptions used in underwater acoustic modeling of impact pile driving of cylindrical steel piles and pipe ramming of casing pipes.

Parameter	Casing pipe	Goal Post
Impact hammer energy	40.5 kJ	40.7 kJ
Hammer model	ICE 75[a]	Delmag D16-32
Helmet weight	1000 lb	1200 lb
Estimated number of strikes to drive pile	43200	5280
Strike rate (per min)	180	44
Number of piles/day	1	2
Expected maximum penetration (vertical)	10.67 m	18.29 m
Modeled seabed penetrations	3.05, 6.10, 10.67 m	6.10, 12.19, 18.29 m
Pile length	91.44 m	30.48 m
Pile diameter	1.07 m	0.30 m
Pile wall thickness	1.91 cm	1.43 cm
Angle of inclination	12°off horizontal	90° off horizontal (vertical pile)

[a]The ICE 75 was chosen as representative as the final model has not yet been selected. Specifications of selected model would be similar to the ICE 75.

Table 6. Environmental assumptions used in underwater acoustic modeling for both goal posts and casing pipes.

Parameter	Value	Reference (if applicable)
Queens		
Bathymetry	3 arc-second U.S. Coastal Relief Model (CRM)	National Center for Environmental Information (NCEI) (https://www.ngdc.noaa.gov/). Coastal bathymetry adjusted by tide fluctuations
Sound speed	Uniform sound speed[a] profile in depth	National Buoy Data Center (NDBC(noaa.gov))
Geoacoustics	Medium to coarse silt without rock basement	U.S. Geological Survey, Atlantic Seafloor Sediment (CONMAP) (Popper et al. 2014) and Ainslie (2010)
Waterford		
Bathymetry	NCEI Multibeam Bathymetry Database	National Center for Environmental Information (NCEI) (https://www.ncei.noaa.gov/maps/bathymetry)
Sound speed	Mean seasonal profiles[b]	GDEM v-3.0 (NAVO 2003)
Geoacoustics	Medium sand	Ainslie (2010)

[a]Sound speed was derived from mean summer surface temperature measured at buoy stations KPTN6 (2019) and BATN6H (2021).

[b] Sound speed was converted to mean early Fall (July-August) profiles.

2.3. Exposure Estimates for Marine Mammals

Exposure calculations assumed 4 days of casing pipe installation and 2 days of goal post installation, for a total of 6 days. The installation was modeled at each of the three cable landing site locations (QUE 1, QUE, and Waterford). The model considered up to two goal posts installed per day and one casing pipe installed per day at each location (Table 1,Table 5). Exposures were estimated using the maximum animal densities for the months from July to November.

2.3.1. Density Calculations

Marine mammal densities in the potential impact area were estimated using the Marine Geospatial Ecology Laboratory (MGEL)/Duke University Habitat-based Marine Mammal Density Models for the US Atlantic (Roberts et al. 2022). Densities in the MGEL/Duke models are provided as the number of animals per 100 square kilometers (animals/100 km^2) and given for each 5 × 5 km cell in the US Atlantic for all species. Sea turtle densities were obtained from the US Navy Operating Area Density Estimate (NODE) database on the Strategic Environmental Research and Development Program Spatial Decision Support System (SERDP-SDSS) portal (DoN, 2012, 2017)

To calculate marine mammal densities for the potential impact pile driving impact area, it was assumed that the construction activities would occur in one area of interest: the export cable landing site located in

Queens, New York and the Waterford export cable landing site. The density perimeters were determined using the greatest 95th percentile acoustic range to threshold ($R_{95\%}$) (see tables in Section 3.1; 1.094 km at QUE1 and QUE2 and 11.228 km at the Waterford site). Monthly densities were calculated for each area of interest and for each species as the average of the densities from all MGEL/Duke model grid cells that overlap partially or completely with each area of interest (Roberts et al. 2022). Cells entirely on land were not included, but cells that overlap only partially with land were included.

There are two cases in this study wherein the MGEL/Duke model reports densities for species guilds, where the species were considered separately for exposure calculations: seals and pilot whales. In these cases, the densities were each scaled by their relative abundances. For example, the density for short-finned pilot whales is computed as:

$$d_{short-finned} = d_{both}\left(\frac{a_{short-finned}}{a_{short-finned} + a_{long-finned}}\right) \tag{1}$$

At the QEU1 and QUE2, there is no overlap between the potential impact area and the marine mammal density data provided by the MGEL/Duke model reports. In this case, the mean of the nearest three density data cells, approximately 10 km from the source, were used.

Sea turtle density data did not overlap with the impact areas at the Waterford or QUE1 and QUE2 sites. The nearest two density data cells (46 km from the source) from the SERDP dataset were used to estimate density for sea turtles at the Waterford location, and the nearest single density data cell (34 km from the source) was used to estimate density for sea turtles at the Queens locations.

The maximum densities were calculated from July to November. The resulting densities are included in Table 7. Figure 5 and Figure 4 provides an example showing the data cells included in the density average at the Queens and Waterford locations.

Table 7. Maximum monthly density (animals per 100 km^2), estimated for July-November), at Queens and Waterford.

Species	Queens	Waterford
Fin whale	<0.001	0.004
Minke whale	0.001	0.027
Humpback whale	0.011	0.057
North Atlantic right whale	0	0.006
Sei whale	<0.001	0.014
Atlantic white-sided dolphin	0.020	0.654
Atlantic spotted dolphin	<0.001	<0.001
Common dolphin	0.019	1.863
Bottlenose dolphin, offshore	0	0.044
Risso's dolphin	<0.001	<0.001
Long-finned pilot whale	<0.001	<0.001
Short-finned pilot whale	<0.001	<0.001
Sperm whale	0.001	0.023
Harbor porpoise	0.007	0.030
Gray seal	3.987	2.939
Harbor seal	8.958	6.602
Harp seal	3.238	2.939
Kemp's ridley turtle	<0.001	<0.001
Leatherback turtle	0.606	0.021
Loggerhead turtle	0.413	0.314
Green turtle	<0.001	<0.001

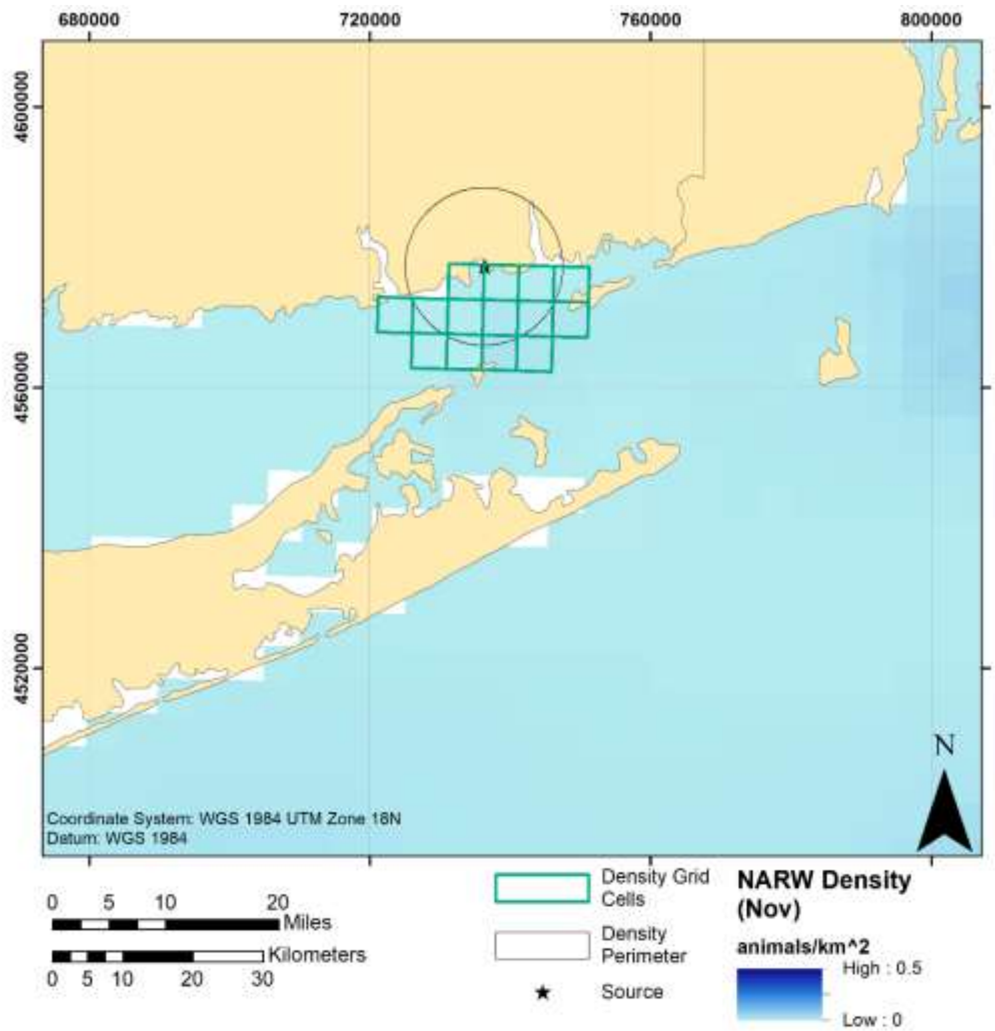

Figure 4. Marine mammal (e.g., North Atlantic right whale) density map showing highlighted grid cells used to calculate maximum seasonal species densities at the Waterford location (Roberts et al. 2022). The density perimeter was 11.228 km, calculated using $R_{95\%}$ for impact pile driving.

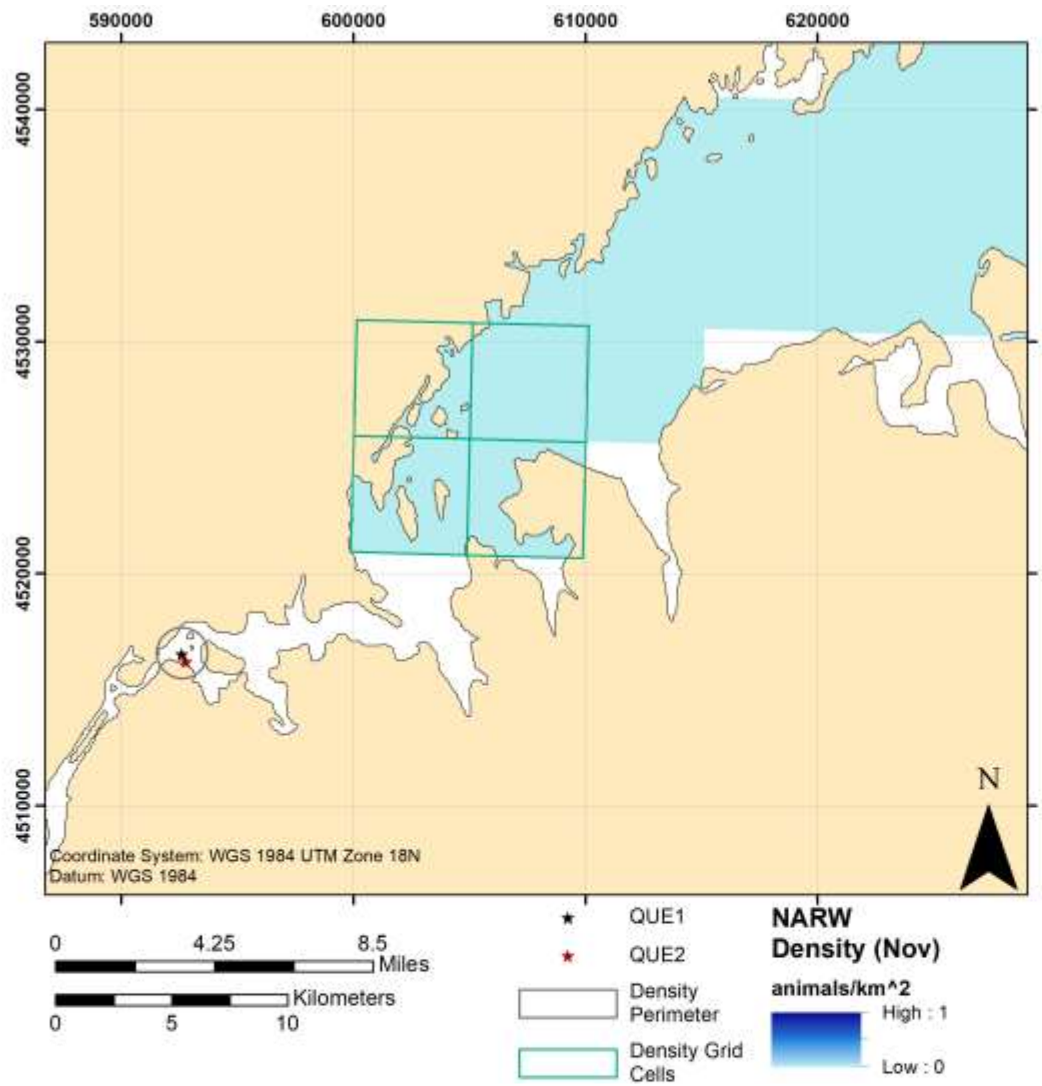

Figure 5. Marine mammal (e.g., North Atlantic right whale) density map showing highlighted grid cells used to calculate maximum seasonal species densities at QUE 1 and QUE2 (Roberts et al. 2022). QUE1 and QUE2 refers to the goal post and casing pipe modeling locations modeled for pile driving. The density perimeter of 1.094 km was not used as there is no data available within the perimeter.

2.3.2. Exposure Estimation

The zone of influence (ZOI) is a representation of the maximum extent of the ensonified area around a sound source over a 24-hour period. The ZOI was obtained directly from the acoustic propagation modeling results for each source separately, where the ensonified area was summed over the gridded maximum-over-depth sound fields corresponding to each of the acoustic thresholds for injury and behavioral response. Exposures were estimated at each location, and for all species using:

$$\text{exposures} = \sum \text{ZOI} \times \text{days} \times \text{density}\,, \qquad (2)$$

where days = 2 days for goal post installation and 4 days for casing pipe installation, ZOI is estimated separately for goal post and casing pipe, and density is from Table 7.

3. Results

3.1. Acoustic Ranges

3.1.1. Decidecade Band Levels

The distribution of a sound's power with frequency is described by the sound's spectrum. In underwater acoustics, a spectrum is commonly split into decidecade bands, which are one tenth of a decade wide. Figures 6-8 show the decidecade band levels at 10 m from the modeled goalposts and casing pipe piles.

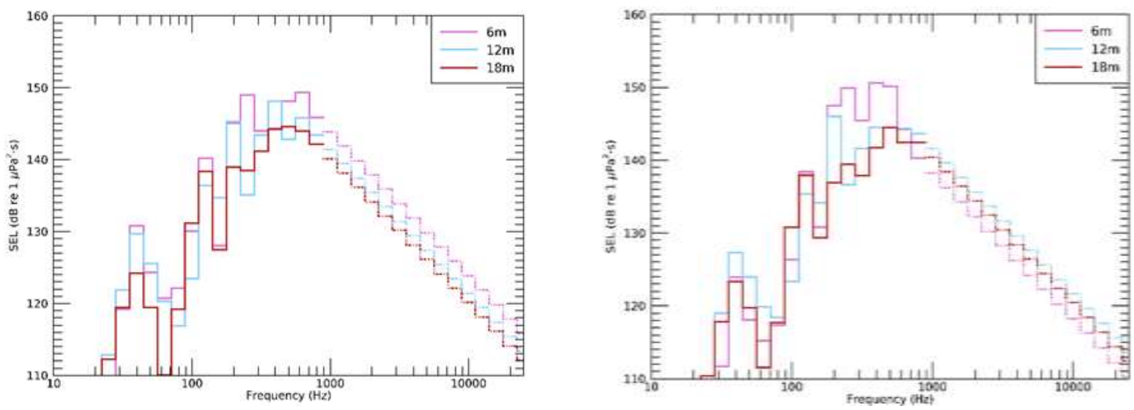

Figure 6. Location QUE1 (Left) and QUE2 (Right): Decidecade band levels for 30 cm diameter goal post assuming an expected installation scenario using a Delmag D16-32 hammer with an average summer sound speed profile.

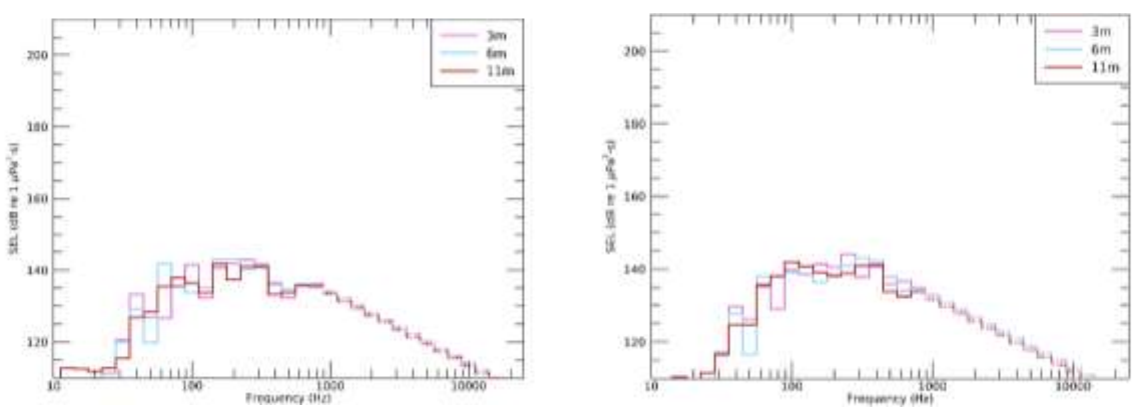

Figure 7. Location QUE1 (Left) and QUE2 (Right): Decidecade band levels for 106 cm diameter casing pipe assuming an expected installation scenario using an ICE75 hammer with an average summer sound speed profile.

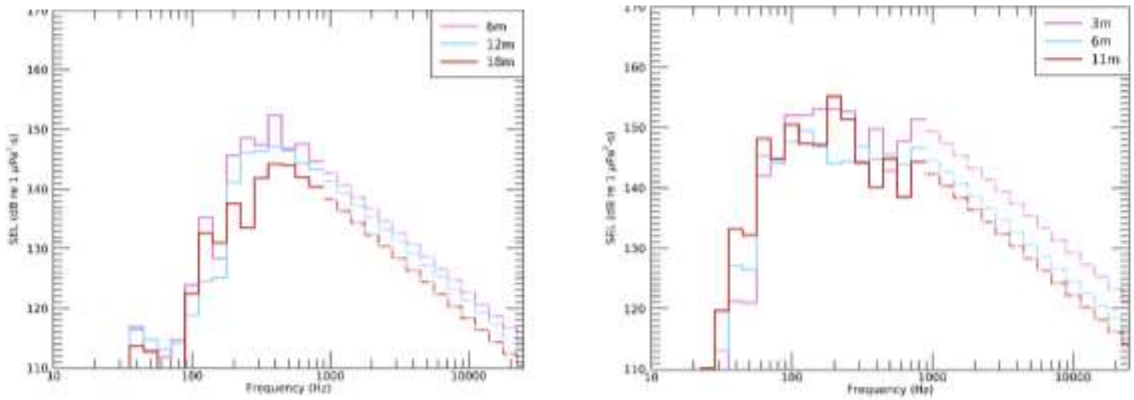

Figure 8. Location Waterford: Decidecade band levels for 30 cm diameter goal post assuming an expected installation scenario using a Delmag D16-32 hammer (Left) and for 106 cm diameter casing pipe assuming an expected installation scenario using an ICE75 hammer (Right)with an average summer sound speed profile.

3.1.2. Goal Post Acoustic Ranges

Assuming either two goal posts or one casing pipe will be installed in a 24-hour period, the frequency-weighted distances to potential injury for the marine mammals, fish and sea turtles hearing groups during goal post installation are shown in Table 8 for the Queens locations and Table 9 for the Waterford location. Figures 9, 10, and 13 show unweighted SEL isopleths in 10 dB intervals to demonstrate sound propagation characteristics away from each modeled goal post location. The lowest isopleth of 120 dB re 1 μPa^2·s is considered close to ambient sound levels, therefore sound levels below this are not acoustically significant. The inset map shows modeled levels closer to the source location. Isopleths to weighted SEL thresholds for marine mammal and sea turtle injury were separately plotted and are shown in Figures 11, 12, and 14. These plots present an additional visualization of the results shown in Tables 8-9 with respect to the area of impact around the source. Fish isopleths to injury thresholds were not plotted because the weighted marine mammal and sea turtle threshold isopleths converged at the same distances, making the plots unreadable.

For the goal posts, distances to the SPL 160 dB re 1 μPa marine mammal behavioral threshold, without frequency weighting, were found to extend to 15 and 11 m at Queens locations QUE1 and QUE2, during high tides, respectively (Table 10,) and 11 m at Waterford locations (Table 11). Maximal tidal depth fluctuation are up to ~2.5 m at Queens, as predicted from nearby buoys for each site (NOAA 2020). Tidal variation at Waterford was considered negligible relative to local water depths. Tidal variation for Queens was incorporated using the maximum annual modeled high tide at North Brothers Island (referenced to Kings Station, from NOAA Tides and Currents).

Table 8. *Queens goal post site*: Distances to injury thresholds for marine mammals, fish and sea turtles for sounds generated by impact pile driving of 2 goal posts piled at QUE1 and QUE2 sites within 24 hours.

Hearing group	$L_{E,24h}$ (dB re 1 µPa²·s)	R_{max} (m)	$R_{95\%}$ (m)	Area (m²)	R_{max} (m)	$R_{95\%}$ (m)	Area (m²)
		QUE1			QUE2		
Low-frequency cetaceans (LFC)[a]	183	51	50	8,495	51	49	7,238
Mid-frequency cetaceans (MFC) [a]	185	0	0	0	0	0	0
High-frequency cetaceans (HFC) [a]	155	51	50	8,495	51	49	7,238
Phocid pinnipeds in water (PPW)[a]	185	7	7	380	11	11	804
Sea turtles[b]	204	0	0	0	0	0	0
Fish ≥ 2 g[c]	187	30	30	3,217	31	31	3,217
Fish < 2 g[c]	183	57	57	9,852	54	51	7,854
Fish without swim bladder[d]	216	0	0	0	0	0	0
Fish with swim bladder involved in hearing[d]	203	0	0	0	0	0	0
Fish with swim bladder not involved in hearing[d]	203	0	0	0	0	0	0

[a] NMFS (2018).
[b] Finneran et al. (2017).
[c] NMFS recommended criteria adopted from the Fisheries Hydroacoustic Working Group (FHWG 2008).
[d] Popper et al. (2014).

Table 9. *Waterford goal post site*: Distances to injury thresholds for marine mammals, fish and sea turtles for sounds generated by impact pile driving of 2 goal posts (cylindrical piles) piled within 24 hours.

Hearing group	$L_{E,24h}$ (dB re 1 µPa²·s)	R_{max} (m)	$R_{95\%}$ (m)	Area (m²)
Low-frequency cetaceans (LFC)[a]	183	82	80	21,642
Mid-frequency cetaceans (MFC)[a]	185	0	0	0
High-frequency cetaceans (HFC)[a]	155	91	82	22,167
Phocid pinnipeds in water (PPW)[a]	185	12	12	804
Sea turtles[b]	204	0	0	0
Fish ≥ 2 g[c]	187	54	52	6,940
Fish < 2 g[c]	183	101	92	26,016
Fish without swim bladder[d]	216	0	0	0
Fish with swim bladder involved in hearing[d]	203	0	0	0
Fish with swim bladder not involved in hearing[d]	203	0	0	0

[a] NMFS (2018).
[b] Finneran et al. (2017).
[c] NMFS recommended criteria adopted from the Fisheries Hydroacoustic Working Group (FHWG 2008).
[d] Popper et al. (2014).

Table 10. *Queens goal post site:* Distances to behavioral thresholds for marine mammals, fish and sea turtles for sounds generated by impact driving of cylindrical piles for mid-depth penetration.

Hearing group	Unweighted L_P (dB re 1 µPa)	R_{max} (m)	$R_{95\%}$ (m)	Area (m²)
			QUE1	
Fish[a]	150[a]	66	65	12,076
Marine mammals[b]	160	15	15	804
Sea turtles[c]	175	0	0	0
			QUE2	
Fish[a]	150	54	54	9,503
Marine mammals[b]	160	11	11	804
Sea turtles[c]	175	0	0	0

[a] Andersson et al. (2007), Mueller-Blenkle et al. (2010), Purser and Radford (2011), Wysocki et al. (2007).
[b] NOAA (2005)
[c] McCauley et al. (2000).

Table 11. *Waterford goal post site*: Distances to behavioral thresholds for marine mammals, fish and sea turtles for sounds generated by impact driving of cylindrical piles for mid-depth penetration.

Hearing group	Unweighted L_P (dB re 1 µPa)	R_{max} (m)	$R_{95\%}$ (m)	Area (m²)
Fish[a]	150	120	109	35,968
Marine mammals[b]	160	18	18	1,257
Sea turtles[c]	175	0	0	0

[a] Andersson et al. (2007), Mueller-Blenkle et al. (2010), Purser and Radford (2011), Wysocki et al. (2007).
[b] NOAA (2005)
[c] McCauley et al. (2000).

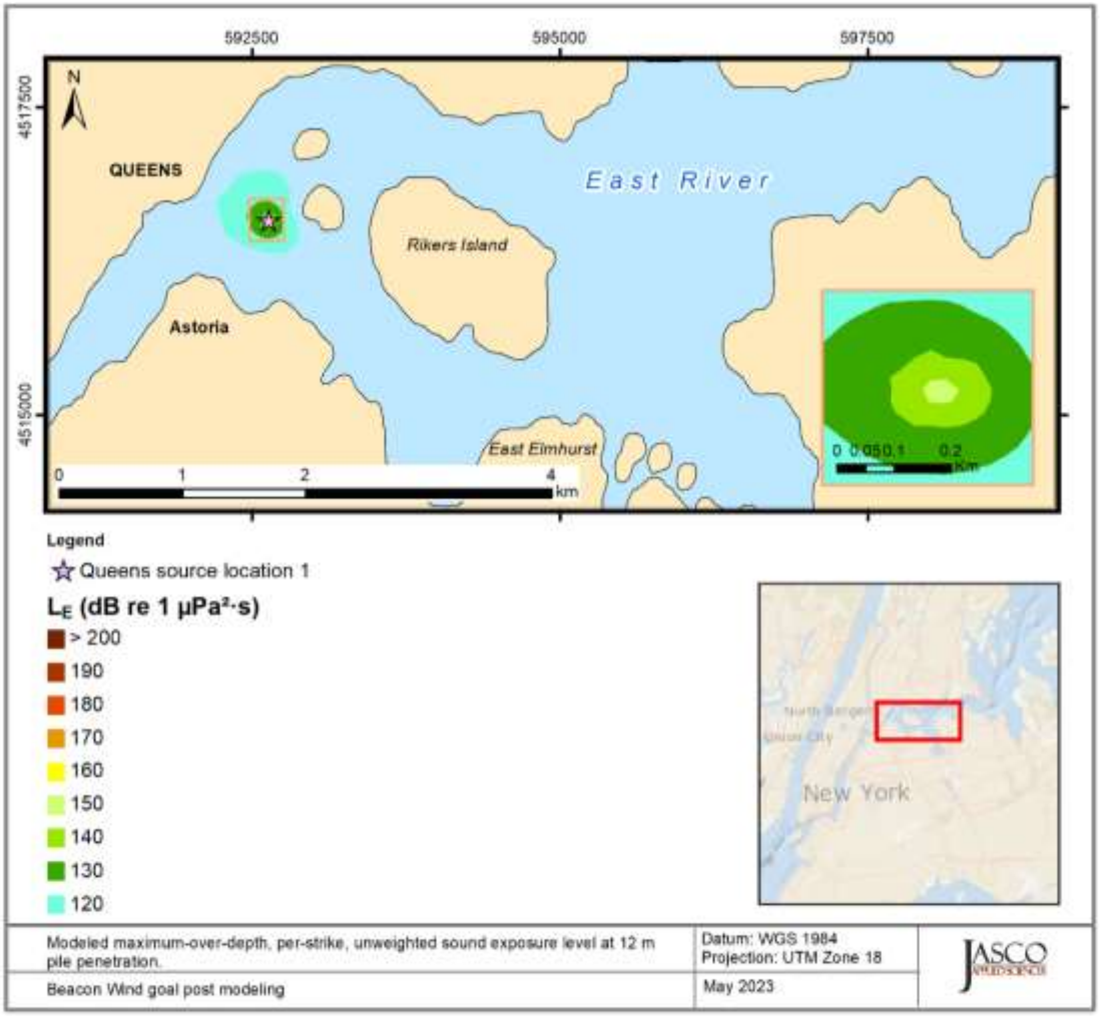

Figure 9. Modeled maximum-over-depth sound exposure level (unweighted SEL) for a goal post in the Queens location QUE 1 at 12 m pile penetration.

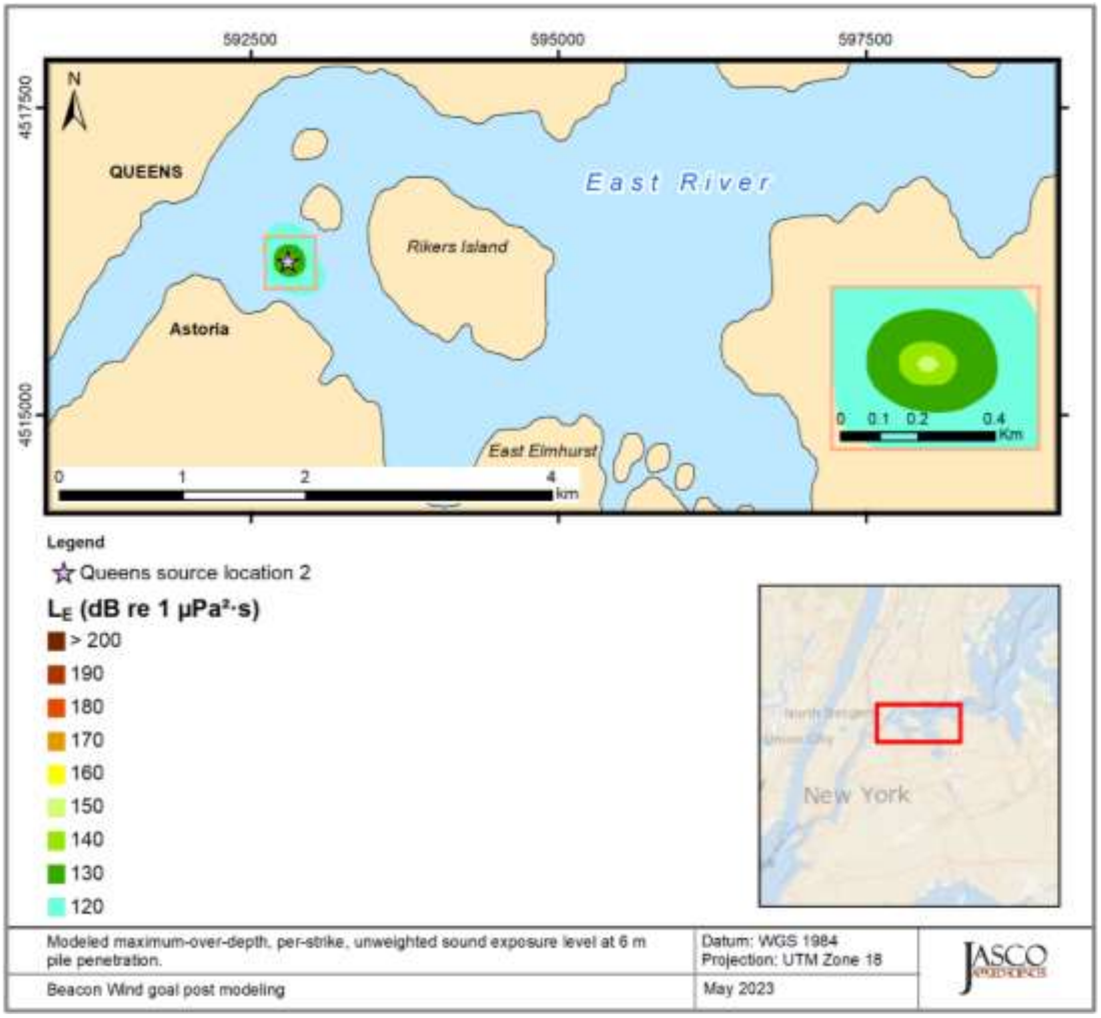

Figure 10. Modeled maximum-over-depth sound exposure level (unweighted SEL) for a goal post in the Queens location QUE 2 at 12 m pile penetration.

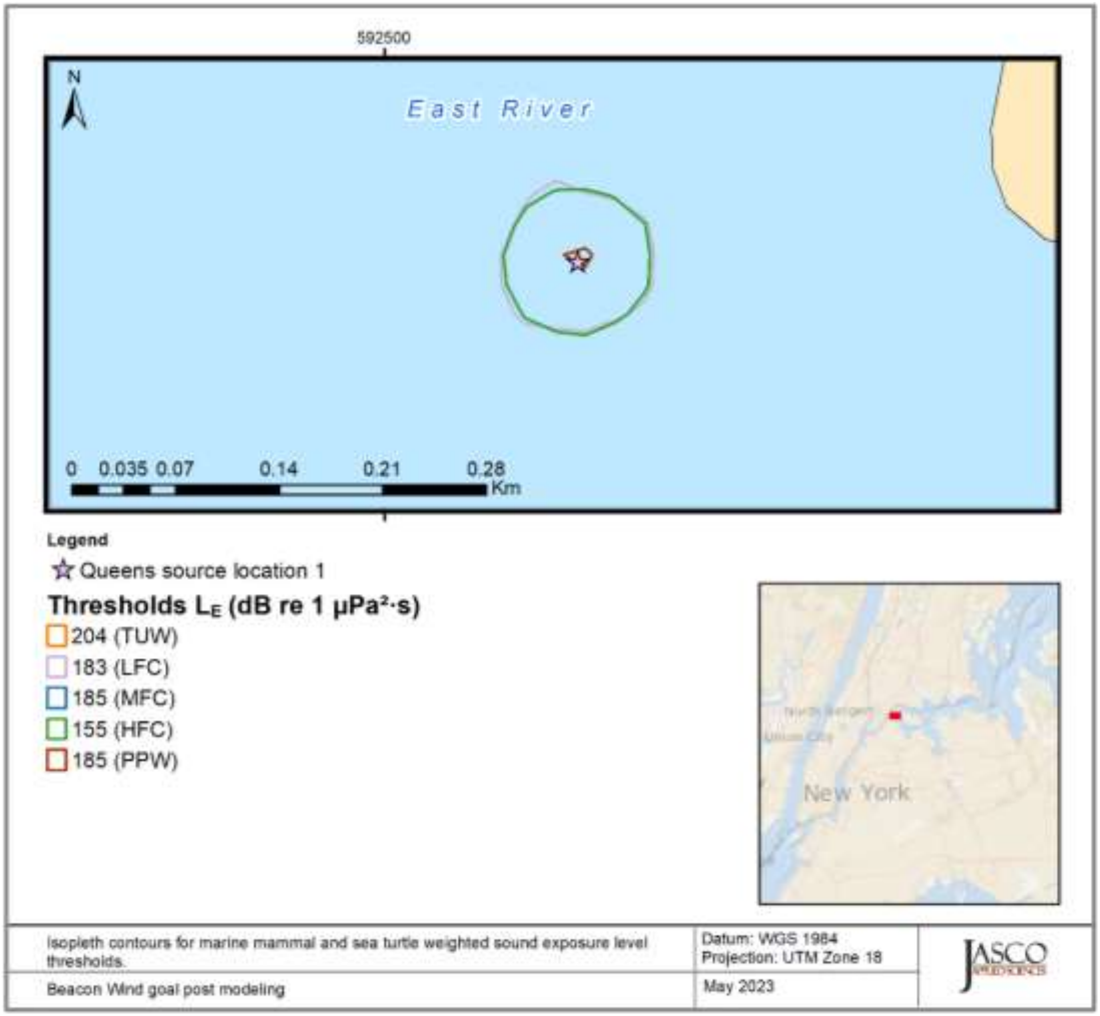

Figure 11. Modeled goal post sound exposure level (weighted SEL) to marine mammal (LFC, MFC, HFC, and PPW) and sea turtle (TUW) injury thresholds for the Queens location QUE 1.

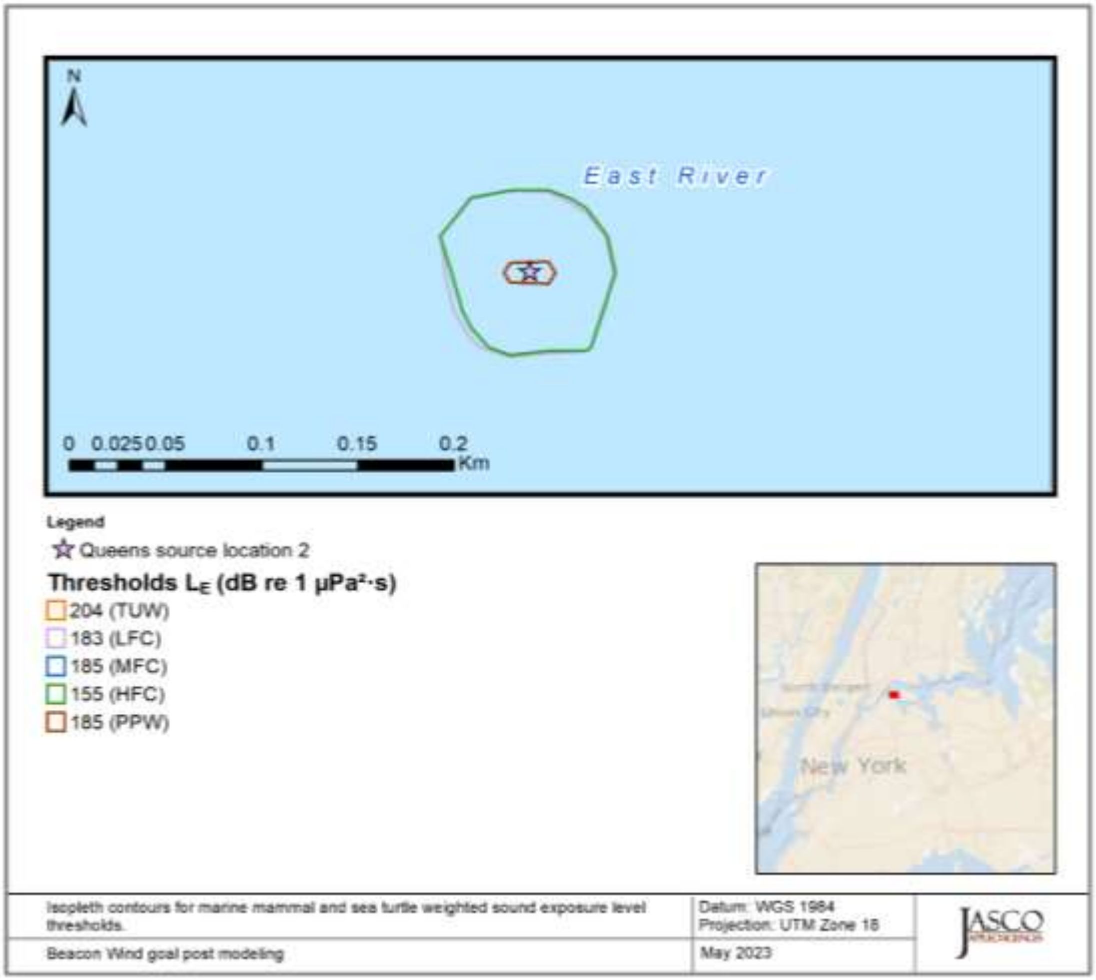

Figure 12. Modeled goal post sound exposure level (weighted SEL) to marine mammal (LFC, MFC, HFC, and PPW) and sea turtle (TUW) injury thresholds for the Queens location QUE 2.

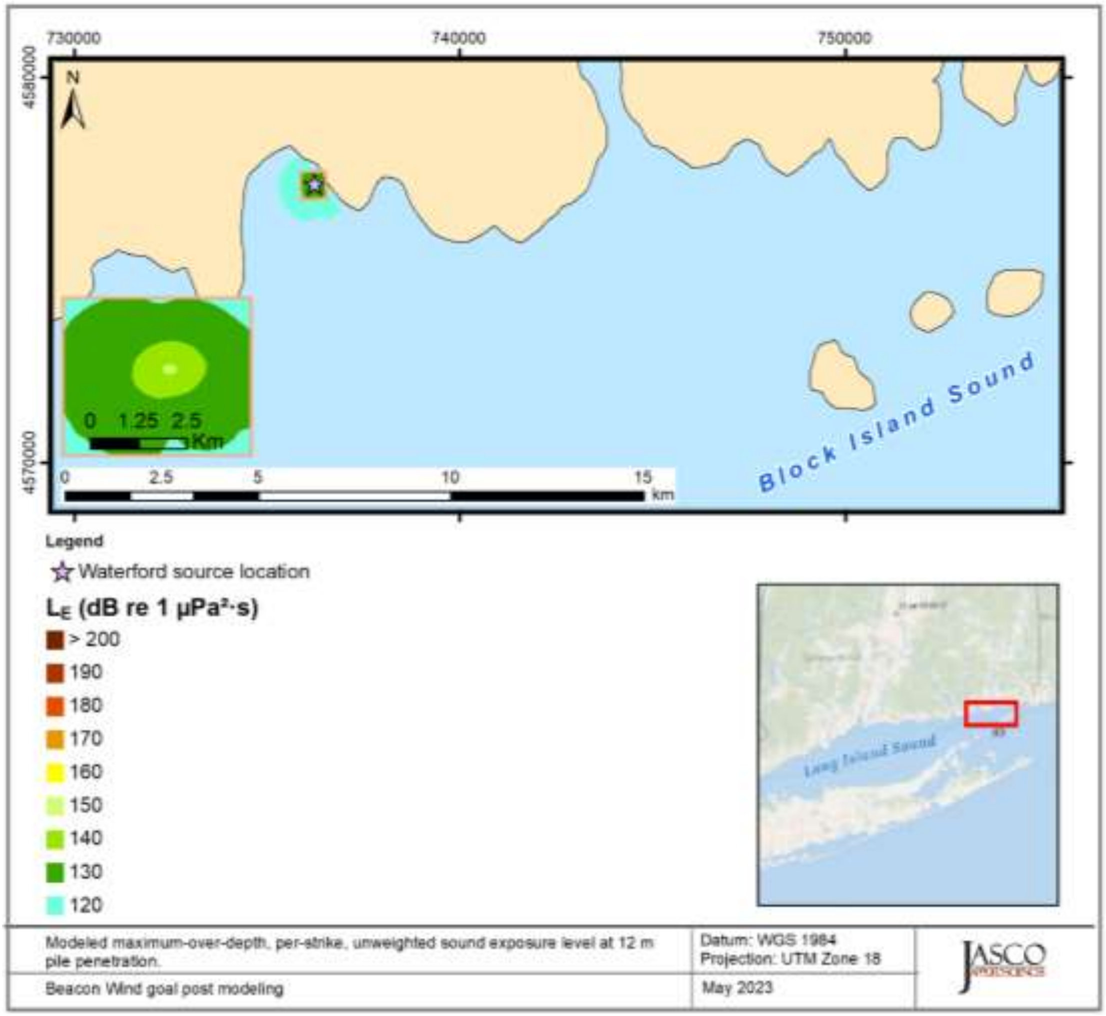

Figure 13. Modeled maximum-over-depth sound exposure level (unweighted SEL) for a goal post in the Waterford location at 12 m pile penetration.

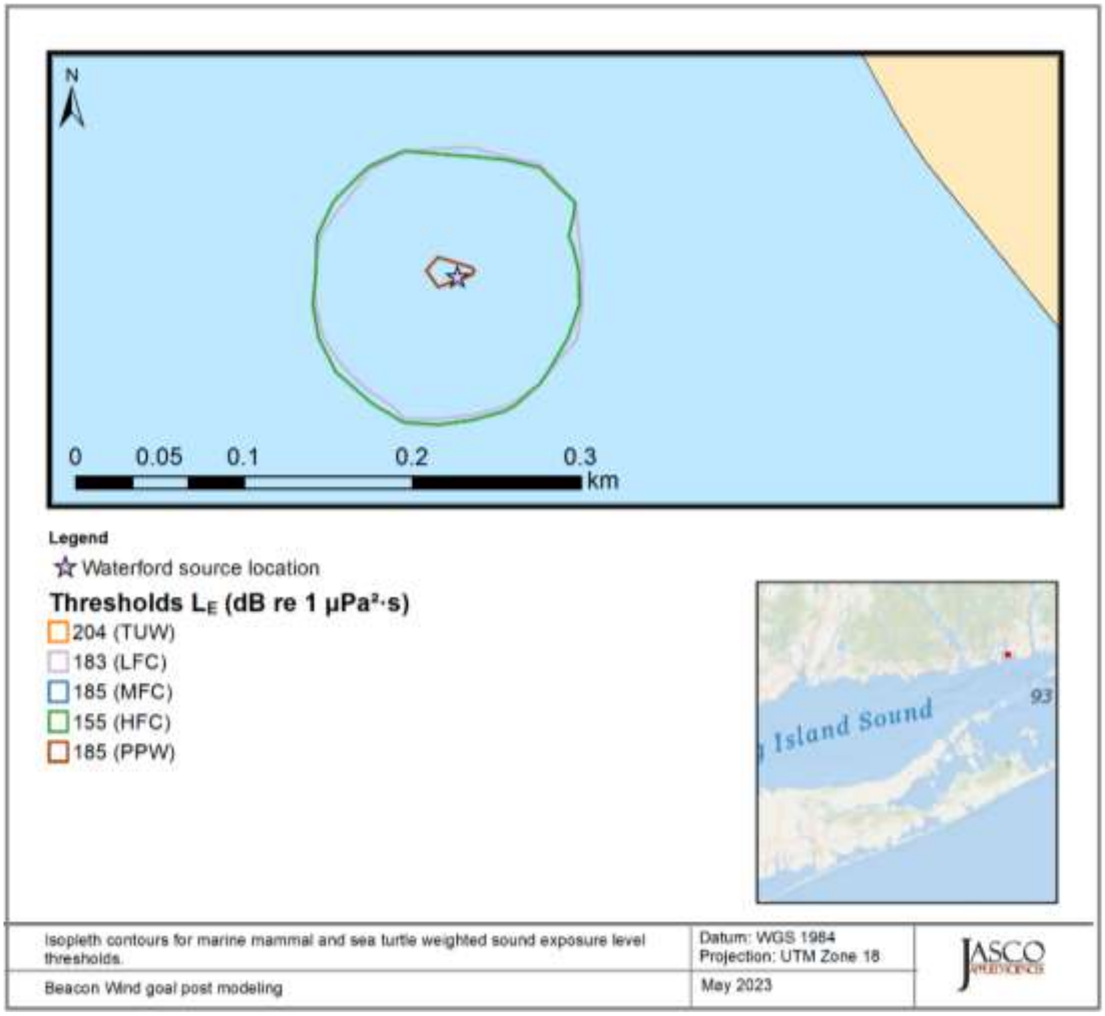

Figure 14. Modeled goal post sound exposure level (weighted SEL) to marine mammal (LFC, MFC, HFC, and PPW) and sea turtle (TUW) injury thresholds for the Waterford location.

3.1.3. Casing Pipe Acoustic Ranges

Modeled distances to potential injury for marine fauna during casing pipe installation are shown in Table 12 for the Queens locations and Table 11 for the Waterford location. Figures 15, 16, and 19 show unweighted SEL isopleths in 10 dB intervals to demonstrate sound propagation characteristics away from each modeled casing pipe location. The lowest isopleth of 120 dB re 1 µPa^2·s is considered close to ambient noise levels in general, so levels below it are not acoustically significant. The inset map shows modeled levels closer to the source location. Isopleths to weighted SEL thresholds for marine mammal and sea turtle injury were separately plotted and are shown in Figures 17, 18, and 20. These plots present an additional visualization of the results shown in Tables 12-13 with respect to the area of impact around the source. Fish isopleths to injury thresholds were not plotted because the weighted marine mammal and sea turtle threshold isopleths converged at the same distances, making the plots unreadable.

For the casing pipe, the isopleth distances to the SPL 160 dB re 1 µPa marine mammal behavioral threshold (NMFS 2018) extends to 810 m and 674 m at the Queens locations QUE1 and QUE2 with high tides (Table 14) and 2.35 km at the Waterford location (Table 15). These ranges exclude 5% of the farthest points ($R_{95\%}$). The Peak (PK) acoustic ranges for marine mammal and sea turtle injury thresholds is essentially zero for the goal posts at the 3 locations and near-zero for the casing pipe at the 3 locations. Each of the ranges were estimated during the early fall season. Propagation extent and shoreline are determined using global bathymetry data (Mean Lower Low Water (MLLW) datum) (Table 6).

Table 12. *Queens casing pipe site*: Distances to PTS onset thresholds for marine mammals, fish and sea turtle injury thresholds for sounds generated by impact driving of casing pipes at the QUE1 and QUE2 sites.

Hearing group	$L_{E,24h}$ (dB re 1 µPa²·s)	R_{max} (m)	$R_{95\%}$ (m)	Area (m²)	R_{max} (m)	$R_{95\%}$ (m)	Area (m²)
		QUE1			QUE2		
Low-frequency cetaceans (LFC)[a, e]	183 [a]	1,243	1,077	943,433	1,362	1,191	885,807
Mid-frequency cetaceans (MFC) [a, e]	185 [a]	481	373	77,437	477	389	65,144
High-frequency cetaceans (HFC)[a, e]	155 [a]	1,267	1,094	899,202	1,412	1,244	950,332
Phocid pinnipeds in water (PPW)[a]	185 [a]	1,186	1,030	633,348	1,153	1,040	505,171
Sea turtles[b, e]	204 [b]	525	443	49,087	477	414	33,980
Fish ≥ 2 g[c]	187[c]	1,219	1,052	856,034	1,217	1,086	699,897
Fish < 2 g[c]	183[c]	1,243	1,072	995,788	1,362	1,189	916,089
Fish without swim bladder[d]	216[d]	247	228	9,852	180	137	10,936
Fish with swim bladder involved in hearing[d]	203[d]	904	747	173,494	667	548	109,858
Fish with swim bladder not involved in hearing[d]	203[d]	904	747	173,494	667	548	109,858

[a] Frequency-weighted threshold NMFS (2018).
[b] Frequency-weighted threshold Finneran et al. (2017).
[c] NMFS recommended criteria adopted from the Fisheries Hydroacoustic Working Group (FHWG 2008).
[d] Popper et al. (2014).

Table 13. *Waterford casing pipe site*: Distances to PTS onset thresholds for marine mammals, fish and sea turtle injury thresholds for sounds generated by impact driving of casing pipes.

Hearing group	$L_{E,24h}$ (dB re 1 µPa²·s)	R_{max} (m)	$R_{95\%}$ (m)	Area (m²)
Low-frequency cetaceans (LFC)[a, e]	183 [a]	9,293	6,427	9,435,110
Mid-frequency cetaceans (MFC) [a, e]	185 [a]	908	597	241,051
High-frequency cetaceans (HFC)[a, e]	155 [a]	14,676	11,228	12,806,300
Phocid pinnipeds in water (PPW)[a]	185 [a]	3,553	2,735	4,154,760
Sea turtles[b, e]	204 [b]	767	626	139,867
Fish ≥ 2 g[c]	187[c]	4,373	3,077	6,104,860
Fish < 2 g[c]	183[c]	9,567	6,596	9,808,960
Fish without swim bladder[d]	216[d]	371	306	35,299
Fish with swim bladder involved in hearing[d]	203[d]	1,389	1,092	482,750
Fish with swim bladder not involved in hearing[d]	203[d]	1,389	1,092	482,750

[a] Frequency-weighted threshold NMFS (2018).
[b] Frequency-weighted threshold Finneran et al. (2017).
[c] NMFS recommended criteria adopted from the Fisheries Hydroacoustic Working Group (FHWG 2008).
[d] Popper et al. (2014).

Table 14. *Queens casing pipe site*: Distances to behavioral thresholds for marine mammals, fish and sea turtles for sounds generated by impact driving of casing pipes for mid depth penetration at the QUE1 and QUE2 sites.

Hearing group	L_P (dB re 1 µPa)	R_{max} (m)	$R_{95\%}$ (m)	Area (m^2)
		QUE1		
Fish	150[a]	1,143	986	916,089
Marine mammals	160[b]	974	810	315,696
Sea turtles	175[c]	354	291	24,885
		QUE2		
Fish	150[a]	1,078	938	699,897
Marine mammals	160[b]	838	674	202,683
Sea turtles	175[c]	307	262	18,627

[a] Andersson et al. (2007), Mueller-Blenkle et al. (2010), Purser and Radford (2011), Wysocki et al. (2007).
[b] NOAA (2005)
[c] McCauley et al. (2000).

Table 15. *Waterford casing pipe site*: Distances to behavioral thresholds for marine mammals, fish and sea turtles for sounds generated by impact driving of casing pipes for mid depth penetration.

Hearing group	L_P (dB re 1 µPa)	R_{max} (m)	$R_{95\%}$ (m)	Area (m^2)
Fish	150[a]	4,203	2,919	6,210,410
Marine mammals	160[b]	2,902	2,351	1,215,430
Sea turtles	175[c]	541	456	68,814

[a] Andersson et al. (2007), Mueller-Blenkle et al. (2010), Purser and Radford (2011), Wysocki et al. (2007).
[b] NOAA (2005)
[c] McCauley et al. (2000)

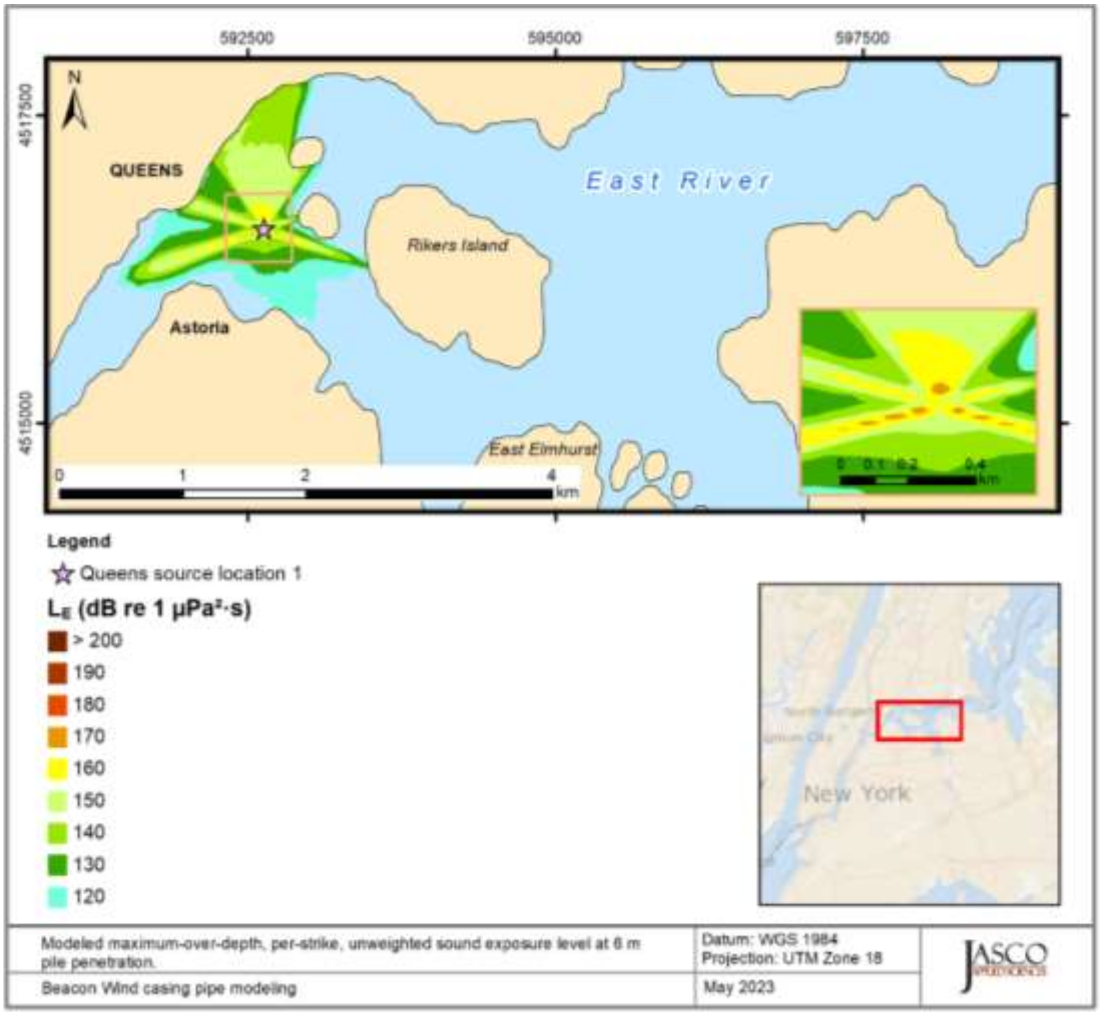

Figure 15. Modeled maximum-over-depth sound exposure level (unweighted SEL) for a casing pipe in the Queens location QUE 1 at 6 m pile penetration.

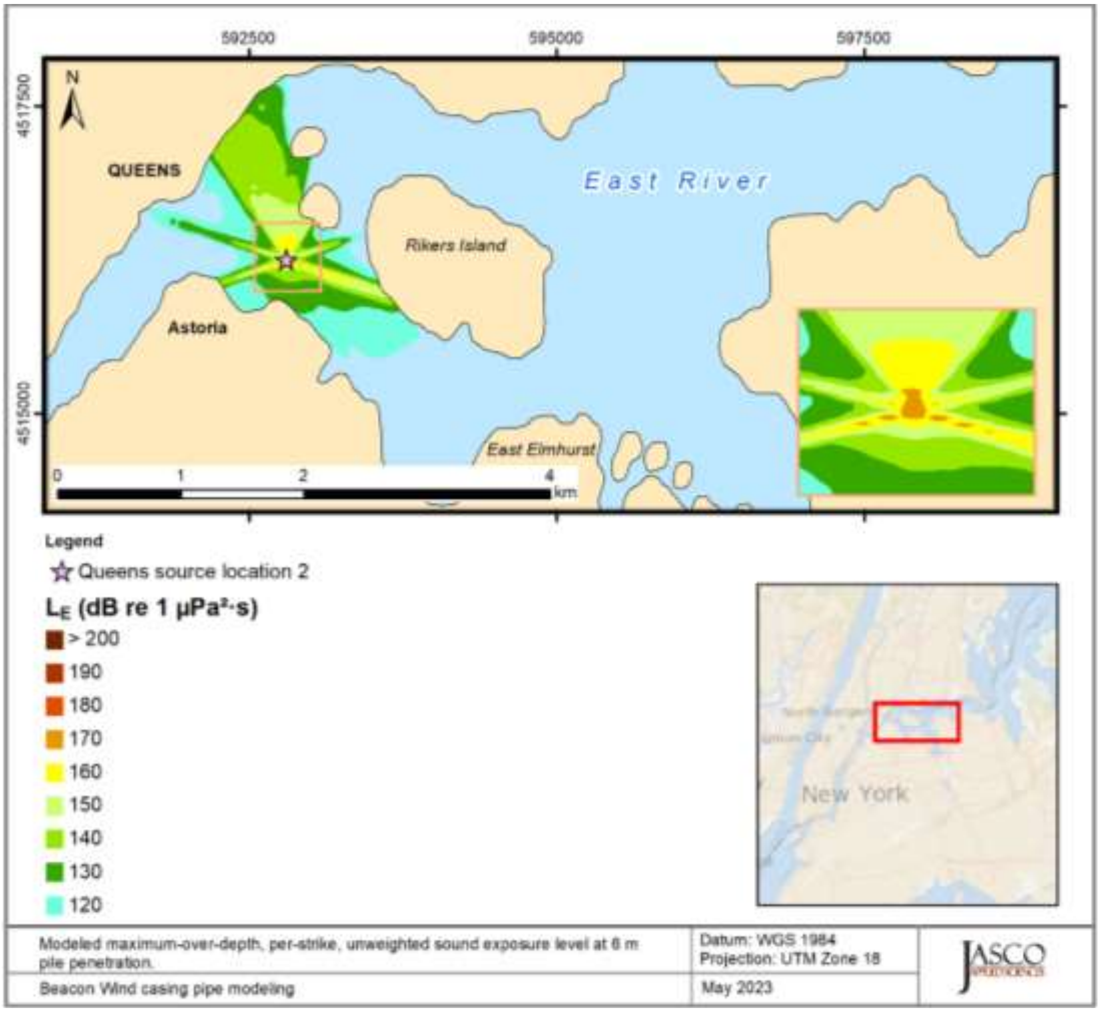

Figure 16. Modeled maximum-over-depth sound exposure level (unweighted SEL) for a casing pipe in the Queens location QUE 2 at 6 m pile penetration.

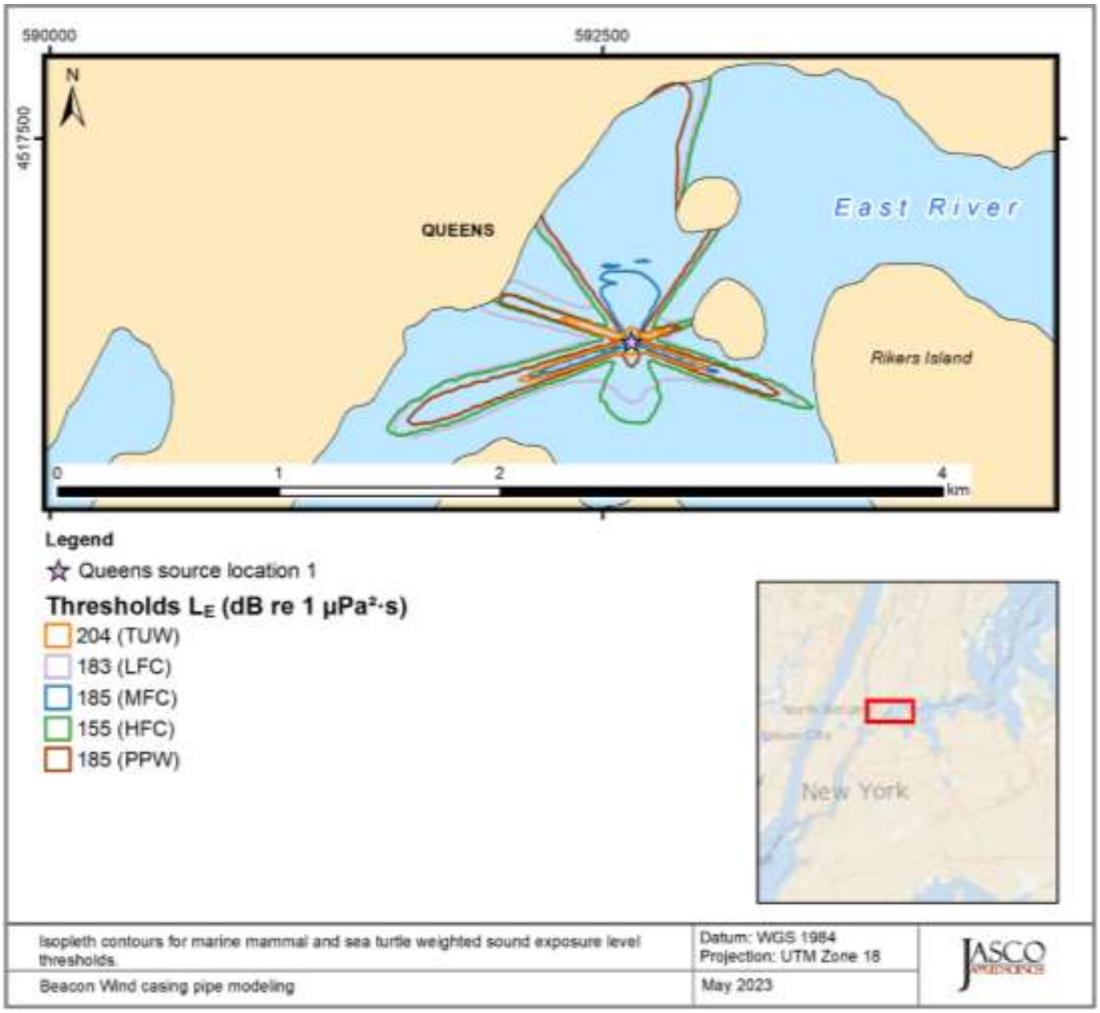

Figure 17. Modeled casing pipe sound exposure level (weighted SEL) to marine mammal (LFC, MFC, HFC, and PPW) and sea turtle (TUW) injury thresholds for the Queens location QUE 1.

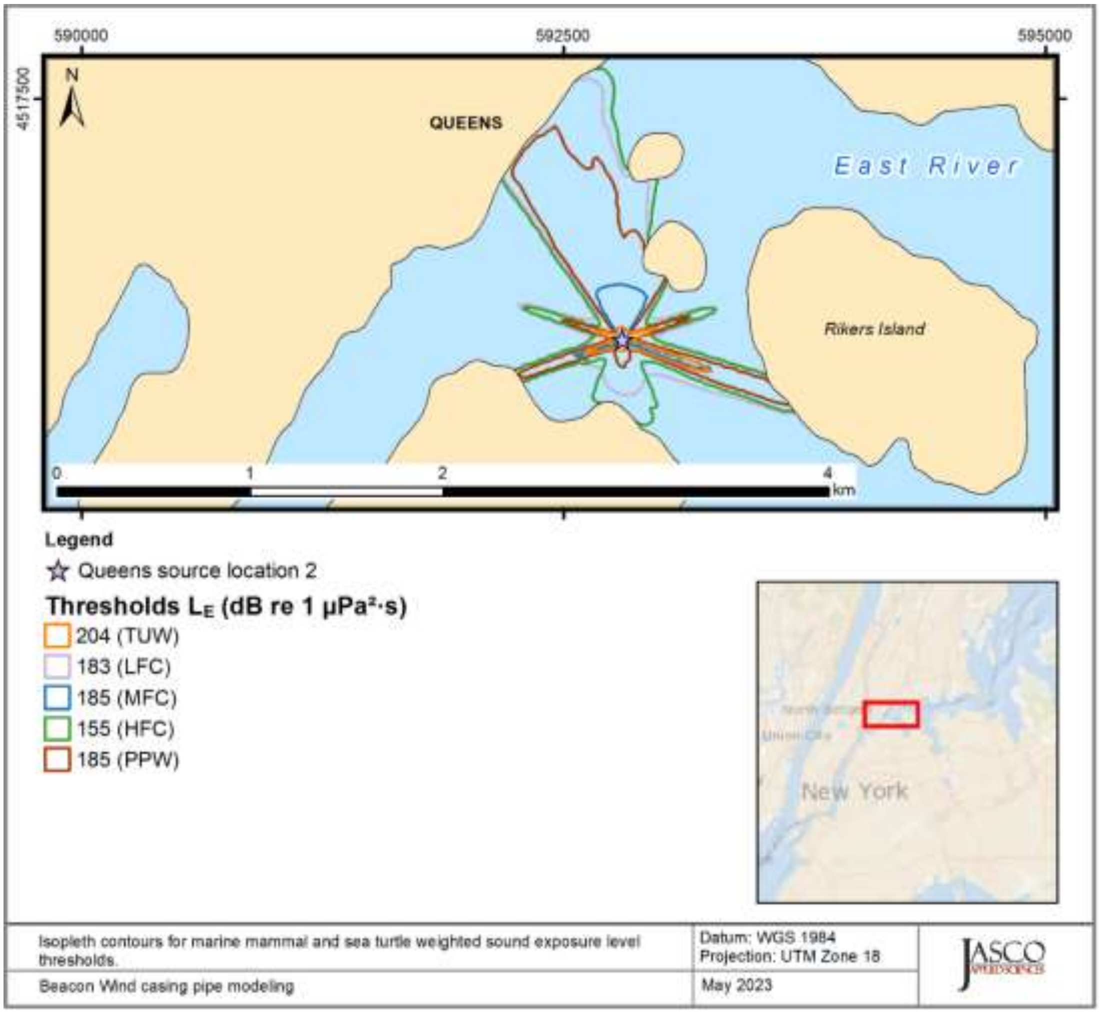

Figure 18. Modeled casing pipe sound exposure level (weighted SEL) to marine mammal (LFC, MFC, HFC, and PPW) and sea turtle (TUW) injury thresholds for the Queens location QUE 2.

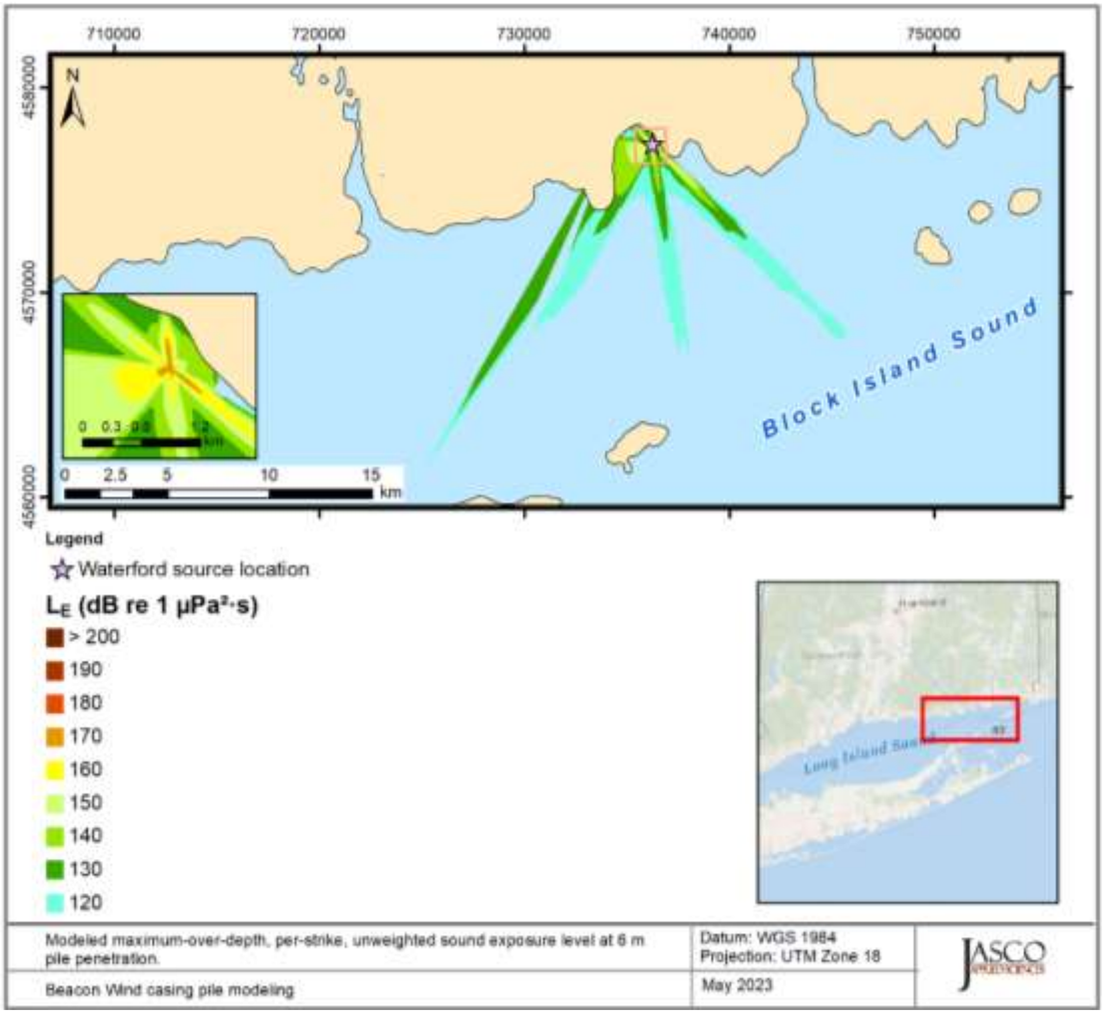

Figure 19. Modeled maximum-over-depth sound exposure level (unweighted SEL) for a casing pipe in the Waterford location at 6 m pile penetration.

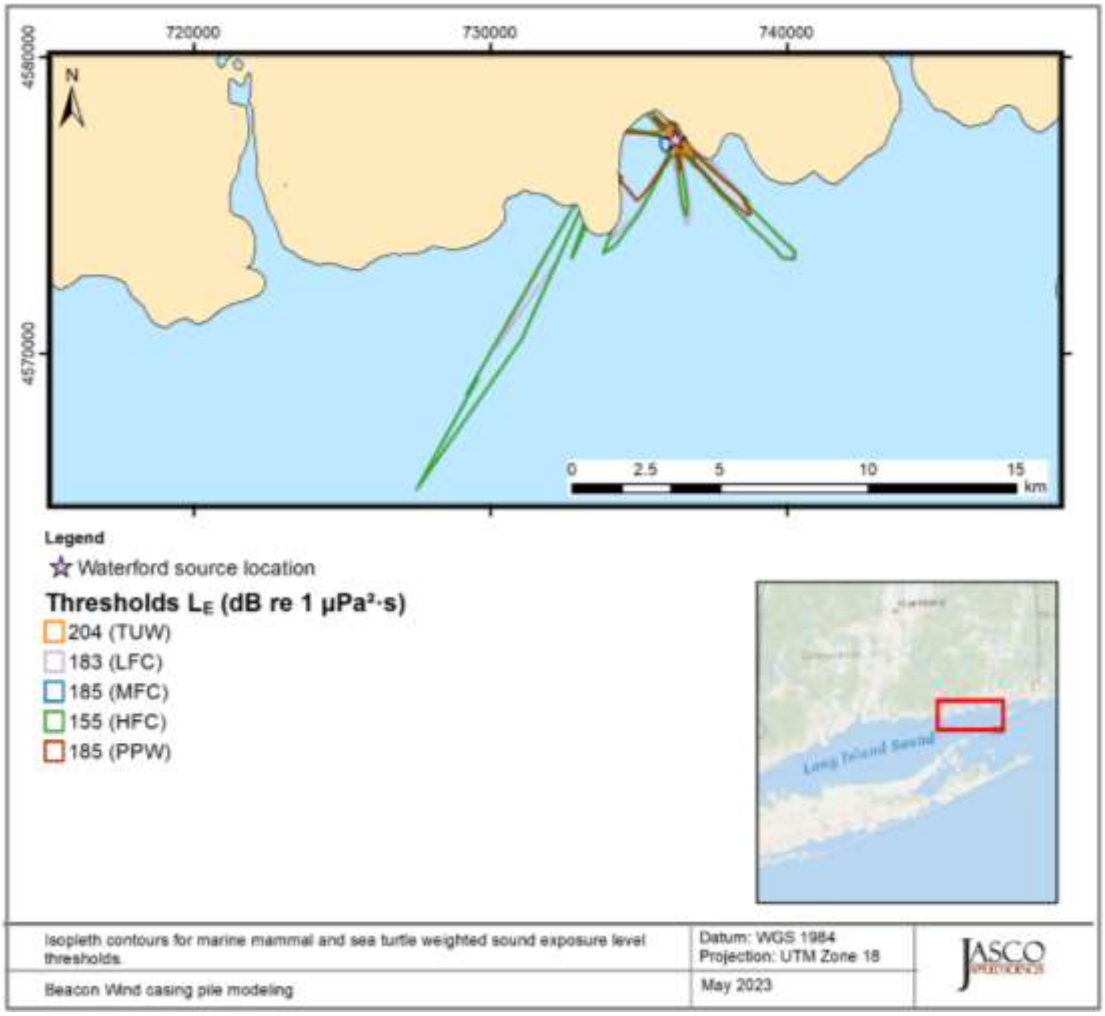

Figure 20. Modeled casing pipe sound exposure level (weighted SEL) to marine mammal (LFC, MFC, HFC, and PPW) and sea turtle (TUW) injury thresholds for the Waterford location.

3.2. Exposure Estimates

Exposure estimates were calculated for the months when goal post and casing pipe installation may occur. The number of exposures to marine mammal and sea turtle injury and behavioral thresholds are provided in Tables 16-18. In the Queens locations, exposures above injury thresholds are low, with less than 0.01 for all species except seals. The number of exposures above injury thresholds were higher at the Waterford location, the highest number of exposures being 1.1 for harbor seals.

The number of exposures above the behavioral threshold were higher at the Waterford location, with the highest number of exposures at 0.48 for harbor seals. The number of exposures above the behavioral threshold for common dolphins was also higher at the Waterford location, with 0.14 exposures. The number of exposures above the behavioral threshold at the Queens location are less than 0.01 for all species, except for seals. Harbor seals had the highest number of exposures above the behavioral threshold for at both Queens locations (0.17, 0.11).

Table 16. Maximum predicted marine mammal exposures above injury and behavioral thresholds resulting from casing pipe and goal post impact piling at the QUE1 site for July through Nov.

Species	QUE1	
	Injury	Behavior
Fin whale	<0.01	<0.01
Minke whale	<0.01	<0.01
Humpback whale	<0.01	<0.01
North Atlantic right whale	0	0
Sei whale	<0.01	<0.01
Atlantic white-sided dolphin	<0.01	<0.01
Atlantic spotted dolphin	<0.01	<0.01
Common dolphin	<0.01	<0.01
Bottlenose dolphin, offshore	0	0
Risso’s dolphin	<0.01	<0.01
Long-finned pilot whale	<0.01	<0.01
Short-finned pilot whale	<0.01	<0.01
Sperm whale	<0.01	<0.01
Harbor porpoise	<0.01	<0.01
Gray seal	0.1	0.08
Harbor seal	0.23	0.17
Harp seal	0.08	0.06
Kemp’s ridley turtle	<0.01	<0.01
Leatherback turtle	<0.01	<0.01
Loggerhead turtle	<0.01	<0.01
Green turtle	<0.01	<0.01

Table 17. Maximum predicted marine mammal exposures above injury and behavioral thresholds resulting from casing pipe and goal post impact piling at the QUE2 site for July through Nov.

Species	QUE2	
	Injury	Behavior
Fin whale	<0.01	<0.01
Minke whale	<0.01	<0.01
Humpback whale	<0.01	<0.01
North Atlantic right whale	0	0
Sei whale	<0.01	<0.01
Atlantic white-sided dolphin	<0.01	<0.01
Atlantic spotted dolphin	<0.01	<0.01
Common dolphin	<0.01	<0.01
Bottlenose dolphin, offshore	0	0
Risso's dolphin	<0.01	<0.01
Long-finned pilot whale	<0.01	<0.01
Short-finned pilot whale	<0.01	<0.01
Sperm whale	<0.01	<0.01
Harbor porpoise	<0.01	<0.01
Gray seal	0.08	0.05
Harbor seal	0.18	0.11
Harp seal	0.07	0.04
Kemp's ridley turtle	<0.01	<0.01
Leatherback turtle	<0.01	<0.01
Loggerhead turtle	<0.01	<0.01
Green turtle	<0.01	<0.01

Table 18. Maximum predicted marine mammal exposures above injury and behavioral thresholds resulting from casing pipe and goal post impact piling at the Waterford site for July through Nov.

Species	Waterford	
	Injury	Behavior
Fin whale	<0.01	<0.01
Minke whale	0.01	<0.01
Humpback whale	0.02	<0.01
North Atlantic right whale	<0.01	<0.01
Sei whale	<0.01	<0.01
Atlantic white-sided dolphin	<0.01	0.05
Atlantic spotted dolphin	<0.01	<0.01
Common dolphin	0.02	0.14
Bottlenose dolphin, offshore	<0.01	<0.01
Risso's dolphin	<0.01	<0.01
Long-finned pilot whale	<0.01	<0.01
Short-finned pilot whale	<0.01	<0.01
Sperm whale	<0.01	<0.01
Harbor porpoise	0.02	<0.01
Gray seal	0.49	0.21
Harbor seal	1.1	0.48
Harp seal	0.49	0.21
Kemp's ridley turtle	<0.01	<0.01
Leatherback turtle	<0.01	<0.01
Loggerhead turtle	<0.01	<0.01
Green turtle	<0.01	<0.01

4. Summary

4.1. Acoustic Ranges

Exposures resulting in injury to marine mammals and sea turtles (PTS), or fish is unlikely to occur from the proposed goal post installations because the modeled isopleth distances to potential injury thresholds are <200 m at the sites considered and few marine mammals and sea turtles are expected in the area (Table 5). The farthest acoustic ranges were predicted at the Waterford goal post site. The modeled isopleth distances ($R_{95\%}$) for marine mammal (PTS), sea turtle, and fish injury, however, for the casing pipe is up to ~1 km at the Queens site (Table 12), and are up to ~11 km at the Waterford location (Table 13). These calculated distances, however, may be considered conservative because it is assumed that animals are stationary (i.e. static receivers) during the 4 hours that are required for either the casing pipe or the goal post installation, but real marine mammals, sea turtles, and (some) fish will likely be moving through the area and would not be exposed to sound for the entire installation. Additionally, animals, especially high-frequency mammalian species, are likely to avoid the construction sounds, which would further reduce the likelihood of injury.

For the goal post, the longest distance for marine mammal behavioral disruption (SPL 160 dB re 1 µPa) is <20 m. For the casing pipe, in Queens, the ranges for SPL 160 dB re 1 µPa behavioral threshold are between 600 and 850 m and up to ~2.35 km in Waterford. Sound propagation in most directions is obscured by bathymetry and land features.

4.2. Exposure Estimates

Calculated exposure estimates above injury thresholds at all three goal post locations are <0.01 individuals for all species except for seals.

Modeled exposures above behavioral threshold for goal post and casing pipe installation at the QUE1 and QUE2 are also <0.01 for all species expect for seals. For harbor seals, the largest number of exposures above the behavioral threshold were 0.17 at QUE1(Table 16). The greatest number of modeled exposures above the behavioral threshold at Queens was for harbor seals, with 0.11 exposures (QUE1). Modeled exposures above the behavioral threshold at the Waterford location were larger overall than at the Queens location since sound fields were less restricted by land and due to higher marine mammal densities at that location. The greatest number of modeled exposures above the behavioral threshold at Waterford and Queens was for harbor seals, with 0.48 exposures and 0.11 exposures (Queens 1), respectively.

Literature Cited

[DoN] Department of the Navy (US). 2012. *Commander Task Force 20, 4th, and 6th Fleet Navy marine species density database*. Technical report for Naval Facilities Engineering Command Atlantic, Norfolk, VA.

[DoN] Department of the Navy (US). 2017. *U.S. Navy marine species density database phase III for the Atlantic Fleet training and testing study area. NAVFAC Atlantic Final Technical Report*. Naval Facilities Engineering Command Atlantic, Norfolk, VA.

[FHWG] Fisheries Hydroacoustic Working Group. 2008. *Agreement in Principle for Interim Criteria for Injury to Fish from Pile Driving Activities*. 12 Jun 2008 edition. http://www.dot.ca.gov/hq/env/bio/files/fhwgcriteria_agree.pdf.

[NMFS] National Marine Fisheries Service (US) and [NOAA] National Oceanic and Atmospheric Administration (US). 2005. Endangered fish and wildlife: Notice of intent to prepare an environmental impact statement. *Federal Register* 70(7): 1871-1875. http://www.nmfs.noaa.gov/pr/pdfs/fr/fr70-1871.pdf.

[NMFS] National Marine Fisheries Service (US). 2018. *2018 Revision to: Technical Guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammal Hearing (Version 2.0): Underwater Thresholds for Onset of Permanent and Temporary Threshold Shifts*. US Department of Commerce, NOAA. NOAA Technical Memorandum NMFS-OPR-59. 167 p. https://www.fisheries.noaa.gov/webdam/download/75962998.

[NOAA] National Oceanic and Atmospheric Administration (US). 2020. Tides & Currents. https://tidesandcurrents.noaa.gov/ (Accessed 31 May 2020).

Andersson, M.H., E. Dock-Åkerman, R. Ubral-Hedenberg, M.C. Öhman, and P. Sigray. 2007. Swimming behavior of roach (*Rutilus rutilus*) and three-spined stickleback (*Gasterosteus aculeatus*) in response to wind power noise and single-tone frequencies. *AMBIO* 36(8): 636-638. https://doi.org/10.1579/0044-7447(2007)36[636:SBORRR]2.0.CO;2.

Buehler, D., R. Oestman, J.A. Reyff, K. Pommerenck, and B. Mitchell. 2015. *Technical Guidance for Assessment and Mitigation of the Hydroacoustic Effects of Pile Driving on Fish*. Report Number CTHWANP-RT-15-306.01.01. Report by California Department of Transportation (CALTRANS), Division of Environmental Analysis. 532 p. https://dot.ca.gov/-/media/dot-media/programs/environmental-analysis/documents/bio-tech-guidance-hydroacoustic-effects-110215-a11y.pdf.

Collins, M.D. 1993. A split-step Padé solution for the parabolic equation method. *Journal of the Acoustical Society of America* 93(4): 1736-1742. https://doi.org/10.1121/1.406739.

Finneran, J.J., E.E. Henderson, D.S. Houser, K. Jenkins, S. Kotecki, and J. Mulsow. 2017. *Criteria and Thresholds for U.S. Navy Acoustic and Explosive Effects Analysis (Phase III)*. Technical report by Space and Naval Warfare Systems Center Pacific (SSC Pacific). 183 p. https://nwtteis.com/portals/nwtteis/files/technical_reports/Criteria_and_Thresholds_for_U.S._Navy_Acoustic_and_Explosive_Effects_Analysis_June2017.pdf.

Illingworth & Rodkin, Inc. 2007. Appendix I. Compendium of pile driving sound data. *In Technical Guidance for Assessment and Mitigation of the Hydroacoustic Effects of Pile Driving on Fish*. Illingworth & Rodkin, Inc. for the California Department of Transportation, Sacramento, CA, Sacramento, CA. p. 129. www.dot.ca.gov/hq/env/bio/files/pile_driving_snd_comp9_27_07.pdf.

MacGillivray, A.O. and N.R. Chapman. 2012. Modeling underwater sound propagation from an airgun array using the parabolic equation method. *Canadian Acoustics* 40(1): 19-25. https://jcaa.caa-aca.ca/index.php/jcaa/article/view/2502/2251.

MacGillivray, A.O. 2014. A model for underwater sound levels generated by marine impact pile driving. *Proceedings of Meetings on Acoustics* 20(1). https://doi.org/10.1121/2.0000030

Malme, C.I., P.R. Miles, C.W. Clark, P.L. Tyack, and J.E. Bird. 1983. *Investigations of the Potential Effects of Underwater Noise from Petroleum Industry Activities on Migrating Gray Whale Behavior. Final Report for the Period of 7 June 1982 - 31 July 1983*. Report Number 5366. Report by Bolt Beranek and Newman Inc. for US Department of the Interior, Minerals Management Service, Alaska OCS Office, Cambridge, MA, USA. https://www.boem.gov/sites/default/files/boem-newsroom/Library/Publications/1983/rpt5366.pdf.

Malme, C.I., P.R. Miles, C.W. Clark, P.L. Tyack, and J.E. Bird. 1984. *Investigations of the Potential Effects of Underwater Noise from Petroleum Industry Activities on Migrating Gray Whale Behavior. Phase II: January 1984 Migration*. Report Number 5586. Report by Bolt Beranek and Newman Inc. for the US Department of the Interior, Minerals Management Service, Cambridge, MA, USA. https://www.boem.gov/sites/default/files/boem-newsroom/Library/Publications/1983/rpt5586.pdf.

Matuschek, R. and K. Betke. 2009. Measurements of construction noise during pile driving of offshore research platforms and wind farms. *NAG-DAGA 2009 International Conference on Acoustics*. 23-26 Mar 2009, Rotterdam, Netherlands. pp. 262-265.

McCauley, R.D., J. Fewtrell, A.J. Duncan, C. Jenner, M.-N. Jenner, J.D. Penrose, R.I.T. Prince, A. Adhitya, J. Murdoch, et al. 2000. Marine seismic surveys: A study of environmental implications. *Australian Petroleum Production Exploration Association (APPEA) Journal* 40(1): 692-708. https://doi.org/10.1071/AJ99048.

Mueller-Blenkle, C., P.K. McGregor, A.B. Gill, M.H. Andersson, J. Metcalfe, V. Bendall, P. Sigray, D.T. Wood, and F. Thomsen. 2010. *Effects of Pile-driving Noise on the Behaviour of Marine Fish*. COWRIE Ref: Fish 06-08; Cefas Ref: C3371. 62 p. https://dspace.lib.cranfield.ac.uk/handle/1826/8235.

Pile Dynamics, Inc. 2010. GRLWEAP. https://www.pile.com/.

Popper, A.N., A.D. Hawkins, R.R. Fay, D.A. Mann, S. Bartol, T.J. Carlson, S. Coombs, W.T. Ellison, R.L. Gentry, et al. 2014. *Sound Exposure Guidelines for Fishes and Sea Turtles: A Technical Report prepared by ANSI-Accredited Standards Committee S3/SC1 and registered with ANSI*. ASA S3/SC1.4 TR-2014. SpringerBriefs in Oceanography. ASA Press and Springer. https://doi.org/10.1007/978-3-319-06659-2.

Purser, J. and A.N. Radford. 2011. Acoustic noise induces attention shifts and reduces foraging performance in three-spined sticklebacks (*Gasterosteus aculeatus*). *PLOS ONE* 6(2): e17478. https://doi.org/10.1371/journal.pone.0017478.

Richardson, W.J., B. Würsig, and C.R. Greene, Jr. 1986. Reactions of bowhead whales, *Balaena mysticetus*, to seismic exploration in the Canadian Beaufort Sea. *Journal of the Acoustical Society of America* 79(4): 1117-1128. https://doi.org/10.1121/1.393384.

Richardson, W.J., B. Würsig, and C.R. Greene, Jr. 1990. Reactions of bowhead whales, *Balaena mysticetus*, to drilling and dredging noise in the Canadian Beaufort Sea. *Marine Environmental Research* 29(2): 135-160. https://doi.org/10.1016/0141-1136(90)90032-J.

Roberts, J.J., T.M. Yack, and P.N. Halpin. 2022. *Habitat-based marine mammal density models for the U.S. Atlantic.* (webpage). https://seamap.env.duke.edu/models/Duke/EC/.

Sills, J.M., B.L. Southall, and C. Reichmuth. 2014. Amphibious hearing in spotted seals (*Phoca largha*): Underwater audiograms, aerial audiograms and critical ratio measurements. *Journal of Experimental Biology* 217(5): 726-734. https://doi.org/10.1242/jeb.097469.

Southall, B.L., A.E. Bowles, W.T. Ellison, J.J. Finneran, R.L. Gentry, C.R. Greene, Jr., D. Kastak, D.R. Ketten, J.H. Miller, et al. 2007. Marine Mammal Noise Exposure Criteria: Initial Scientific Recommendations. *Aquatic Mammals* 33(4): 411-521. https://doi.org/10.1578/AM.33.4.2007.411.

Wysocki, L.E., S. Amoser, and F. Ladich. 2007. Diversity in ambient noise in European freshwater habitats: Noise levels, spectral profiles, and impact on fishes. *Journal of the Acoustical Society of America* 121(5): 2559-2566. https://doi.org/10.1121/1.2713661.

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