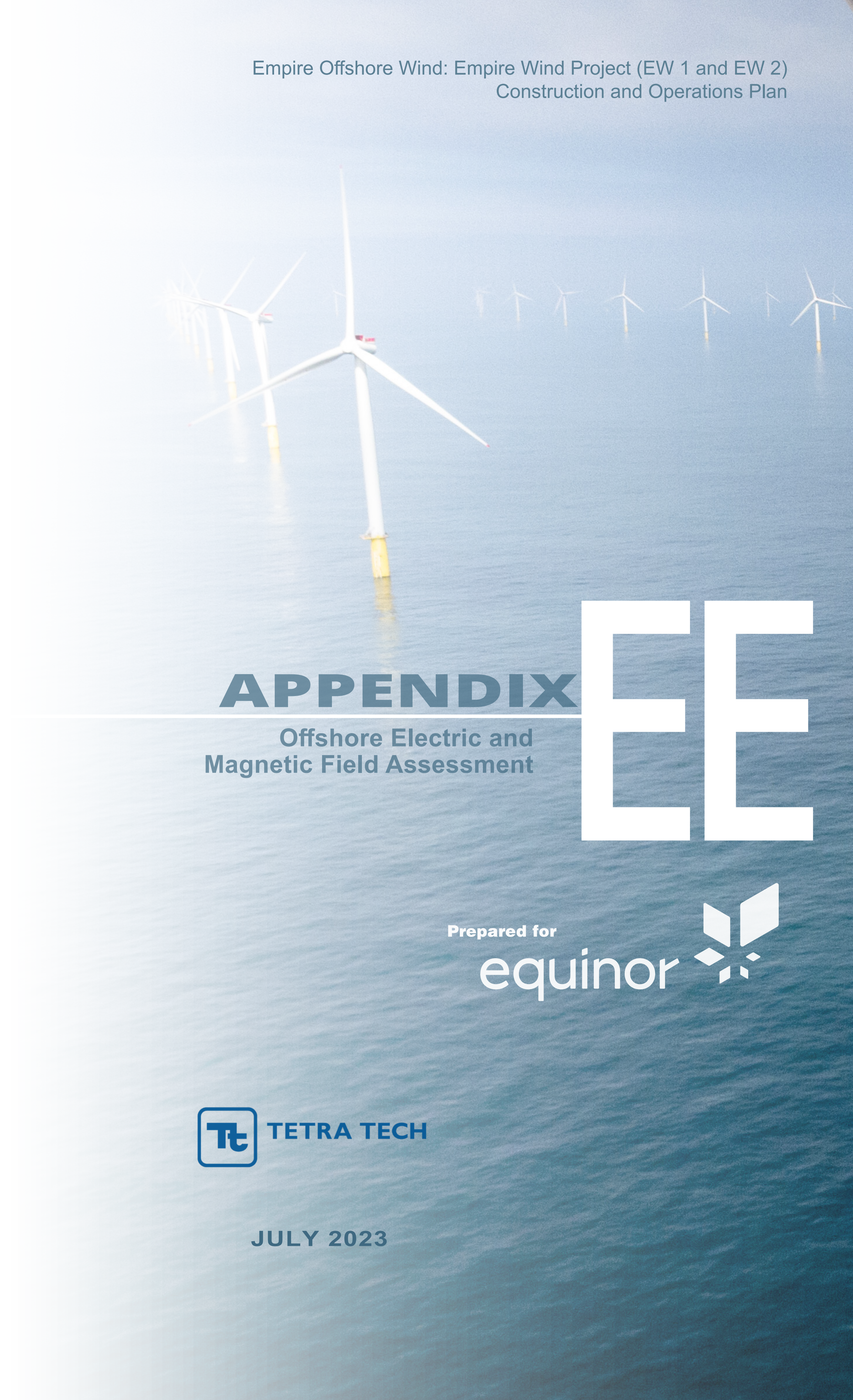
The latest revision date of Appendix EE to the Empire Offshore Wind COP is July 2023. This appendix was not revised as part of the November 2023 submittal; therefore, the date on the Appendix EE cover sheet remains as July 2023.



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

APPENDIX EE

Offshore Electric and Magnetic Field Assessment

Prepared for
equinor

TETRA TECH

JULY 2023

Exponent Engineering P.C.

Electrical Engineering and Computer Science Practice

Ecological and Biological Sciences Practice

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

Updated Offshore Electric- and Magnetic-Field Assessment

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

Updated Offshore Electric- and Magnetic-Field Assessment

Prepared for

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June 22, 2023

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Acronyms and Abbreviations

µV/m	Microvolts per meter
A	Ampere
AC	Alternating current
ASFMC	Atlantic States Fisheries Commission
BOEM	Bureau of Energy Ocean Management
DC	Direct current
EMF	Electric and magnetic fields
Empire	Empire Offshore Wind LLC
EW	Empire Wind
ft	Feet
G	Gauss
HDD	Horizontal directional drilling
Hz	Hertz
ICES	International Committee on Electromagnetic Safety
ICNIRP	International Commission on Non-Ionizing Radiation
IEEE	Institute of Electrical and Electronics Engineers
km	Kilometer
kV	Kilovolt
Lease Area	designated Renewable Energy Lease Area OCS-A 0512
m	Meter
MAFMC	Mid-Atlantic Fishery Management Council
mG	Milligauss
mi	Statute miles
mm	Millimeter
mT	Millitesla
mV/m	Millivolts per meter
MRE	Marine Renewable Energy
MW	Megawatt
NEFMC	New England Fishery Management Council
Nysted	Nysted Wind Farm in Denmark

nm	Nautical mile
NOAA	National Oceanic and Atmospheric Administration
OD	Outer diameter
POI	Point of Interconnection
Project	The offshore wind project for OCS A-0512 proposed by Empire Offshore Wind LLC consisting of Empire Wind 1 (EW 1) and Empire Wind 2 (EW 2).
Project Area	The area associated with the build out of the Lease Area, submarine export cables, interarray cables, and all onshore Project facilities.
XLPE	Cross linked polyethylene

Executive Summary

Empire Offshore Wind LLC (Empire) proposes to construct and operate an offshore wind facility in the designated Renewable Energy Lease Area OCS-A 0512 located approximately 14 statute miles (mi) (12 nautical miles [nm], 22 kilometers [km]) south of Long Island, New York, and 19.5 mi (16.9 nm, 31.4 km) east of Long Branch, New Jersey. Empire proposes to develop the Lease Area with two wind farms, known as Empire Wind 1 (EW 1) and Empire Wind 2 (EW 2) (collectively referred to hereafter as the Project). At the request of Empire, Exponent calculated the magnetic fields and electric fields induced by the magnetic field during operation of the submarine cables that will transport electricity generated by the Project to shore. Field levels were calculated for the interarray cables connecting wind turbine generators to offshore substations, and for the offshore portion of submarine export cables connecting offshore substations to landfall locations in Brooklyn, New York, and Long Beach and Hempstead, New York.

In this updated report, the primary design change is that the voltage of the EW 2 submarine export cable has been increased from 230 kilovolt (kV) to 345-kilovolt (kV) and the number of EW 2 export cables was reduced from three to two. The purpose of the report is to describe the weak magnetic fields and weak electric fields in nearby seawater and marine organisms from the EW 1 and EW 2 66-kV interarray cables, the EW 1 230-kV submarine export cables, and the EW 2 345-kV submarine export cables, and to compare the calculated levels to those reported in the literature for potential effects on key marine species that inhabit the vicinity of the Project. The calculated field levels also are compared to exposure criteria for the general public for reference.

Calculated magnetic-field levels were below reported thresholds for effects on the behavior of magnetosensitive marine organisms. Levels of electric fields induced in seawater and large fishes also were calculated to be below reported detection thresholds of local electrosensitive marine organisms. These findings are in agreement with the 2020 comprehensive review of the ecological impacts of Marine Renewable Energy development by the U.S. Pacific Northwest National Laboratory, which concluded that "[t]o date, . . . the general conclusion [is] that EMFs associated with subsea cables are not harmful and do not pose a risk to biota. This would appear to be an appropriate conclusion for MRE devices and cables because their EMF signatures are low." (Copping et al., 2020). In addition, calculated magnetic-field levels in seawater were far below limits published by the International Committee on Electromagnetic Safety and the International Commission on Non-Ionizing Radiation designed to protect the health and safety of the general public.

Note that this Executive Summary does not contain all of Exponent's technical evaluations, analyses, conclusions, and recommendations. Hence, the main body of this report is at all times the controlling document.

Introduction

Project Description

Empire Offshore Wind LLC (Empire) proposes to construct and operate the Project located in the designated Renewable Energy Lease Area OCS-A 0512 (Lease Area). The Lease Area covers approximately 79,350 acres (32,112 hectares) and is located approximately 14 statute miles (mi) (12 nautical miles [nm], 22 kilometers [km]) south of Long Island, New York, and 19.5 mi (16.9 nm, 31.4 km) east of Long Branch, New Jersey. Empire proposes to develop the Lease Area with two wind farms, known as Empire Wind 1 (EW 1) and Empire Wind 2 (EW 2) (collectively referred to hereafter as the Project).

Both EW 1 and EW 2 are covered in this Construction and Operations Plan (COP). EW 1 and EW 2 will be electrically isolated and independent from each other. Each wind farm will, independently of one another, connect via offshore substations to Points of Interconnection (POI) at onshore locations by way of export cable routes. The cables will proceed from separate landfalls to onshore substations. The onshore substation of the EW 1 Project will connect to the existing Gowanus POI in Brooklyn, New York. The onshore substation of the EW 2 Project will connect to the Oceanside POI in Oceanside, New York.

An overview of the Project is shown in Figure 1. For EW 1 and EW 2, the renewable electricity generated will be carried over alternating current (AC) interarray cables at a voltage of 66 kilovolts (kV) to an offshore substation where it will be converted to 230 kV for EW 1 and 345 kV for EW 2, and then carried to shore via submarine export cables. This report summarizes the calculated levels of AC magnetic fields and induced electric fields for the interarray and submarine export cables in the offshore portion of the Project. In this updated report, the primary change is that the voltage of the EW 2 submarine export cable has been increased from 230 kV to 345 kV, and the number of EW 2 export cables was reduced from three to two. It also provides a detailed assessment of magnetic fields and induced electric fields in marine species in the proposed Project Area. The locations and routes of the interarray cables are different for EW 1 and EW 2, but the interarray cables and calculations are the same and representative of interarray cables in both EW 1 and EW 2.

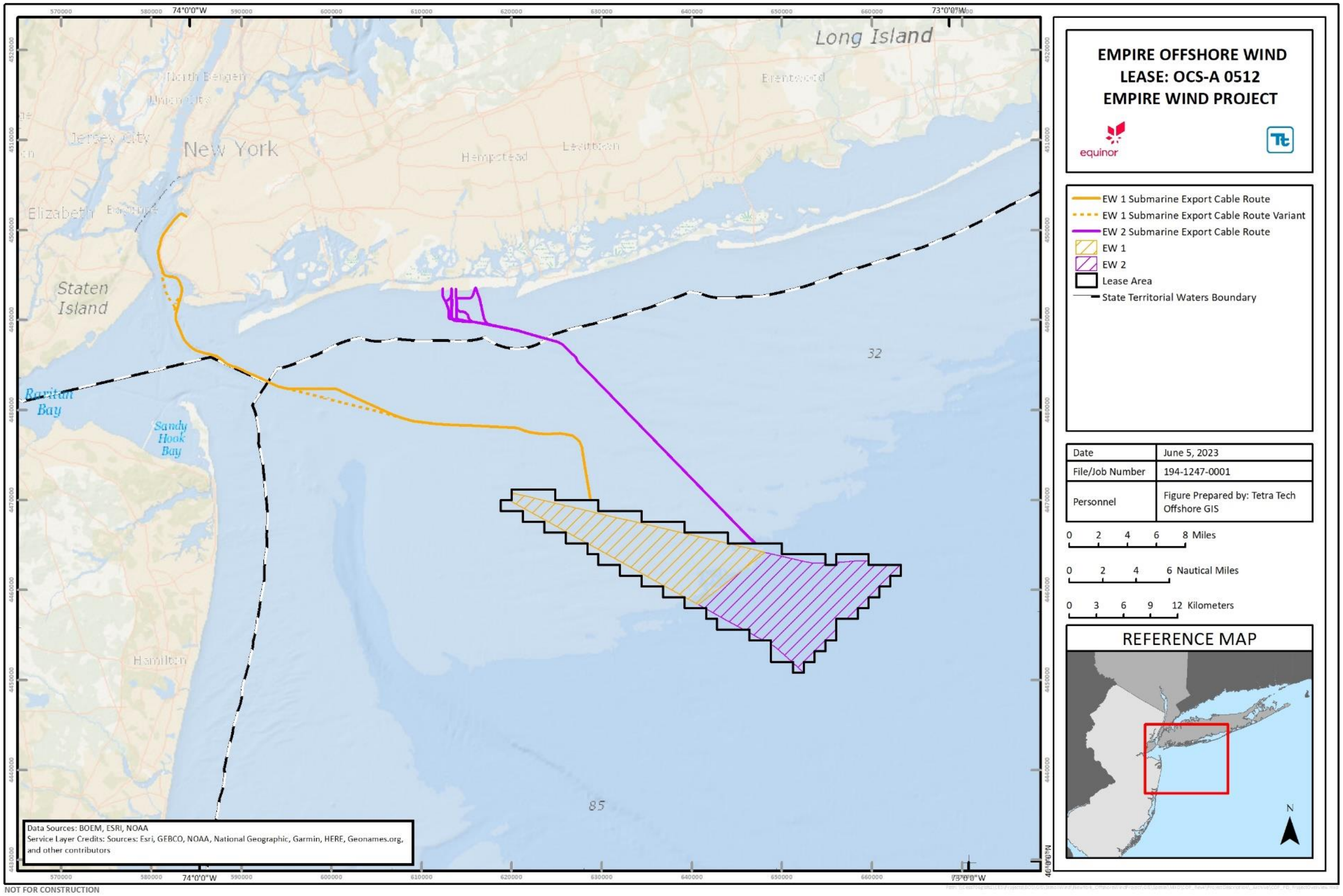

Figure 1. Overview of the proposed Lease Area and submarine export cable routes.

The assessment of the onshore export and interconnection cables connecting the Project to existing POIs is provided in a companion report titled *Empire Offshore Wind: Empire Wind Project (EW 1 and EW 2) - Updated Onshore Electric and Magnetic Field Assessment*.

Magnetic Fields and Electric Fields

The flow of electric currents in the submarine export and interarray cables will be new sources of magnetic fields in the marine environment. These magnetic-field levels will be highest at the cables' surface and decrease rapidly with distance, generally in proportion to the square of the distance from the cables. Magnetic fields are reported as root-mean-square flux density in units of milligauss (mG), where 1 Gauss is equal to 1,000 mG.[1]

The submarine export cables also are a source of electric fields inside the cable insulation and armoring due to the voltage applied to the conductors located within the cables. However, since the conductors are encased within the cables with grounded metallic sheathing and the cable is covered with steel armor, these electric fields do not enter the marine environment because they are entirely blocked by this shielding (CSA Ocean Sciences Inc. and Exponent, 2019).

The oscillating magnetic field produced by the cables, however, will induce a weak electric field in the marine environment and in marine species near the cables. Since the electric field is induced by the cables' magnetic field, it will vary depending on the flow of electric currents in the cables, rather than voltage. Similar to magnetic fields, the induced electric fields decrease rapidly with distance from the cables. Induced electric fields are reported in units of millivolts per meter (mV/m).

The levels of both magnetic fields and induced electric fields will vary depending on the magnitude of the electric current—reported in units of Ampere (A)—carried on the cables at any one time. Therefore, calculations of magnetic fields represent only a snapshot at one moment due to the varying power generated by the turbines, which depends both on operational status and wind speed. To account for the variability of current, calculations of magnetic fields were performed for the peak current at which the windfarm can operate, which will indicate the

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[1] Magnetic fields also are commonly reported in units of microtesla, where 0.1 microtesla is equal to 1 mG.

highest magnetic-field levels that can occur, and for the annual average current that represents more typical field levels over time. Additional discussion of the fields associated with offshore windfarm submarine cables in general is provided in a 2019 report issued by the Bureau of Ocean Energy Management (CSA Ocean Sciences Inc., and Exponent, 2019).

Assessment Criteria

Human Exposure

While the likelihood of persons coming in close proximity to the buried undersea cables is minimal and limited to those who might be scuba diving at the seabed, the level of potential exposure was still considered.

There are no federal standards that limit either magnetic or electric fields produced by transmission infrastructure, but two international organizations provide guidance on limiting exposure to magnetic fields, which is based on extensive review and evaluations of relevant research of health and safety issues—the International Committee on Electromagnetic Safety (ICES), which is a committee under the oversight of the Institute of Electrical and Electronics Engineers, and the International Commission on Non-Ionizing Radiation (ICNIRP), an independent organization providing scientific advice and guidance on electromagnetic fields. Both organizations have recommended limits designed to protect health and safety of persons in occupational settings and for the general public. The ICES maximum permissible exposure limit for the general public to 60-Hertz (Hz) magnetic fields is 9,040 mG, and ICNIRP determined a reference level limit for whole-body exposure to 60-Hz magnetic fields at 2,000 mG (ICES, 2002/2005, ICNIRP, 2010). The World Health Organization (WHO) views these standards as protective of public health (WHO, 2007). As the WHO (2019) also states on its website, “[b]ased on a recent in-depth review of the scientific literature, the WHO concluded that current evidence does not confirm the existence of any health consequences from exposure to low level electromagnetic fields.”

Marine Species Exposure

Some marine species have specialized electro-sensory receptors that enable them to detect electric fields or magnetic fields, or both, so fields from undersea cables are of ecological interest. Generally, marine species that have these specialized receptors can detect electric fields and magnetic fields over a limited frequency range (CSA Ocean Sciences Inc. and Exponent, 2019):

- The earth's geomagnetic field (i.e., a static field at a frequency of approximately 0 Hz);
- The approximately 0-Hz electric fields created by ocean currents;
- The induced electric field created by fish movements in the earth's geomagnetic field; and
- Electric fields produced by biological functions of fish with frequencies from 0 to approximately 10 Hz (Bedore and Kajiura, 2013).

While some species are capable of detecting fields at these lower frequencies in the natural environment, the electric and magnetic fields from the AC cables associated with the Project oscillate at a much higher frequency—60 Hz. Therefore, this assessment has focused on 50/60 Hz fields from AC submarine cables. A detailed assessment of magnetic fields and induced electric fields in marine species in the proposed Project Area is included in later sections of this report.

Cable Configurations

Exponent calculated the 60-Hz magnetic and induced electric fields from the submarine export and interarray cables proposed to be installed as part of the Project. These values were compared to assessment criteria to assess potential effects on marine species. Detailed descriptions of the cable configurations are provided in Attachment A, and description of the calculation methods is provided in Attachment B. A brief summary of each is provided below.

The proposed submarine cables consist of up to 260 nm of 66-kV AC[2] interarray cables for both EW 1 and EW 2, as well as and up to 41 nm of 230-kV AC submarine export cables for EW 1 and up to 26 nm of 345-kV AC submarine export cables for EW 2. Cables are expected to be buried at least 6 feet (ft, 1.8 meters [m]) beneath the seabed. Calculations were performed at 4 ft (1.2 m) burial depth, resulting in higher field levels than where the cables are buried deeper.

Where it is impossible to bury a cable, it will be laid on the seabed and covered with rock berm or other protective covering with a minimum coverage of 3.3 ft (1 m) for the submarine export cable and 2.3 ft (0.7 m) for the interarray cable. At landfall, the submarine export cable at EW 2 will be installed via horizontal directional drilling (HDD) with a minimum horizontal distance between the two submarine export cables of 33 ft (10 m) and minimum burial depth of 6.0 ft (1.8 m). At the EW 1 landfall, the submarine export cables will be installed via open-cut trench or HDD, with a minimum burial depth of 6.0 ft (1.8 m), except for a short (less than 30 ft [9.1 m]) protected duct installation where the protective covering will decrease to a minimum depth of 1 ft (0.3 m) at the transition to HDD. For either HDD or open cut trench installation, the expected burial depth for the vast majority of the installation will be much greater than the 1 ft (0.3 m) modeled, and so field levels would be lower than calculated herein.

Magnetic- and induced electric-field levels were calculated for each of these cable configurations using minimum target burial depths and conservative assumptions to ensure that

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[2] Some other submarine cables, such as those primarily investigated by Hutchison et al., (2018) operate using direct current (DC) transmission lines

the calculated field levels would overestimate the field levels that would be measured at any specified loading. Note that all indicated burial depths are specified to the top of the cable.

Calculated Magnetic and Electric Fields

Magnetic-field and induced electric-field levels were calculated for each of the proposed submarine export and interarray cable configurations for buried, surface-laid, and (where applicable) landfall installation types. Field levels were calculated for average and peak loading, and for locations at the seabed and at a height of 3.3 ft (1.0 m) above the seabed. The calculated field levels at 3.3 ft (1.0 m) above the seabed for a 4-ft (1.2 m) burial depth and average loading are summarized below.

Calculated magnetic-field levels are summarized and compared to limits on human exposure below. Calculated induced electric-field levels are summarized below and compared to relevant detection thresholds for marine species in subsequent sections of this report. Calculated field levels for all modeled cable configurations are provided in Attachment C.

Calculated Magnetic-Field Levels

Calculated magnetic-field levels are plotted in Figure 2 for the EW 1 submarine export cable, while calculated magnetic-field level values are summarized in Table 1 for both the EW 1 submarine export cable, the EW 2 submarine export cable, and the Project’s interarray cable for a 4-ft (1.2 m) burial depth and average loading. The highest calculated magnetic-field level at a height of 3.3 ft (1.0 m) above the seabed is 35 mG for both the EW 1 and EW 2 submarine export cables, and 16 mG for the interarray cable. Field levels decrease rapidly with distance, falling to less than 3 mG beyond a horizontal distance of 30 ft (9.1 m) from any of the modeled cable types. All calculated field levels are well below the ICNIRP reference level of 2,000 mG and the ICES maximum permissible exposure limit of 9,040 mG for exposure of the general public.

Where the cables are surface-laid for short distances and covered with protective rock berm or other protective covering, or where the submarine export cable burial depth may potentially decrease for short distances approaching landfall, the field levels would be higher than summarized above. Field levels would also be higher for peak loading on the cables.[3] These higher field levels, however, would occur for short distances along the route and for short periods of time at peak loading. Conversely, where the cables are installed even deeper than 4 ft below the seabed (target burial depth is 6 ft), the magnetic- and induced electric-field levels will be lower than modeled. The magnetic-field levels for all burial depths and loading levels would decrease rapidly with distance from the cables and would be well below the ICNIRP and ICES limits for exposure of the general public.

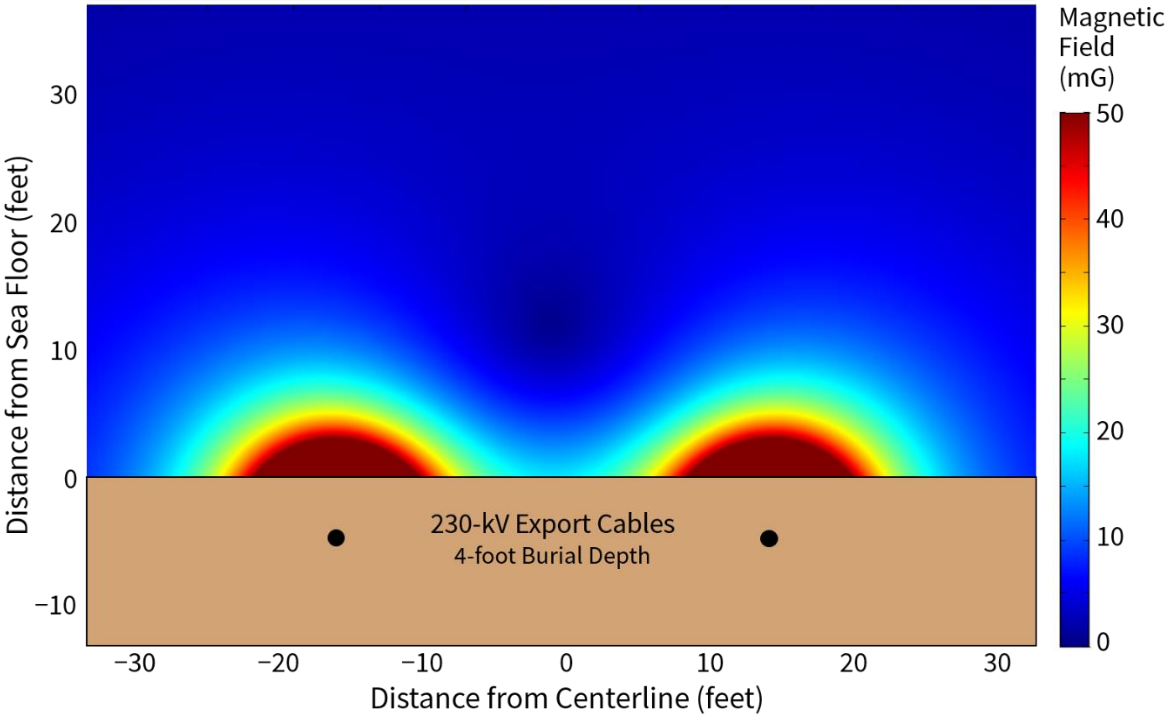

Figure 2. Example calculated magnetic-field levels in seawater above the EW 1 submarine export cable for 4-ft (1.2-m) burial depth and average loading.

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[3] The highest calculated magnetic field at the seabed for any configuration was 1,237 mG at average loading and 1,455 mG at peak loading. At a height of 3.3 ft (1.0 m) above the seabed, the highest calculated magnetic-field level was 98 mG at average loading and 116 mG at peak loading. All these maxima are calculated above the submarine export cable at landfall and are expected to apply only to a short (less than 30 ft [9.1 m]) distance along the route. Field levels for all configurations decrease rapidly to 30 mG or less at a ±10 ft (±3 m) horizontal distance from the cable.

Table 1. Calculated magnetic-field levels (mG) at a height of 3.3 ft (1.0 m) above the seabed for a 4-ft (1.2-m) burial depth and average loading

	Horizontal Distance from the Cable		
	Max	±10ft (±3 m)	±30 ft (±9.1 m)
EW 1 Submarine Export Cable*	35	14	2.8
EW 2 Submarine Export Cable*,†	35	14	2.8
Interarray Cable	16	5.9	1.0

* The submarine export cable includes two cables side-by-side. The horizontal distance is measured outward from nearest cable.

† The increased size of the EW 2 cable and decreased current compared to the EW 1 cable offset almost exactly for average loading, resulting in the same calculated values above seabed despite differences in voltage and configuration the submarine export cables.

Calculated Electric-Field Levels Induced in Seawater

Calculated electric-field levels induced in seawater are summarized in Table 2 for the EW 1 submarine export cable, the EW 2 submarine export cable, and the Project’s interarray cable for a 4-ft (1.2-m) burial depth and average loading. The highest calculated field levels at a height of 3.3 ft (1.0 m) above the seabed are 2.4 mV/m for both the EW 1 and EW 2 submarine export cables, and 1.0 mV/m for the interarray cable. Where the cables may be surface-laid for short distances, or where the burial depth may decrease for short distances (for example approaching landfall), the field levels would be higher. Field levels also will be higher at peak cable loading.[4] These higher field levels, however, would occur for short distances along the route and for short periods of time. Conversely, where the cables are installed even deeper than 4 ft (1.2 m) below the seabed, the magnetic- and induced electric-field levels will be lower than modeled. As for all modeled cable configurations, field levels would decrease rapidly with distance. For horizontal distances beyond 30 ft (9.1 m) from the cables, the induced electric-field levels were calculated to be 1.3 mV/m or less for all cable configurations at average and peak loading.

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[4] The highest calculated electric field induced in seawater for any configuration at the seabed was 14 mV/m at average loading and 16 mV/m at peak loading. At a height of 3.3 ft (1.0 m) above the seabed the highest calculated electric-field level in seawater was 3.8 mV/m at average loading and 4.5 mV/m at peak loading. All these maxima are calculated above the submarine export cable at landfall and are expected to apply only to a short (less than 30 ft [9.1 m]) distance along the route. Field levels for all configurations decrease rapidly to 3.1 mV/m or less at a ±10 ft (±3 m) horizontal distance from the cable.

Table 2. Calculated electric-field levels (mV/m) induced in seawater at a height of 3.3 ft (1.0 m) above the seabed for a 4-ft (1.2-m) burial depth and average loading

	Horizontal Distance from the Cable		
	Max	±10 ft (±3 m)	±30 ft (±9.1 m)
EW 1 Submarine Export Cable*	2.4	1.7	0.8
EW 2 Submarine Export Cable*,†	2.4	1.7	0.8
Interarray Cable	1.0	0.6	0.2

* The submarine export cable includes two cables side-by-side. The horizontal distance is measured outward from the nearest cable.

† The increased size of the EW 2 cable and decreased current compared to the EW 1 cable offset almost exactly for average loading, resulting in the same calculated values above seabed despite differences in voltage and configuration the submarine export cables.

Calculated Electric-Field Levels Induced in Fish

In addition to induced electric fields in seawater, the oscillating magnetic field also will induce an electric field within the body of a marine organism. The strength of the electric field induced in an object like a fish, however, depends upon the size (length and girth) of the fish. As shown in Table 3 below, the electric fields induced within large representative fish are about 10-fold lower than the electric field induced in seawater. The calculated electric fields induced in electrosensitive marine organisms at a height of 3.3 ft (1.0 m) above the seabed are summarized in Table 3 for both the EW 1 and the EW 2 submarine export cable, and the interarray cable for a 4-ft (1.2-m) burial depth and average loading. The calculated electric-field levels induced in marine organisms at 3.3 ft above the seabed are 0.4 mV/m or less for all cable configurations. The maximum electric-field value would occur when the fish swim directly over the submarine export cables. Electric-field levels induced in marine organisms would be higher for short distances along the route where burial depth decreases and for short periods at increased loading.[5] Calculated field levels decrease rapidly with distance, falling to less than 0.06 mV/m for horizontal distances beyond 30 ft (9.1 m) from the cables for all cable configurations for both average and peak loading.

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[5] The highest calculated electric field induced in marine organisms for any configuration at the seabed was 15 mV/m at average loading and 18 mV/m at peak loading. At a height of 3.3 ft (1.0 m) above the seabed the highest calculated electric-field level induced in marine organisms was 1.2 mV/m at average loading and 1.4 mV/m at peak loading. All these maxima occurred in the Sturgeon and above the submarine export cable at landfall and are expected to occur for only a short (less than 30 ft [9.1 m]) distance along the route. Field levels for all configurations decrease rapidly with distance from the cable.

Table 3. Calculated electric-field levels (mV/m) induced in electrosensitive marine organisms at a height of 3.3 ft (1.0 m) above the seabed for a <u>4-ft (1.2-m) burial depth</u> and average loading

	Dogfish	**Sturgeon**
EW 1 Submarine Export Cable	0.2	0.4
EW 2 Submarine Export Cable	0.2	0.4
Interarray Cable	0.1	0.2

Evaluation of EMF Exposure for Finfish Species in the Project Area

A wide range of marine and freshwater fish species have been observed to exhibit magnetosensitivity; these include salmonids, tuna, herrings, carp, and mackerel. The ability to detect magnetic fields is theorized to be due to the presence of magnetite particles in the bones and organs of various species, the presence of which allows the fish to perceive small changes in the earth's geomagnetic field (Hanson and Westerberg, 1987; Harrison et al., 2002; Tanski et al., 2011; Walker et al., 1998). Together with other environmental cues, such as water temperature, olfactory signals, current direction, current strength, and light, perceived changes in the geomagnetic field can be incorporated to guide fish migration between key habitats.

It is important to note that the earth's geomagnetic field (~0 Hz) has a frequency quite different from the magnetic field produced by 60-Hz AC submarine cables, so it is not possible to interpret responses of fish to AC cables from studies conducted with static fields. However, given that specialized sensory mechanisms evolved in fish to take advantage of a common cue (the earth's geomagnetic field) and occurs across a broad diversity of species, it is reasonable to assume that where responses to EMF have been observed, these would be similar to those for fish species that have not been studied.

In addition to the ability to detect magnetic fields, a subset of fish species have developed specialized and sensitive electroreceptors (called ampullae of Lorenzini) that can detect low-level electric fields. Electrosensitive fish include sturgeon species (family Acipenseridae); these are primarily anadromous fish that move between freshwater, estuarine, and coastal environments along the Atlantic coast of the United States. Electrosensitive fish can detect and respond to the low-level bioelectric fields produced by prey, so this ability allows for optimized foraging.

Description of Important Finfish Species Residing in the Project Area

The Project Area is within the known habitat and range of a number of commercially important finfish[6] species (listed in Table 4 and Table 5): many of these species are actively managed by governmental agencies to ensure population stability and sustainability. In terms of the potential for encountering cable associated EMF, bottom-dwelling (demersal) fish have been identified as the most likely to be exposed, since these species inhabit the portion of the water column closest to the cable (Bull and Helix, 2011). Conversely, fish that inhabit the upper portions of the water column (pelagic) are less likely to spend time within the area immediately above buried cables where the levels of EMF are higher. Additionally, highly mobile fish species with a large range also are more likely to inhabit regions distant from the cables, reducing the possibility of exposure to EMF from the Project cables. Hence, identified fish species have been categorized by behaviors and preferred habitats that are expected to affect the likelihood of encountering the cable route. Size information is provided in these tables as the magnitude of electric fields induced within fish scales with body size. Fish species of commercial importance that are managed and monitored by fisheries are identified as well.

Table 4. Key demersal and benthopelagic fish species expected to inhabit the Project Area (size at maturity = size at which 50% of species are reproductively mature; common length = most frequent length within a species' population)

Species	Occurrence/Range/Habitat	Size at maturity (cm)[1]	Size, common length(cm)[1]	Managing Agency or FMC
Atlantic Butterfish (*Peprilus triacanthus)*	Schooling over the continental shelf in waters 49 to 1380 (15 m to 420 m) deep	12	20	MAFMC
Atlantic Cod (*Gadus morhua*)	Shoreline to outer continental shelf	63		NEFMC
Atlantic Croaker (*Micropogonias undulates)*	Over sandy and muddy bottoms from coastal areas to 330 ft (100 m)	18	30	ASFMC
Atlantic Sturgeon (*Acipenser oxyrinchus oxyrinchus*)	Nearshore areas with long migrations into freshwater rivers	190	250	ASFMC
Black Sea Bass (*Centropristis striata*)	Inhabits rock jetties and bottoms in shallow coastal waters	19.1	30	ASFMC

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[6] The term finfish is used to distinguish these species from the elasmobranchs, which are discussed in a separate section.

Species	Occurrence/Range/Habitat	Size at maturity (cm)[1]	Size, common length(cm)[1]	Managing Agency or FMC
Black Drum (*Pogonias cromis*)	In coastal areas over sandy and muddy bottoms	NA	50	ASFMC
Cunner (*Tautogolabrus adspersus)*	Inshore, shallow waters, frequently in large numbers around structures	NA	38 (max length)	
Haddock (*Melanogrammus aeglefinus*)	Common over rock, gravel and shell substrate from 260 ft to 660 ft (80 to 200 m)	35	35	NEFMC
Monkfish (*Lophius americanus*)	Throughout continental shelf	47	90	NEFMC
Ocean Pout (*Zoarces americanus*)	Throughout continental shelf	28.8	110 (max length)	NEFMC
Northern Kingfish (*Menticirrhus saxatilis)*	Shallow coastal waters of an approximate 3.3-ft (10 m) depth	NA	30	
Northern Puffer (*Sphoeroides maculatus)*	Bays, inlets, estuaries and other protected coastal waters	NA	20	
Northern Searobin (*Prionotus carolinus)*	On sandy bottoms between 49 ft and 560 ft (15 m and 170 m) deep	NA	30	
Pollock (*Pollachius virens*)	Inshore and offshore to >660 ft (200 m)	39.1	60	NEFMC
Red Hake (*Urophycis chuss*)	Soft substrate in nearshore to a 430-ft (130 m) depth	26	NA	NEFMC
Silver Hake or Whiting (*Merluccius bilinearis*)	Sandy bottoms in shallow areas and to outer continental shelf	23	37	NEFMC
Smallmouth Flounder (*Etropus microstomus)*	On soft bottoms to depths of 300 ft (91 m)	NA	NA	
Spot (*Leiostomus xanthurus)*	Associated with sandy or muddy substrates in coastal waters to 200 ft (60 m)	NA	25	ASFMC
Spotted Hake (*Urophycis regia)*	Common along the continental shelf at depths between 360 ft and 600 ft (110 m and 185 m)	NA	17	
Summer Flounder (*Paralichthys dentatus*)	Sandy substrates in mostly nearshore areas (usually to 120 [37 m])	28	NA	MAFMC
Tautog (*Tautoga onitis)*	Hard-bottom and reef habitats in waters to 250 ft (75 m) deep	18	NA	
Weakfish (*Cynoscion regalis)*	In shallow waters to 85 ft (26 m) over sandy and muddy substrates	14	50	
White Hake (Urophycis tenuis)	Muddy substrates from 330 ft to 820 ft (100 m to 250 m)	46	70	NEFMC
Witch Flounder (Glyptocephalus cynoglossus)	Soft mud substrates usually between 150 ft and 1150 ft (45 m and 350 m)	30	NA	NEFMC
Windowpane Flounder (*Scophthalmus aquosus*)	Sand substrates from nearshore to a 150-ft (45-m) depth	22	NA	NEFMC

Species	Occurrence/Range/Habitat	Size at maturity (cm)[1]	Size, common length(cm)[1]	Managing Agency or FMC
Winter Flounder (*Pseudopleuronectes americanus*)	Muddy and hard substrate in depths of less than 460 ft (140 m)	27	NA	NEFMC
Yellowtail Flounder (*Limanda ferruginea*)	Sand and mud substrates usually between 100 ft and 295 ft (30 m and 90 m)	30	NA	NEFMC

[1]Information from fishbase.org; Size information is important for calculating fields induced within the body of a marine animal and is discussed further in Attachment B.

Key: ASFMC – Atlantic States Fisheries Commission; MAFMC – Mid-Atlantic Fishery Management Council; NEFMC-New England Fishery Management Council; NA – Not available

Table 5. Key pelagic species expected to inhabit the Project Area (size at maturity = size at which 50% of species are reproductively mature; common length = most frequent length within a species' population)

Species	Occurrence/Range/Habitat	Size at maturity (cm)[1]	Size, common length (cm)[1]	Managing Agency or FMC
Albacore Tuna (*Thunnus alalunga*)	In surface waters of depths of to 2,000 ft (600 m)	85	100	NOAA Fisheries, Atlantic Highly Migratory Species
Atlantic Bluefin Tuna (*Thunnus thynnus*)	Nearshore and offshore.	97	200	NOAA Fisheries, Atlantic Highly Migratory Species
Atlantic Herring (*Clupea harengus*)	Open waters of depths between 0 ft and 1190 ft (0 m and 364 m)	17	30	NEFMC
Atlantic Mackerel (*Scomber scombrus)*	In surface waters over the continental shelf	29	30	MAFMC
Atlantic Menhaden (*Brevoortia tyrannus)*	Forms large schools in coastal waters	18	NA	ASFMC
Atlantic Skipjack Tuna (*Katsuwonus pelamis*)	Epipelagic, open ocean	40	80	NOAA Fisheries, Atlantic Highly Migratory Species
Atlantic Yellowfin Tuna (*Thunnus albacares*)	Epipelagic, oceanic fish in upper 330 ft (100 m)	103	150	NOAA Fisheries, Atlantic Highly Migratory Species
Bay Anchovy (*Anchoa mitchilli)*	In shallow tidal areas, especially those with brackish water and muddy bottoms	4	6	
Blueback Herring (*Alosa aestivalis)*	In estuaries and coastal areas, usually in schools	NA	27.5	
Bluefish (*Pomatomus saltatrix*)	Nearshore to offshore	30	60	MAFMC
Striped Anchovy (*Anchoa hepsetus)*	In dense schools at the surface of shallow coastal waters	NA	11	

[1] Information from fishbase.org; Size information is important for calculating fields induced within the body of a marine animal and is discussed further in Attachment B

Key: ASFMC – Atlantic States Fisheries Commission; MAFMC – Mid-Atlantic Fishery Management Council; NEFMC – New England Fishery Management Council; NOAA – National Oceanic and Atmospheric Administration; NA – Not available

Although a large number of studies have been conducted to assess the sensitivity and behavioral responses of various fish species to static magnetic fields, relatively fewer investigations have been conducted with AC magnetic fields. Furthermore, when such studies have been conducted, many have focused on low frequency fields (i.e., 10 Hz or less), as these are common in the natural marine environment. Therefore, scientists have summarized the available information regarding the ability of finfish to detect AC magnetic fields and used it to predict the general responses of magnetosensitive fish based on the observation that magnetosensitivity in finfish developed to detect a common signal, the geomagnetic field. Much of the information on fish detection and response thresholds has been assessed in laboratory studies, which can be categorized into those evaluating physiological effects on fish following long-term (>24 hours) exposure to AC EMF, and those that examine the effect of such fields on the immediate behavior of individual adult fish. Since the majority of fish are expected to experience only transitory exposure to the Project cables, the first group of studies is of limited relevance.

Behavioral Effects of Exposure to EMF from 50- and 60-Hz AC Sources

The bulk of the scientific literature generated from laboratory studies does not indicate that 50- or 60-Hz fields have adverse effects on adult finfish behavior and orientation. Richardson et al. (1970) exposed both Atlantic salmon (*Salmo salar*) and American eel (*Anguilla rostrata*) to a 500 mG magnetic field produced by a 60-75-Hz AC power source. Exposed fish exhibited no change in swim behaviors, leading the study authors to conclude that, under field conditions, EMF produced by 60-Hz AC cables is not likely to alter the behavior or activity of either species (Richardson et al., 1970).

More recently, the Marine Scotland Science Agency also assessed European eel (*A. anguilla*) and Atlantic salmon behavior in response to high frequency magnetic fields, produced by a 50-Hz AC power source. Atlantic salmon were exposed to magnetic-field strengths between 1.3 and 950 mG, during which no significant change in salmon swimming or behavior was noted (Armstrong et al., 2015). Similarly, European eel were exposed to a 50-Hz AC power source that produced a magnetic field of 960 mG. Researchers observed no effects of magnetic-field exposure on eel swim behavior, orientation, or passage through tank system (Orpwood et al., 2015). Overall, studies conducted by Richardson et al. (1970), Armstrong et al. (2015), and

Orpwood et al. (2015) demonstrate that 50-75 Hz AC cables do not alter the behavior of either salmon or eel under controlled laboratory conditions, indicating that magnetic fields produced by these power sources are not readily detected by these magnetosensitive migratory fish species.

The effects of magnetic fields produced by 60-Hz AC power sources were also assessed for a series of freshwater fish species, including pallid sturgeon (*Scaphirhynchus albus*), largemouth bass (*Micropterus salmoides*), and redear sunfish (*Lepomis microlophus*), at the U.S. Department of Energy's Oak Ridge Laboratory. Fish were exposed to magnetic fields produced by an AC electromagnet and changes in behavioral and orientation were observed. During exposure to a 1,657,800 mG magnetic field, redear sunfish were observed to significantly prefer shelters nearest to the magnetic-field source (Bevelhimer et al., 2013). Once removed from the magnetic field, however, redear sunfish resumed normal distribution within the tank, indicating that once removed from the produced field, normal behavior was re-established. The authors also reported no long-term effect on fish health resulting from the exposure to this high-strength field (Bevelhimer et al., 2013). When largemouth bass were exposed to a 24,500 mG magnetic field from a 60-Hz AC power source, researchers observed no significant changes in fish behavior or swimming, leading to the conclusion that "the evidence from this study does not support an effect on free-swimming largemouth bass … from EMF delivered at an intensity that would be expected from a power transmission cable" (Bevelhimer et al., 2015, p. 12). Pallid sturgeon were exposed to magnetic fields from a 60-Hz AC power source, using a more complex laboratory mesocosm apparatus (Bevelhimer et al., 2015). Researchers observed that magnetic fields strengths of approximately 18,000 to 24,500 mG had no effect on sturgeon behavior or positioning within the tanks suggesting that magnetic fields of these strengths are not detected by sturgeon (Bevelhimer et al., 2015).

In summary, the scientific literature evaluated here demonstrates that magnetosensitive fish do not readily detect or alter their behavior in response to magnetic fields produced by 50/60Hz AC cables. Moreover, even when the field is high enough for fish to detect (i.e., over 1,000,000 mG), effects are minor and reversible once fish move away from the magnetic field.

Field Studies that Address Effects of Submarine Cables on Finfish Distribution

In addition to controlled laboratory studies, field surveys of finfish distributions at submarine cables sites can provide important data on the *in situ* effects of AC EMF on local populations of fish. These types of surveys include those conducted specifically at marine AC cables sites and those conducted at offshore wind farm sites where generated power is transmitted to shore by AC submarine cables.

Between 2012 and 2014, researchers at the Marine Science Institute at the University of California, Santa Barbara, and BOEM tracked fish populations at both energized and unenergized 60-Hz submarine cables off the California coast. Measured magnetic fields at energized cable sites ranged between 730 to 1,100 mG (Love et al. 2016). Over the three years, more than 40 different fish species were observed, including demersal California halibut (*Paralichthys californicus*), sanddab (*Citharichthys sordidus*), and seaperch (*Sebastes* spp). No differences, however, were identified between fish communities observed at the energized versus unenergized cable routes. While the physical structure of the unburied cables attracted a higher density of fish when compared to natural sediment bottoms (“reef effect”), the presence of magnetic fields produced by the cable had no attractive or repulsive effect on resident fish (Love et al. 2016). Thus, the results of this survey indicate that the magnetic fields produced by an AC cable do not alter fish distributions or behavior.

Similarly, multiple studies have been conducted at many established offshore wind farm sites that use 50/60 Hz AC transmission cables to conduct generated energy on shore; results from these studies overwhelmingly demonstrate that the presence of wind farms and operating cables have no effect on resident fish populations. For example, at the Horns Rev Offshore Wind Farm site near Denmark, nearly 10 years of pre- and post-construction biological population data were collected, including data on species similar to those expected to inhabit the Project Area such as various flounder and flatfish species. Evaluation of all collected population data at this site demonstrated that there were “no general significant changes in the abundance or distribution patterns of pelagic and demersal fish” (Leonhard et al., 2011). For reef-associated species, increased abundance was noted around turbine footings, which were concluded to be a result of the vertical structure provided by footings.

Similarly, at the Wolfe Island Wind Farm site in Lake Ontario, multiple survey methods were used to track changes in fish populations; results of these surveys led researchers to conclude that there was "little to no effect of the Wolfe Island submarine cable on local fish communities" (Dunlop et al., 2016). Following the construction of Thorntonbank Wind Farm in Belgium, some short-lived changes in the abundance of certain fish and invertebrate species were observed; however, the temporary nature of these alterations strongly indicate that the changes were not related to the cable's magnetic fields (Vandendriessche et al., 2015).

Conversely, some minor potential effects on fish distributions—termed "asymmetries in the catches"—were observed along the Project cables of the Nysted Wind Farm in Denmark (Nysted) (Vattenfall and Skov-og, 2006). In contrast to other surveys, however, baseline fish population data were not collected at the Nysted site, complicating the interpretation of these data. Moreover, the energy loading of the Nysted cable did not correlate with measures of fish distribution, indicating that EMF levels were not the source of differences in distributions and that the cable did not act as a barrier to fish movement, with the possible exception of flounder (Vattenfall and Skov-og, 2006). The authors theorized, however, that the physical conditions of the seabed along the cable route may explain the reactions in flounder.

Most recently, a long term study of populations has been conducted over the course of construction and operation of the Block Island Wind Farm off the coast of Rhode Island. This included seven years of surveys prior to construction and into the operational period to track populations of resident marine species. Resulting data indicated increases in populations of hardground-associated species, including commercially important black sea bass (*C. striata*) and Atlantic cod (*G. morhua*), in the wind farm vicinity (Wilber et al., 2022). Population data for other commercially important demersal fish species that prefer non-hardground or vertical habitat, such as flounder species, butterfish (*P. triacanthus*), and scup (*S. chrysops*), indicated no changes in resident populations based on the presence of the wind farm and operating transmission cables. Based on these findings, researchers concluded that the operating wind farm did not adversely affect catches of fish in the wind farm vicinity (Wilber et al., 2022).

Overall, the various population studies conducted at either submarine AC cable sites or offshore wind farm sites show that 50/60 Hz magnetic fields do not affect fish distributions. As such, the results of these surveys agree with the findings of the laboratory studies that demonstrate no significant population-level distributional or behavioral effects of AC EMF on fish species.

Electrosensitivity in Sturgeon Species

Comparatively few fish species are capable of detecting electric fields in addition to magnetic fields. The endangered Atlantic sturgeon, which inhabits the Project Area, is one of these fish species. Given this, the ability of sturgeon to detect electric fields associated with 50/60-Hz power sources was evaluated in the scientific literature. Basov (1999) exposed two different sturgeon species—sterlet (*Acipenser ruthenus*) and Russian sturgeon (*Acipenser gueldenstaedtii*)—to 50-Hz AC electric fields at intensities between 20 to 60 mV/m and observed how fish responded to these (Basov,1999). The lower 20 mV/m level induced minor alterations in fish orientation and also increased search and foraging behaviors in the vicinity of the power source. This indicates that small-scale behavior effects may occur in electrosensitive sturgeon exposed to electric-field intensities of 20 mV/m at 50/60 Hz.

Evaluation of EMF Exposure from Project Cables

The magnetic fields calculated at peak loading from cable configurations and burial depth of 4 ft (1.2 m) proposed for the Project Area are presented in Table 6. At peak loading and at a 3.3 ft (1 m) distance from the seabed, the maximum magnetic-field level in the Project area was calculated to be 53 mG directly over the EW 2 cables at a burial depth of 4 ft. This value is about 9 times lower than the 500 mG magnetic field that was demonstrated to have no behavioral effects on either Atlantic salmon or American eel. Field strengths associated with significant changes in fish behavior are orders of multiple magnitude higher (i.e., 1,657,800 mG for redear sunfish) than those expected at the Project cables. These studies of multiple fish species indicate that the magnetic fields produced by the Project cables will be below the level of detection for marine finfish species.

In addition to magnetic-field levels, induced electric-field strengths, based on an Atlantic sturgeon model, were calculated (Table 6). The Atlantic sturgeon was selected as a model species due to their electrosensitivity, and the sturgeon were modeled as an ellipsoid 6 ft (1.8 m) in length and a maximum girth of 2.5 ft (0.8 m).[7] The maximum induced electric-field value during peak loading at 3.3 ft (1.0 m) above the buried Project cables was calculated to be 0.6 mV/m, occurring directly over the EW 2 submarine export cable. This maximum calculated induced electric-field strength is 33 times lower than the 20 mV/m electric field reported as the threshold for changes in behavioral Russian sturgeon and sterlet (Basov et al., 1999). Modeled induced electric fields in seawater also are predicted to be below this reported detection threshold level (Table 6).

Subsequently, the scientific literature summarized above does not indicate that EMF from the Project cables would be detectable by resident magnetosensitive and electrosensitive finfish species, including the federally endangered Atlantic sturgeon and shortnose sturgeon. Because of this, the operating cables therefore are not expected to adversely affect the populations or distributions of finfish in the Project Area.

Table 6. Calculated maximum magnetic field (mG) and induced electric field for peak loading at 3.3 ft (1.0 m) above the seabed based on proposed cable configurations for the Project

Cable Type	Burial Depth	Magnetic Field (mG)	Induced Electric Field (mV/m)	
			Seawater	Sturgeon Model
EW 1 Submarine Export Cable	4 ft (1.2 m)	41	2.8	0.5
EW 2 Submarine Export Cable	4 ft (1.2 m)	53	3.6	0.6
Interarray cable	4 ft (1.2 m)	20	1.2	0.3

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[7] Body girth was determined using a standard length-girth-weight relationship for the related lake sturgeon (http://files.dnr.state.mn.us/areas/fisheries/baudette/lksweight.pdf).

Evaluation of EMF Exposure for Elasmobranchs in the Project Area

Cartilaginous fish, like skates, sharks, and rays, are referred to collectively as elasmobranchs; these species are common in coastal and oceanic environments. Elasmobranchs, as a group, are both magnetosensitive and electrosensitive. Several species have been documented to utilize alterations in the geomagnetic field to direct movement and migration, and the ability to detect low frequency bioelectric fields (generally between 1 and 10 Hz) allows predators to locate prey via the low frequency electric fields they produce (Bedore and Kajiura, 2013).

Description of Elasmobranch Species Residing in the Project Area

A number of different elasmobranch species are expected to inhabit the Project Area, including at least 13 different shark, skate, and dogfish species (Table 7). Individual species are expected to utilize this area at different rates: smaller demersal species like skates and dogfish tend to have smaller ranges, constrained to coastal areas, while large pelagic shark species may be migratory with ranges of hundreds of kilometers (Vandeperre et al., 2014). For pelagic species, the Project Area represents only a tiny proportion of the total marine habitat, while the localized populations of the smaller, demersal elasmobranch species may more frequently encounter submarine export cable routes. Hence, elasmobranchs have been categorized according to these groups, as shown in Table 7.

Table 7. Elasmobranch species expected to utilize the Project Area (size at maturity = size at which 50% of species are reproductively mature; common length = most frequent length within a species' population)

Habitat	Species	Occurrence/Range/Habitat	Size at maturity (cm)[1]	Size, common length (cm)[1]
Demersal	Clearnose Skate (*Raja eglanteria)*	From bays and estuaries to depths of up to 330m	49	NA
	Little Skate (*Leucoraja erinacea)*	On sand and gravel substrates to water depths to 90m	32	NA
	Winter Skate (*Leucoraja ocellata)*	Sand and gravel bottoms in shoal waters, out to waters of 90m depth	73	NA
	Smooth Dogfish (*Mustelus canis)*	From shallow inshore waters to depths of up to 200m	95	100

Habitat	Species	Occurrence/Range/Habitat	Size at maturity (cm)[1]	Size, common length (cm)[1]
	Spiny Dogfish (*Squalus acanthias)*	Lives in near bottom waters of depths between 10 and 200m	69	100
	Blue Shark (*Prionace glauca)*	Oceanic, epipelagic and circumglobal in distribution	170	335
Pelagic	Dusky Shark (*Carcharhinus obscurus*)	Migratory throughout coastal areas; reef-associated	220	250
	Sand Tiger Shark (*Carcharias Taurus)*	Found in bottom, midwater and pelagic waters from coastal areas to the outer continental shelf	220	250
	Sandbar Shark (*Carcharhinus plumbeus)*	Coastal-pelagic, sometimes benthopelagic in waters to 280m	126	200
	Shortfin Mako Shark (*Isurus oxyrinchus*)	Oceanic and epipelagic in waters up to 500m depth	275	270
	Thresher Shark (*Alopias vulpinus*)	Epipelagic in coastal and oceanic waters, though most abundant in coastal waters	226	450
	Tiger Shark (*Galeocerdo cuvier*)	From surface waters to depths of 140m along continental and insular shelves	210	500
	White Shark (*Carcharodon carcharias*)	Oceanic-pelagic species that undergoes significant migration	450	NA

[1] Information from fishbase.org; Size information is important for calculating fields induced within the body of a marine animal and is discussed further in Attachment B.
NA = Not available

Evidence of Magnetosensitivity and Electrosensitivity in Elasmobranchs

It should be noted that the majority of research examining the effects of EMF on elasmobranch behavior have focused on fields produced by low frequency (i.e., approximately 10 Hz or less) sources. This is because the ability of elasmobranchs to detect EMF is greatest within this range, and significantly decreases as the frequency of the source increases over 20 Hz. Andrianov et al. (1984) demonstrated this with a series of studies conducted with thorny skates (*Amblyraja radiata*) where increasing the source frequency to 10 Hz from 1 Hz caused a 100-fold decrease in the sensitivity of skates. A similar study conducted with bamboo shark (*Chiloscyllium punctatum*) embryos indicated that embryonic sharks reacted most strongly to electrical signals below 20 Hz, with response behavior peaking at frequencies of 0.1 to 2.0 Hz; no responses were observed to fields produced at frequencies above 20 Hz (Kempster et al., 2013). This suggests that magnetic- and electric-field sensitivities identified using low frequency power sources do not reflect elasmobranch sensitivities at higher frequencies, including 50/60 Hz sources. Hence, it is important to interpret the likelihood of elasmobranch responses to the submarine export cable route in the field using laboratory studies conducted specifically with 50/60-Hz power sources.

Orr (2016) investigated the swim and orientation behaviors of a benthic shark (*Cephaloscyllium isabellum*) following exposure to a 50-Hz power source with a maximum measured magnetic field of 14,300 mG. Even though sharks were exposed for over 72 hours, no significant behavioral aberrations were observed; rather, sharks engaged in normal foraging behaviors when stimulated with olfactory feeding cues (Orr, 2016). These observations suggest that the presence of the 50-Hz AC EMF does not alter normal swim behavior, nor does it interfere with the forage ability of sharks. This led the author to conclude that 50-Hz transmission cables located in coastal areas would have neither attractive or repulsive effects on local elasmobranchs. Similarly, juvenile thornback rays were exposed to 4,500 mG 50-Hz magnetic fields to determine potential effects on swim behaviors (Albert et al., 2022). This exposure did not have significant effects on immobility periods or on vertical or horizontal activity. Overall, these studies with catsharks and rays indicate that 50/60-Hz magnetic fields are not likely to be detected by elasmobranchs and therefore will not result in altered behavior.

Field Studies that Address Effects of Submarine Cables on Elasmobranch Distributions

Unlike finfish species, very few field studies at submarine cables or offshore wind farms have explicitly focused on surveying the possible effect of 50/60 Hz AC power cables on elasmobranch populations and distributions. This might be a result of the broader distribution of elasmobranchs compared to other finfish species, resulting in lower densities of elasmobranchs in study areas. Yet, one of the specific study goals reported by Love et al. (2016) was to investigate whether elasmobranch distributions were altered by 60-Hz AC cables off the coast of California. To these ends, resident elasmobranchs were surveyed in relation to energized and unenergized power cable sites; multiple years of survey data indicate no effect from the cable, leading researchers to conclude that there was no evidence that “energized power cables in this study were either attracting or repelling these fishes [Elasmobranchs]” and that “energized cables are either unimportant to these organisms [Elasmobranchs] or that at least other environmental factors take precedence” (Love et al., 2016, pp. 11, 46).

Recent BOEM-funded research studied the effect of submarine cables on North Atlantic species, including little skate (*L. erinacea*) (Hutchinson et al., 2018). Although conducted at a direct current (DC) submarine cable site, it was later determined that this cable also carried measurable (but small) AC currents. Skates held in enclosures above the cable route were observed to travel further and closer to the seabed versus skates held in control enclosures (Hutchinson et al., 2018). There was no evidence based on skate behaviors, however, that either the DC fields or the AC magnetic and electric fields reported as 1.3 mG and 0.76 mV/m produced a barrier to elasmobranch migration or movement.

Evaluation of EMF Exposure from the Project Cables

Orr (2015) reported that 14,300 mG 50-Hz magnetic fields did not cause any significant changes in elasmobranch behaviors under laboratory conditions. Moreover, Love et al. (2016) noted no apparent effect on populations of elasmobranchs at field cable sites producing magnetic fields up to 1,100 mG in strength.[8] The magnetic-field level for buried cables at peak loading of all offshore Project cables (53 mG at 3.3 ft [1.0 m] above the seabed) is lower than these "no-effect" magnetic fields reported by Orr (2015) and Love et al. (2016). Overall, the available research indicates that magnetic fields associated with the buried Project cables would not be detected by resident elasmobranchs. Additionally, induced electric fields were calculated for a dogfish model (finding a maximum of 0.3 mV/m over the buried EW 2 submarine export cable at peak loading 3.3 ft above the seabed); this was generated as an ellipsoid with a length of 3.3 ft (1 m) and a maximum girth of 1.3 ft (0.4 m) (Table 8).[9] Although the scientific literature suggests that elasmobranchs are capable of detecting a 1 mV/m electric field produced by a 10-Hz power source (Andrianov et al., 1984), detection ability of elasmobranchs was also shown to rapidly decline as the frequency of the source increases. In fact, Kempster et al. (2013) reported that elasmobranchs did not detect electric fields produced at frequencies above 20 Hz. As such, it is not expected that resident elasmobranchs in the Project Area are capable of detecting the induced electric fields from the 60-Hz source.

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[8] The presence of DC EMF in the Hutchinson et al. (2018) study renders it inappropriate for predicting detection thresholds for an AC cable, given that elasmobranchs are documented to behaviorally react to static EMF.

[9] Body girth estimated from width-length relationship presented in the fishbase.org description of spiny dogfish.

Table 8. Calculated maximum magnetic field (mG) and induced electric field for peak loading at 3.3 ft (1.0 m) above the seabed based on proposed cable configurations for the Project

Cable Type	Burial Depth	Magnetic Field (mG)	Induced Electric Field (mV/m)	
			Seawater	Dogfish Model
EW 1 Submarine Export Cable	4 ft (1.2 m)	41	2.8	0.3
EW 2 Submarine Export Cable	4 ft (1.2 m)	53	3.6	0.3
Interarray Cable	4 ft (1.2 m)	20	1.2	0.1

Evaluation of EMF Exposure for Large Invertebrates in the Project Area

In addition to finfish and elasmobranchs, there are a number of commercially-important large invertebrate species that inhabit the Project Area. These include squid, large crustaceans, and bivalves (Table 9). Harvestable bivalves known to inhabit the Project Area include Atlantic surf clam (*Spisula solidissima*), Atlantic sea scallop (*Plactopecten magellanicus*) and Ocean quahog clam (*Artica islandica*), which either burrow into muddy substrates or occur in stationary aggregations on the sea bottom. These species exhibit limited movement, however, and thus are not expected to encounter the cable route in large numbers. A community of small burrowing worms and other sediment-dwelling invertebrates (termed infauna) are expected to reside in the sediments overlaying the cable route; recent research indicates that these organisms are not adversely affected by magnetic fields produced by operating AC cables (Stankevičiūtė et al. 2019; Jakubowska et al. 2019). In addition to sediment-associated species, there are a number of large, mobile invertebrates that are more likely to regularly move across the cable route during foraging and migration and will experience the greatest chance of being exposed to cable-produced EMF. Within the Project area, these species include crustaceans and arthropods like crabs, lobsters, and shrimp, which inhabit sea bottoms and migrate and move throughout coastal waters. Two squid species are also important inhabitants of the Project Area—longfin squid (*Doryteuthis pealeii*) and northern shortfin squid (*Illex illecebrosus*). These species school over a diversity of bottom habitats and undergo seasonal migrations along the continental shelf.

Because large mobile crustaceans and squid are most likely to move through the submarine export cable route, the assessment of EMF exposure will focus on these invertebrates.

Table 9. Important crustacean, bivalve, and squid species expected to inhabit the Project Area

Class	Species	Preferred Habitat
Crustacean	American Lobster (*Homarus americanus*)	Prefers rocky and mixed habitat types but may burrow in sand and mud. Migratory.
	Horseshoe Crab (*Limulus polyphemus*)	Benthic on sandy tidal flats to deeper demersal habitats.
	Jonah Crab (*Cancer borealis*)	Rocky gravelly and sandy substrates in shallow waters and depths ranging between 66 ft to 1,300 ft (20 m to 400 m).
	Northern Shrimp (*Pandalus borealis*)	On soft muddy and sometime rocky bottoms in coastal waters.
Bivalve	Atlantic Sea Scallop (*Plactopecten magellanicus*)	Associated with sand, gravel, shells, and other rocky habitat.
	Atlantic Surf Clam (*Spisula solidissima*)	Burrows in medium grained sand and finer substrates usually at depths between 26 ft to 220 ft (8 m to 66 m).
	Ocean Quahog Clam (*Artica islandica*)	Sandy substrates, generally at depths between 80 ft and 200 ft (25 m and 61 m).
Squid	Longfin Squid (*Doryteuthis pealeii*)	Benthopelagic in inshore areas and to the outer continental shelf.
	Northern Shortfin Squid (*Illex illecebrosus*)	Found over various bottom substrates from coastal areas throughout the continental shelf.

Evidence of Magnetosensitivity in Large Marine Invertebrates

The scientific literature contains a number of investigations of the sensitivity and behavioral responses of large crustaceans to static and geomagnetic fields (i.e., Ugolini and Pezzani 1995; Boles and Lohmann, 2003; Cain et al., 2005), and recently laboratory studies have been conducted examining 50/60-Hz magnetic fields as well. Overall, available data indicate that the effects of acute and chronic invertebrate exposure to AC EMF are negligible.

Juvenile European lobsters (*Homarus gammarus*) were exposed to 2,300 mG 50-Hz AC magnetic fields up over a week to assess the potential effects on tank exploration and sheltering behaviors (Taormina et al., 2020). Over the course of the studies, authors reported that the AC magnetic field had no observable impacts on lobster behavior or survival and concluded "anthropogenic magnetic fields, at these intensities, do not significantly impact the behavior of juvenile European lobsters" (Taormina et al., 2020). Bivalve physiology and survival during AC magnetic field exposures has also been assessed under laboratory conditions. Over 8 days, cockles (*Cerastoderma glaucum*) were exposed to 64,000 mG 50-Hz magnetic fields, and measures of physiological fitness, including food consumption rate, oxygen consumption rate, ammonia excretion rate, and measures of oxidative stress, were measured and tracked (Jabubowska-Lehrmann et al., 2022). Some, though not all, of these endpoints were altered by exposure to the AC magnetic field, including ammonia excretion rates, protein carbonyl levels (a biomarker of stress), and acetylcholinesterase concentrations. However, it should be noted that the magnetic field strength used in this study (64,000 mG) is significantly higher than levels associated with AC submarine cables. Because of this, authors concluded that it would be "necessary to investigate lower values" to assess such sites (Jakubowska-Lehrmann et al., 2022).

In addition to laboratory studies, a series of field studies were conducted with various crab species at cable sites off the coasts of California and Washington to determine if the presence of the cables alter crustacean behavior and distributions (Love et al., 2015, 2017b). Additional field surveys recorded the presence and abundance of shrimp and octopus species at AC cable sites (Love et al. 2017a). These field studies provide valuable data because they are conducted under more realistic conditions than laboratory studies.

In addition to surveying fish communities present at energized and unenergized cable off the coast of California, Love et al. (2017a) also recorded the numbers of invertebrate species at these sites. Common species observed included a shrimp species (*Pandalus platyceros*) and an octopus (*Octopus rubescens)*. Over surveys conducted between 2012 and 2014, both shrimp and octopus were observed along energized and unenergized cables at equivalent rates. Although invertebrate communities at all cable sites differed from that of natural sedimented areas, these differences were a result of the physical presence of the unburied cable, and not the EMF produced by the cable (Love et al., 2017a). Thus, the findings of this study indicate that EMF produced by 60-Hz AC cables (730 to 1,100 mG) does not affect the behavior of large, mobile crustaceans and cephalopods like octopus and squid.

At the same southern California sites, caged rock crabs (*Metacarcinus anthonyi* and *Cancer productus*) were deployed along unburied 60-Hz AC cables. The study design allowed for detection of individual crab distribution relative to the cables; cages were deployed along both energized and unenergized cables. Measured magnetic fields along the energized submarine cable were between 462 and 800 mG, with levels decreasing to 9 mG at the distant side of the cages (Love et al., 2015). This gave crabs a wide range of magnetic-field levels to gravitate either toward or away from, and the low end of the distribution was similar to levels recorded at unenergized cables. Over the four survey periods, repeated observations by researchers indicated that crabs were neither more or less likely to be congregated adjacent to the cable or at the far end of the cages; crab distributions around the energized cable were therefore determined to not significantly differ from those around the unenergized cable (Love et al., 2015). These findings strongly suggest that crabs, along with other large crustaceans, do not experience altered behavior when exposed to 60-Hz EMF as generated by AC submarine cables.

Assessments of the potential effects of AC submarine cables on the harvestability of uncaged, wild crab populations were conducted in Puget Sound, Washington, and southern California. This study was specifically designed to determine whether the presence of a 60-Hz submarine cable affected the ability to trap and harvest crab (*Metacarcinus magister* in Washington and *Cancer productus* in California) in the cable vicinity and has implications for both catch estimates and the underlying distribution of crabs throughout the study area. The California cable in this study was more heavily-loaded than those studied in the Puget Sound, producing magnetic fields up to 1,168 mG versus 428 mG (Love et al., 2017b). Trapped crabs were introduced to experimental units designed to examine whether cables presented a barrier to crab movement, which could alter the local population densities and distributions. Results indicate that both species of crabs were freely able to cross cable routes, demonstrating that energized submarine cables do not constitute a barrier to movement. These studies provide further evidence that local populations and distributions of large crustaceans are unaffected by the presence of energize AC cables. This conclusion is further supported by a recent field study with American lobsters (*Homarus americanus*), conducted at a DC submarine cable site that also carried measurable AC currents. Lobsters were enclosed in mesh cages and behavioral responses recorded. Although some changes in lobster activity were noted, specifically in regard to number of turns, there was no evidence that either the DC or AC magnetic and electric fields (1.3 mG and 0.76 mV/m, respectively) produced by the cable acted as a barrier to lobster movement (Hutchison et al., 2018).

Evaluation of EMF Levels Produced by the Project Cables

Results of field studies and surveys conducted along 60-Hz AC submarine cables indicate that behaviors and distributions of both large crustaceans and cephalopods are not likely to be affected by 60-Hz cables, like those in the Project Area. Crab movement and migration were reported to be unaffected by magnetic fields between 138 and 1,168 mG. For the Project cables the maximum modeled magnetic-field strength at peak loading is 165 mG at the seabed above the EW 2 submarine export cable at a burial depth of 4 ft (1,2 m), which is below magnetic-field levels associated with no effects on crab movement and distributions (Love et al., 2015, 2017a). Moreover, localized cephalopod distributions were not altered by 730 to 1,100 mG magnetic fields produced by 60-Hz AC cables (Love et al., 2017a), levels that again exceed the Project's projected maximum magnetic-field level of 165 mG at the seabed over buried cables.

In conclusion, evidence from a series of field surveys demonstrates that the behavior and distributions of large crustacean and cephalopod invertebrates would not be altered by magnetic-field levels projected for the Project cables.

Evaluation of Chronic EMF Exposure for Finfish at Protective Coverings

At points along the cable route, burial may not be practical, but this can be addressed by installing rock berms or other protective covering over the cables. These segments with protective coverings are likely to be somewhat attractive to a subset of marine organisms that prefer to inhabit hard substrates, but such organisms prefer vertical habitats. The potential for chronic exposure to magnetic fields generated by the Project cables related to segments where burial is not practical and protective coverings are needed is assessed based upon the available scientific literature on chronic exposure. In addition to investigations on the effects of 60-Hz AC EMF on the swim behaviors and orientation of fish, a number of studies have researched the physiological or developmental effects associated with chronic or long-term exposures to these magnetic fields. This research has focused on the potential developmental effects on early embryonic fish and on physiological effects in older fish. In either case the bulk of the evidence demonstrates that these endpoints are largely unaffected by exposure to AC EMF, especially at levels expected along the Project route.

Cameron et al (1985) examined the effect of a 1,000 mG magnetic field produced by a 60-Hz power source on medaka (*Oryzias latipes*) embryos. Exposed embryos were observed to develop more slowly (a delay of approximately 18 hours), but ultimately there were no significant effects on hatching rate, survival, or the occurrence of physical abnormalities. A similar delay in embryonic development was observed in zebrafish (*Danio rerio*) embryos exposed to a 10,000 mG magnetic field from a 50-Hz source (Skauli et al., 2000). Exposure to electric fields between 5 to 5,000 mV/m in strength, however, caused no developmental delays or adverse effects in salmonid (*Oncorhynchus mykiss*; rainbow trout) embryos (Brouard et al., 1996). Moreover, when older trout fry and fingerling stages were similarly exposed over a two-month period, there were no notable effects on growth and survival (Brouard et al., 1996). Fey et al. (2019) exposed rainbow trout eggs to a 1 mT (10,000 mG) magnetic field produced by a 50-Hz source for 36 days; this period covered embryonic development through the swim-up phase. Trout larvae mortality, time to hatch, growth rate, and swim-up time were not affected by the exposure (Fey et al., 2019).

Several physiological studies have also been conducted with invertebrate embryos, with similar results. Levin and Ernst (1995) exposed (*Strongylocentrotus purpuratus*) urchin embryos to 3.4 millitesla (mT) (i.e., 34,000 mG) AC magnetic fields and reported that this exposure altered the timing of cell division. Lower strength fields (i.e., 17,000 mG), however, had no effect on the rates or timing of purple sea urchin embryo cell division, and embryonic mortality rates were unaffected by either exposure. Embryos exposed to a 1,000 mG 60-Hz magnetic field over the first 24-hours after fertilization developed more slowly, with an estimated 1-hour delay in developmental progression (Zimmerman et al., 1990). A similar delay was observed for sea urchin embryos exposed to a 500 mG 60-Hz magnetic field (Cameron et al., 1993).

Results from these studies indicate that any effects of 50/60 Hz magnetic fields on developing marine embryos are minor. More importantly, under field conditions, it is not expected that these early life stages will be experience these types of exposures, as these stages are passively distributed throughout the water column.

In addition to developmental studies, the potential impacts of long-term AC magnetic-field exposure on fish physiology have also been researched. Young carp (*Cyprinus carpio*) were exposed to 50-Hz magnetic fields between 1,000 and 70,000 mG to assess the potential effects of exposure on brain histopathology (Samiee and Samiee, 2017). There was no significant evidence of lesions or other histopathological changes in the brain, until magnetic-field levels were increased to above 30,000 mG; the exact mechanism of how the magnetic-field exposures caused these effects was not reported. In another study, exposure to magnetic fields between 1.5 to 500 mG produced by 200- to 5,000-Hz power sources results in improved immune response and increased survival of disease in goldfish (Cuppen et al., 2007). Similarly, Nofouzi et al. (2015) exposed rainbow trout periodically to magnetic fields between 1 and 500 mG produced by a 15-Hz AC source for a term of 60 days. When fish were exposed to 5 mG EMF for a one-hour period daily for three months, they exhibited both enhanced growth and increased immune system activity, which demonstrated no adverse impact from these low-level exposures (Nofouzi et al., 2015). Conversely, Li et al. (2015) reported that juvenile tilapia (*Oreochromis niloticus*) exposed for 30 days to magnetic fields ranging from 30 to 200 microtesla (µT) (i.e., 300 to 2,000 mG; 50 Hz) exhibited significantly reduced growth and lowered digestive enzyme activity. These responses, however, did not increase as the intensity of the magnetic field increased and the juvenile tilapia recovered from the apparent effects following cessation of magnetic-field exposure (Li et al., 2015). Stankevičiūtė et al. (2019) noted that a 40-day exposure to a 1 mT (10,000 mG) magnetic field produced by a 50-Hz source caused an increase in measures of cytotoxicity in early stage rainbow trout. Survival of exposed fish, however, did not differ from that of controls; moreover, it is unclear if this type of exposure would be relevant to field conditions, where the field levels are far lower and developing fish are unlikely to be constrained to areas of elevated EMF along cable routes.[10]

Evaluation of EMF Levels at Areas with Protective Coverings

In areas with protective coverings the magnetic-field levels at average loading[11] calculated at the top of the protective covering was 160 mG for the EW 1 submarine export cable, 157 mG for the EW 2 submarine export cable, and 146 mG for the interarray cables, respectively. Based on information from the scientific literature, these expected values are lower than magnetic-field levels expected to cause adverse physiological effects (i.e., from approximately 500 mG to greater than 10,000 mG). Conversely, chronic exposures to low level magnetic fields produced by 50- and 60-Hz AC power sources had no adverse growth or health effects in exposed fish. Hence, it can be reasonably concluded that those marine fish species inhabiting areas along the cable route with protective coverings will not be adversely affected by magnetic fields.

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[10] The majority of key demersal finfish species expected to inhabit the Project Area are broadcast spawners, which results in the distribution of their eggs over wide areas. In contrast, only ocean pout deposit eggs directly on rocky areas.

[11] This assessment focuses on chronic, long-term exposures, and hence magnetic field levels for average loading were evaluated.

Conclusions

The calculated magnetic-field levels generated by the Project's EW 1 and EW 2 submarine export cables and interarray cables are well below limits published by the ICES and ICNIRP designed to protect the health and safety of the general public and calculated magnetic-field and induced electric-field levels are not expected to adversely affect nearby marine organisms.

A number of species expected to be found in the Project Area, including certain fish, invertebrates, and elasmobranchs, have developed the ability to detect and respond to the static geomagnetic field and in a few cases, low-frequency magnetic fields (~0 to 10 Hz). The electric and magnetic fields generated due to the presence of 50/60 Hz AC cables, however, are not perceived in the same manner as those produced by 0 Hz DC cables. Hence, data and information generated from laboratory and fields experiments with static magnetic fields cannot be used to predict the likelihood of effects from 50/60 Hz fields produced by submarine AC cables. Therefore, this assessment has focused on 50/60 Hz fields from AC submarine cables.

As part of the evaluation process, Exponent conducted modeling of the magnetic-field levels and induced electric-field levels associated with the Project cables. Results from these calculations indicate that the magnetic field at 3.3 ft (1.0 m) above the seabed will be below 35 mG for the interarray cables and the EW 1 and EW 2 submarine export cables for a 4-ft (1.2 m) burial depth and average loading. The calculated field levels were then compared to magnetic-field levels reported in the scientific literature as causing behavioral responses in species groups expected to inhabit the Project Area, including fish, elasmobranchs, and marine invertebrates. This assessment resulted in the following conclusions, which are consistent with those of a 2019 BOEM report by CSA Ocean Sciences Inc., and Exponent, 2019:

- Surveys conducted in the field at existing 60-Hz AC submarine cables demonstrate that behavior and distribution of large crustaceans are unaffected by the produced magnetic fields.
- Observations of cephalopod populations at the same sites indicated that the distributions of such species are not affected by energized 60-Hz AC cables.
- Modeled magnetic-field levels predicted for Project cables are below thresholds at which altered behavior in magnetosensitive fish are reported in both laboratory and field surveys.

- Elasmobranchs are not expected to detect the magnetic fields generated by the AC submarine cables.
- Modeled electric fields are below the electric-field detection thresholds of electrosensitive fish and elasmobranchs generated by 50/60 Hz power sources.
- Long-term exposure of fish to magnetic fields at areas with protective coverings is not expected to cause any effects on fish growth or health, since modeled levels are far below those associated with even minor changes in fish fitness.

In conclusion, modeling results for magnetic fields and induced electric fields at the Project site indicate that EMF produced by proposed Project cables will be below the levels of detection for magnetosensitive and electrosensitive marine organisms. As such, these species' behaviors and distributions are not expected to be adversely affected by the presence of the energized submarine export and interarray cables. Moreover, years of population surveys conducted at existing wind farm sites support the above conclusions that there are no long-term or large-scale changes to populations of marine organisms residing at these sites.[12] These conclusions are in line with the findings of a review concerning the effects of Marine Renewable Energy (MRE) projects on marine ecology. Based on their work, authors found that "there has been no evidence to show that EMFs at the levels expected from MRE devices will cause an effect (whether negative or positive) on any species" (Copping et al., 2016). Finally, a recent BOEM report concerning potential effects of AC EMF from offshore wind facilities concluded that for the southern New England area, no negative effects are expected for populations of the commercial and recreational fish species assessed (CSA Ocean Sciences Inc. and Exponent, 2019). Thus, the findings of this report concur with the general scientific and regulatory understanding of AC EMF and responses of marine species.

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[12] The exception is for hardground- and reef-associated species, which can increase following the installation of footings, which are utilized as additional habitat.

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Limitations

At the request of Empire, Exponent modeled the electric- and magnetic-field levels associated with the operation of the submarine interarray cables and export cables that will transport electricity generated by the Project.

This report summarizes the analysis performed to date and presents the findings resulting from that work. In the analysis, we have relied on cable design geometry, usage, specifications, and various other types of information provided by Empire. We cannot verify the correctness of this input data and rely on Empire for the data’s accuracy. Although Exponent has exercised usual and customary care in the conduct of this analysis, the responsibility for the design and operation of the Project remains fully with the client. Empire has confirmed to Exponent that the data contained herein are not subject to Critical Energy Infrastructure Information restrictions.

The results presented herein are made to a reasonable degree of engineering and scientific certainty. Exponent reserves the right to supplement this report and to expand or modify opinions based on review of additional material as it becomes available, through any additional work, or review of additional work performed by others.

The scope of services performed during this investigation may not adequately address the needs of other users of this report, and any re-use of this report or its findings, conclusions, or recommendations presented herein for purposes other than intended for permitting of the proposed Project are at the sole risk of the user. The opinions and comments formulated during this assessment are based on observations and information available at the time of the investigation. No guarantee or warranty as to future life or performance of any reviewed condition is expressed or implied.

Benjamin R.T. Cotts, Ph.D., P.E. (Licensed Electrical Engineer, New York, #103209-01), employed by Exponent, performed and reviewed calculations of the magnetic fields associated with the operation of the proposed Project.

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Attachment A

Cable Configurations

The specifications for the proposed submarine export and interarray cables are summarized in Table A-1 below. Both the 230-kV EW 1 submarine export cables and the 345-kV EW 2 submarine export cables will be installed in a double circuit (i.e., two cables side-by-side) configuration with a minimum horizontal distance of 33 ft (10 m) between cables, while the 66-kV interarray cable will be installed in a single circuit configuration. The interarray cables as well as both the EW 1 and EW 2 submarine export cables will comprise three-core cross linked polyethylene (XLPE). A cross-sectional drawing illustrating the components of a representative three-core XLPE cable is shown in Figure A-1.

Table A-1. Summary of offshore modeling configurations

Configuration	1a	1b	1c	2a	2b	3a	3b
Description	EW 1 Submarine Export Cable double circuit			EW 2 Submarine Export Cable double circuit		Interarray Cable single circuit	
Voltage	230-kV			345-kV		66-kV	
Average Loading	927 A			750 A		600 A	
Peak Loading	1090 A			1118 A		751 A	
Power Factor	0.95			0.9		0.91	
Cable Type, Nominal Outer Diameter (OD)	3-core XLPE, 300 mm OD			3-core XLPE 290 mm OD		3-core XLPE, 170 mm OD	
Conductor	3 × 2000 mm^2			3 × 2000 mm^2		3 × 800 mm^2	
Distance Between Conductor Centers Within Cable	102 mm			123.4 mm		65 mm	
Minimum Horizontal Distance Between Cables	33 ft (10 m)			33 ft (10 m)		n/a	
Installation Type	Buried[a]	Surface-Laid[b]	Landfall[c]	Buried	Surface-Laid[b]	Buried	Surface-Laid[b]
Minimum Target Burial Depth to Top of Cable	4 ft (1.2 m)	3.3 ft (1.0 m)	6 ft (1.8 m)	4 ft (1.2 m)	3.3 ft (1.0 m)	4 ft (1.2 m)	2.3 ft (0.7 m)
Evaluation Heights	At seabed and 3.3 ft (1.0 m) above seabed						

[a] The portion of the EW 1 submarine export cable proposed to be installed in federally-maintained areas will be installed to a minimum target burial depth of 15 ft (4.6 m).

[b] Surface-laid cables will be covered with rock berm or other protective covering.

[c] The minimum burial depth of 1.0 ft (0.3 m) will only occur for the EW 1 export cable is limited to less than 30-ft (9.1 m) of the route. The minimum burial depth elsewhere along each landfall will be 6 ft (1.8 m). The evaluation modeled burial depths at 1 ft (0.3 m) to conservatively overestimate levels at landfall.

The target burial depth for both the EW 1 and EW 2 submarine export cables and the interarray cables is 6 ft (1.8 m) beneath the seabed. Calculations are performed at 4-ft (1.2-m) burial depth, which will result in higher electric and magnetic fields than if the cable were buried deeper. Where it is impossible to bury the cable, it will be laid on the surface for short distances and covered with rock berm or other protective covering. The minimum coverage depths for these surface-laid portions of the route are 3.3 ft (1.0 m) for the EW 1 and EW 2 submarine export cable and 2.3 ft (0.7 m) for the interarray cable, and it is expected that no more than 10 percent of each route will be surface-laid. At landfall, the EW 2 submarine export cable will be installed via HDD with a minimum burial depth of 6 ft (1.8 m); the EW 1 submarine export cable will be installed via either open-cut trench or HDD. A representative illustration of a typical HDD landfall is shown in Figure A-2. As shown in this figure, the cable burial depth over most of this portion of the route is expected to be much greater than 6 ft (1.8 m), resulting in much lower field levels above ground. The one exception to this minimum burial depth for the landfalls will be a short (less than 30 ft [9.1 m]) protected duct installation beneath a dock at the EW 1 export cable landfall where the protective covering will decrease to a minimum depth of 1 ft (0.3 m). If the cable is installed via an open trench the trench depths may be up to 10 ft (3 m), but the minimum burial depth of 1 ft (0.3 m) used for modeling is representative of a conservative burial depth.

The varying covering types (rock berm or other protective coverings) are not calculated to appreciably attenuate or alter the magnetic- and induced electric-field levels generated by the submarine export cables; their primary effect is to change the cable burial depth with larger burial depths resulting in lower field levels above the seabed. As such, field levels were calculated for the burial depth of 4 ft (1.2 m) (EW 1 and EW 2 submarine export and interarray cables), the minimum surface-laid covering depths of 3.3 ft (1.0 m) (EW 1 and EW 2 submarine export cables) and 2.3 ft (0.7 m) (interarray cable), and the minimum landfall burial depth of 1.0 ft (0.3 m) (EW 1 submarine export cables).

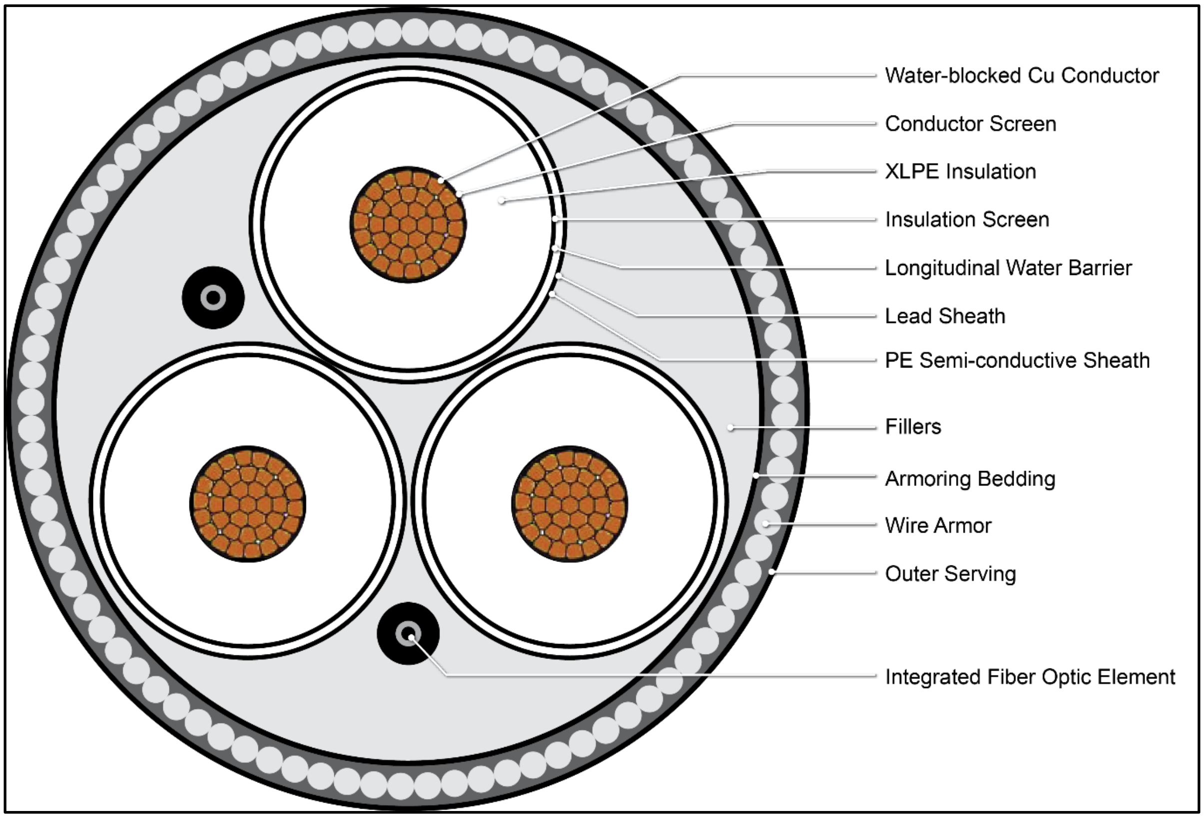

Figure A-1. Representative cross-section of the three-core submarine export cables.

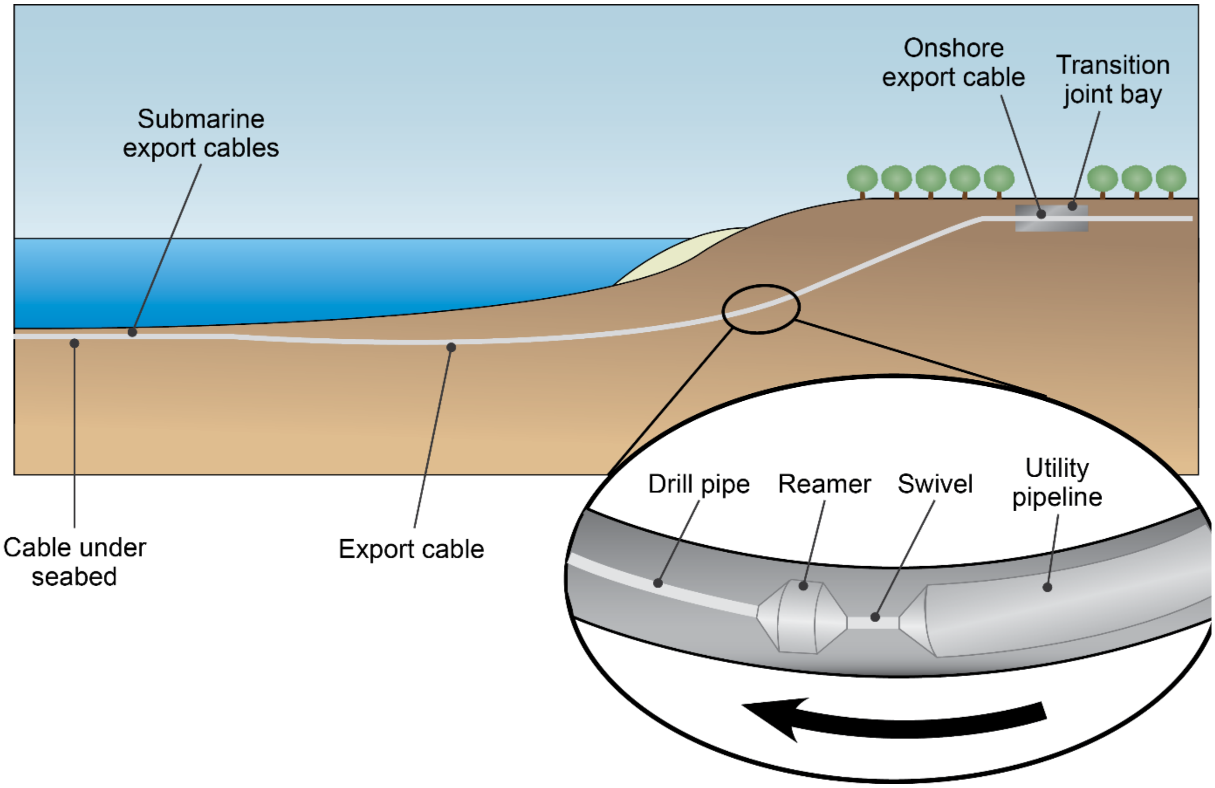

Figure A-2. Representative illustration of a typical HDD landfall.

Attachment B

Calculation Methods

Empire provided input data regarding the loading for each proposed cable configuration as well as the preliminary design parameters of the cable and duct bank, as summarized in Attachment A. Exponent used these data to develop models of the submarine cable configurations to calculate the magnetic fields and induced electric fields.

Magnetic Fields and Induced Electric Fields

Table B-1 summarizes the material properties used to calculate both magnetic-field and induced electric-field levels. Calculations were performed with finite element analysis simulations in COMSOL Multiphysics 5.4 software, at the seabed surface and at a height of 3.3 ft (1.0 m) above the seabed, in accordance with IEEE Std. 0644-2019 and IEEE Std. C95.3-2021 (IEEE, 2019, 2021). Certain modeling assumptions were used when performing calculations:

- The conductors of each cable were assumed parallel to one another and infinite in extent;
- The model assumed there was no attenuation of magnetic fields from any surrounding material (e.g., seabed, earth, grout, rock berm, etc.);
- That there were no unbalanced currents flowing along the outer sheaths of the cables; and
- The model did not include the effect of cable armoring (ferromagnetic shielding and induced eddy currents, discussed below) that will reduce the magnetic field outside the cable.

These modeling assumptions were made to ensure that the calculated field levels would overestimate the actual magnetic- and induced electric-field level at any specified loading.

Table B-1. Material properties used for calculating 60-Hz field levels in seawater

Material	Conductivity (S/m)	Relative Permittivity	Relative Permeability	Reference
Seawater	5	72	1	Chave et al., 1990; Somaraju and Trumpf, 2006
Seabed	1.1	30	1	Chave et al., 1990; Hulbert et al., 1992; Cihlar and Ulaby, 1974
Concrete	0.04	200	1	Wilson, 1986

Magnetic-Field Attenuation Assumptions

Cable armoring will attenuate (i.e., reduce) field levels outside the cable in two ways: 1) by ferromagnetic shielding (i.e., flux shunting) and 2) due to eddy currents. The degree of attenuation by flux shunting depends on the magnetic permeability of the cable; the higher the permeability, the greater the attenuation. Eddy currents induced in the cable's conductive sheathing create a partial cancellation of the magnetic field created by the conductors in the cable, which subsequently reduces magnetic-field levels outside the cable.

Silva (2006) determined that flux shunting accounts for an almost two-fold reduction in the magnetic field; while eddy currents also reduce the magnetic field, these reductions are not as great as those caused by flux shunting. A recent study commissioned by the BOEM (Hutchinson, 2018), which performed post-construction measurement of three-core XLPE AC cables, reported that "[t]he magnetic field produced by the [AC cable] was ~10 times lower than modeled values commissioned by the grid operator…"[13] An additional study (Pettersson and Schönborg, 1997) noted that the manufactured design of XLPE three-core cables utilizes helical twisting of conductors within the cable. The authors determined that this helical twisting further increases the mutual cancellation of the magnetic fields from the three conductors within the cable thereby decreasing magnetic-field levels more rapidly with distance than if the cables were not helically twisted.

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[13] Note that while the Hutchison et al. (2018) report focused on DC submarine cables, a portion of the study also reported measurements around an AC submarine cable, which is referenced here.

Induced Electric-Fields Assumptions for Marine Species

During operation, the 60-Hz current from the submarine export cables will produce an oscillating 60-Hz magnetic field that in turn will induce an electric field within the body of a marine organism. To assess whether certain electrosensitive marine organisms may detect these fields, the magnitude of the electric field produced in marine organisms swimming over the two cable segments were calculated by modeling key species as homogeneous ellipsoids. Induced electric fields were calculated in two electrosensitive marine species—sturgeon and dogfish, two of the largest in the region. For each species, an ellipsoidal dimension was assumed:

- **Sturgeon**: 6 ft (1.8 m) long with a maximum girth of 2.5 ft (0.8 m);[14] and
- **Dogfish**: 3.3 ft (1.0 m) long with a maximum girth of 1.3 ft (0.4 m).[15]

Generally, a larger animal will have a higher induced electric field; however, the specific detection threshold for electrosensitive species is important to determine the likelihood that a specific species is capable of detecting and responding to the 60-Hz cable.

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[14] Girth was determined using a standard length-girth-weight relationship for the related lake sturgeon (http://files.dnr.state.mn.us/areas/fisheries/baudette/lksweight.pdf).

[15] Girth is estimated from the width-length relationship presented in the fishbase.org description of spiny dogfish

Attachment C

Calculated Magnetic- and Electric-Field Levels for All Modeled Cable Configurations

Calculated magnetic- and electric-field levels are provided below for each cable configuration and installation type.

Calculated magnetic-field levels are summarized in Table C-1 and Table C-2 for average and peak loading, respectively. Similarly, calculated electric-field levels induced in seawater are summarized in Table C-3 and Table C-4, and calculated electric-field levels induced in marine species are summarized in Table C-5 and Table C-6. In each table, calculated field levels are summarized for the EW 1 and EW 2 submarine export and interarray cables, at the seabed and at 3.3 ft (1.0 m) above the seabed (or 3.3 ft [1.0 m] above protective covering), and for buried, surface-laid, and landfall installation types.

Calculated magnetic-field levels and electric-field levels induced in seawater are presented in Figure C-1 through Figure C-6 for a 4-ft (1.2 m) burial depth and average loading for the EW 1 and EW 2 submarine export and interarray cables. Results for this installation type (4-ft [1.2 m] burial depth) and loading (average) represent field levels expected to occur along most of the proposed cable route under typical loading. Calculated field levels are plotted as a function of horizontal distance from the circuit centerline for a representative cross-section of each cable configuration.

Table C-1. Calculated magnetic-field levels (mG) for average loading

Cable	Installation Type	Location	Horizontal Distance from Cable		
			Max	±10 ft (±3 m)	±30 ft (±9.1 m)
EW1 Submarine Export Cable*	Buried (4 ft)	Seabed	111	19	2.9
		3.3 ft (1.0 m) Above Seabed	35	14	2.8
	Surface-Laid	Top of Protective Cover	160	20	2.9
		3.3 ft (1.0 m) Above Protective Cover	43	15	2.8
	Landfall†	Seabed	1237	22	2.9
		3.3 ft (1.0 m) Above Seabed	98	19	2.9
EW2 Submarine Export Cable*	Buried (4 ft)	Seabed	110	19	3.0
		3.3 ft (1.0 m) Above Seabed	35	14	2.8
	Surface-Laid	Top of Protective Cover	157	20	3.0
		3.3 ft (1.0 m) Above Protective Cover	43	15	2.9
Interarray Cable	Buried (4 ft [1.2 m])	Seabed	52	7.8	1.0
		3.3 ft (1.0 m) Above Seabed	16	5.9	1.0
	Surface-Laid	Top of Protective Cover	146	8.7	1.0
		3.3 ft (1.0 m) Above Protective Cover	27	6.9	1.0

* Submarine export cable includes two cables side-by-side. Horizontal distance is measured outward from nearest cable.

Table C-2. Calculated magnetic-field levels (mG) for peak loading

Cable	Installation Type	Location	Horizontal Distance from Cable		
			Max	**±10 ft (±3 m)**	**±30 ft (±9.1 m)**
EW 1 Submarine Export Cable*	Buried (4 ft [1.2 m])	Seabed	130	22	3.4
		3.3 ft [1.0 m] Above Seabed	41	17	3.3
	Surface-Laid	Top of Protective Cover	188	23	3.4
		3.3 ft [1.0 m] Above Protective Cover	51	18	3.3
	Landfall†	Seabed	1455	26	3.4
		3.3 ft [1.0 m] Above Seabed	116	22	3.4
EW 2 Submarine Export Cable*	Buried (4 ft [1.2 m])	Seabed	165	29	4.4
		3.3 ft [1.0 m] Above Seabed	53	21	4.2
	Surface-Laid	Top of Protective Cover	233	30	4.4
		3.3 ft [1.0 m] Above Protective Cover	64	23	4.3
Interarray Cable	Buried (4 ft [1.2 m])	Seabed	65	9.8	1.3
		3.3 ft [1.0 m] Above Seabed	20	7.4	1.2
	Surface-Laid	Top of Protective Cover	183	11	1.3
		3.3 ft [1.0 m] Above Protective Cover	34	8.6	1.2

* Submarine export cable includes two cables side-by-side. Horizontal distance is measured outward from nearest cable.

Table C-3. Calculated electric-field levels (mV/m) induced in seawater for average loading

Cable	Installation Type	Location	Horizontal Distance from Cable: Max	±10 ft (±3 m)	±30 ft (±9.1 m)
EW 1 Submarine Export Cable*	Buried (4 ft [1.2 m])	Seabed	4.1	2.0	0.8
		3.3 ft [1.0 m] Above Seabed	2.4	1.7	0.8
	Surface-Laid	Top of Protective Cover	4.9	2.0	0.9
		3.3 ft [1.0 m] Above Protective Cover	2.6	1.7	0.8
	Landfall†	Seabed	14	2.2	0.9
		3.3 ft [1.0 m] Above Seabed	3.8	1.9	0.9
EW 2 Submarine Export Cable*	Buried (4 ft [1.2 m])	Seabed	4.2	2.0	0.9
		3.3 ft [1.0 m] Above Seabed	2.4	1.7	0.8
	Surface-Laid	Top of Protective Cover	5.0	2.1	0.9
		3.3 ft [1.0 m] Above Protective Cover	2.7	1.8	0.9
Interarray Cable	Buried (4 ft [1.2 m])	Seabed	1.8	0.7	0.3
		3.3 ft [1.0 m] Above Seabed	1.0	0.6	0.2
	Surface-Laid	Top of Protective Cover	3.0	0.7	0.3
		3.3 ft [1.0 m] Above Protective Cover	1.3	0.6	0.3

* Submarine export cable includes two cables side-by-side. Horizontal distance is measured outward from nearest cable.

Table C-4. Calculated electric-field levels (mV/m) induced in seawater for peak loading

Cable	Installation Type	Location	Horizontal Distance from Cable: Max	±10 ft (±3 m)	±30 ft (±9.1 m)
EW 1 Submarine Export Cable*	Buried (4 ft [1.2 m])	Seabed	4.8	2.3	1.0
		3.3 ft [1.0 m] Above Seabed	2.8	2.0	1.0
	Surface-Laid	Top of Protective Cover	5.8	2.4	1.0
		3.3 ft [1.0 m] Above Protective Cover	3.1	2.0	1.0
	Landfall†	Seabed	16	2.5	1.0
		3.3 ft [1.0 m] Above Seabed	4.5	2.3	1.0
EW 2 Submarine Export Cable*	Buried (4 ft [1.2 m])	Seabed	6.2	3.0	1.3
		3.3 ft [1.0 m] Above Seabed	3.6	2.6	1.3
	Surface-Laid	Top of Protective Cover	7.4	3.1	1.3
		3.3 ft [1.0 m] Above Protective Cover	4.0	2.7	1.3
Interarray Cable	Buried (4 ft [1.2 m])	Seabed	2.2	0.9	0.3
		3.3 ft [1.0 m] Above Seabed	1.2	0.7	0.3
	Surface-Laid	Top of Protective Cover	3.8	0.9	0.3
		3.3 ft [1.0 m] Above Protective Cover	1.6	0.8	0.3

* Submarine export cable includes two cables side-by-side. Horizontal distance is measured outward from nearest cable.

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Table C-5. Calculated electric-field levels (mV/m) induced in marine species for average loading

Cable	Installation Type	Location	Marine Species	
			Dogfish	Sturgeon
EW 1 Submarine Export Cable	Buried (4 ft [1.2 m])	Seabed	0.7	1.4
		3.3 ft [1.0 m] Above Seabed	0.2	0.4
	Surface-Laid	Top of Protective Cover	1.0	2.0
		3.3 ft [1.0 m] Above Protective Cover	0.3	0.5
	Landfall*	Seabed	8.0	15
		3.3 ft [1.0 m] Above Seabed	0.6	1.2
EW 2 Submarine Export Cable	Buried (4 ft [1.2 m])	Seabed	0.7	1.4
		3.3 ft [1.0 m] Above Seabed	0.2	0.4
	Surface-Laid	Top of Protective Cover	1.0	1.9
		3.3 ft [1.0 m] Above Protective Cover	0.3	0.5
Interarray Cable	Buried (4 ft [1.2 m])	Seabed	0.3	0.6
		3.3 ft [1.0 m] Above Seabed	0.1	0.2
	Surface-Laid	Top of Protective Cover	0.9	1.8
		3.3 ft [1.0 m] Above Protective Cover	0.2	0.3

* Values calculated for landfall are expected to occur for less than 30 ft [9.1 m] of the route. Outside this short distance, values are calculated to be equal to or less than those of the surface-laid installation.

Table C-6. Calculated electric-field levels (mV/m) induced in marine species for peak loading

Cable	Installation Type	Location	Marine Species	
			Dogfish	**Sturgeon**
EW 1 Submarine Export Cable	Buried (4 ft [1.2 m])	Seabed	0.8	1.6
		3.3 ft [1.0 m] Above Seabed	0.3	0.5
	Surface-Laid	Top of Protective Cover	1.2	2.3
		3.3 ft [1.0 m] Above Protective Cover	0.3	0.6
	Landfall*	Seabed	9.5	18
		3.3 ft [1.0 m] Above Seabed	0.8	1.4
EW 2 Submarine Export Cable	Buried (4 ft [1.2 m])	Seabed	1.1	2.0
		3.3 ft [1.0 m] Above Seabed	0.3	0.6
	Surface-Laid	Top of Protective Cover	1.5	2.9
		3.3 ft [1.0 m] Above Protective Cover	0.4	0.8
Interarray Cable	Buried (4 ft [1.2 m])	Seabed	0.4	0.8
		3.3 ft [1.0 m] Above Seabed	0.1	0.3
	Surface-Laid	Top of Protective Cover	1.2	2.2
		3.3 ft [1.0 m] Above Protective Cover	0.2	0.4

* Values calculated for landfall are expected to occur for less than 30 ft [9.1 m] of the route. Outside this short distance, values are calculated to be equal to or less than those of the surface-laid installation.

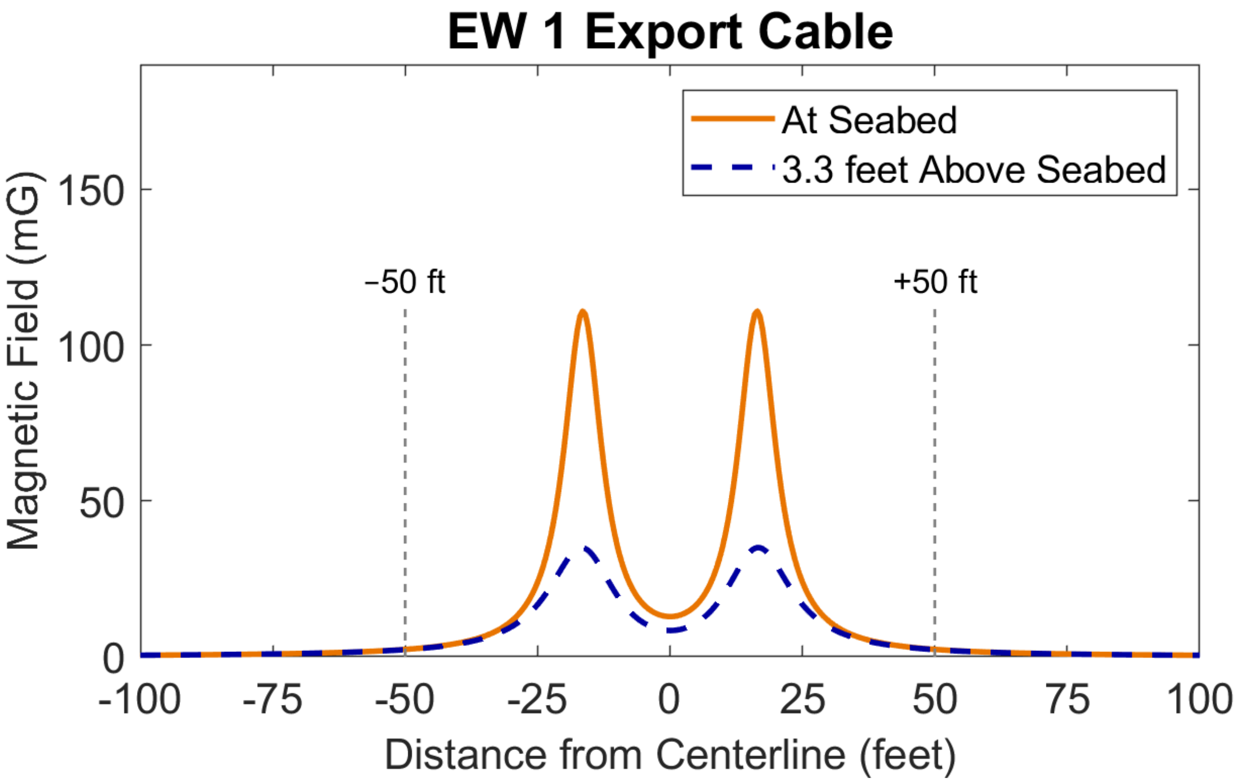

Figure C-1. Calculated magnetic-field levels in seawater above the EW 1 submarine export cable for a 4-ft (1.2 m) burial depth and average loading.

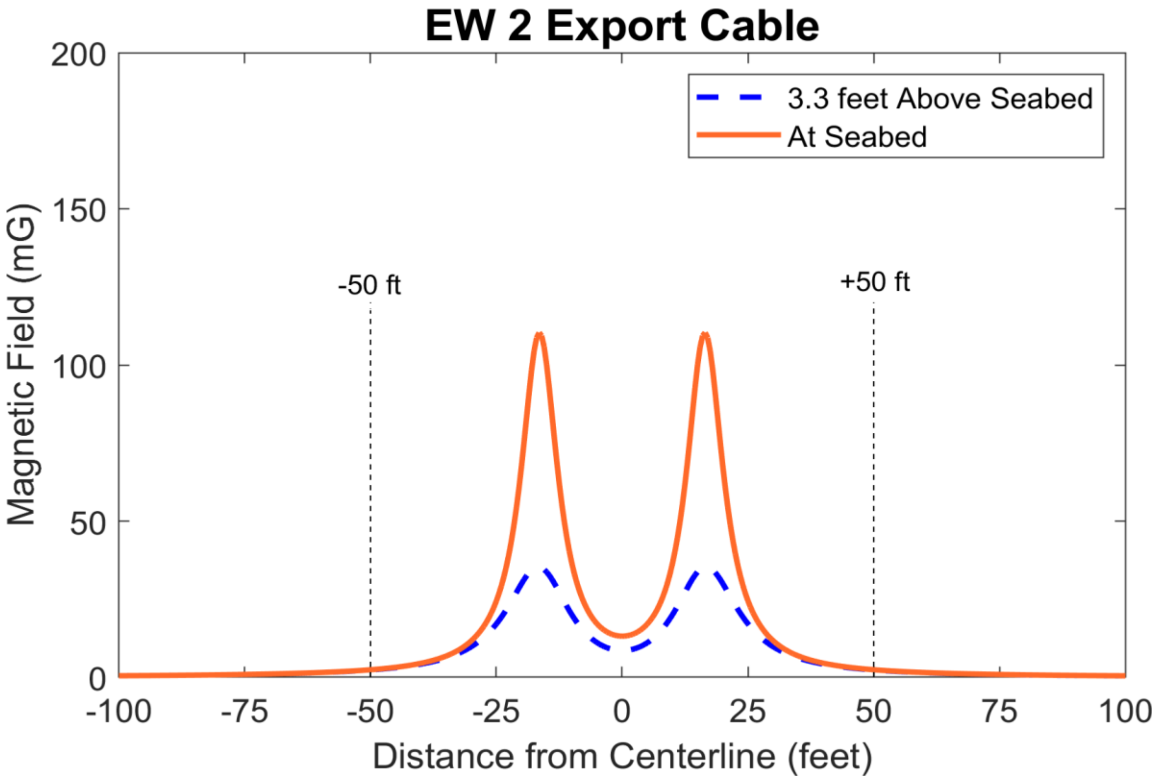

Figure C-2. Calculated magnetic-field levels in seawater above the EW 2 submarine export cable for a 4-ft (1.2 m) burial depth and average loading.

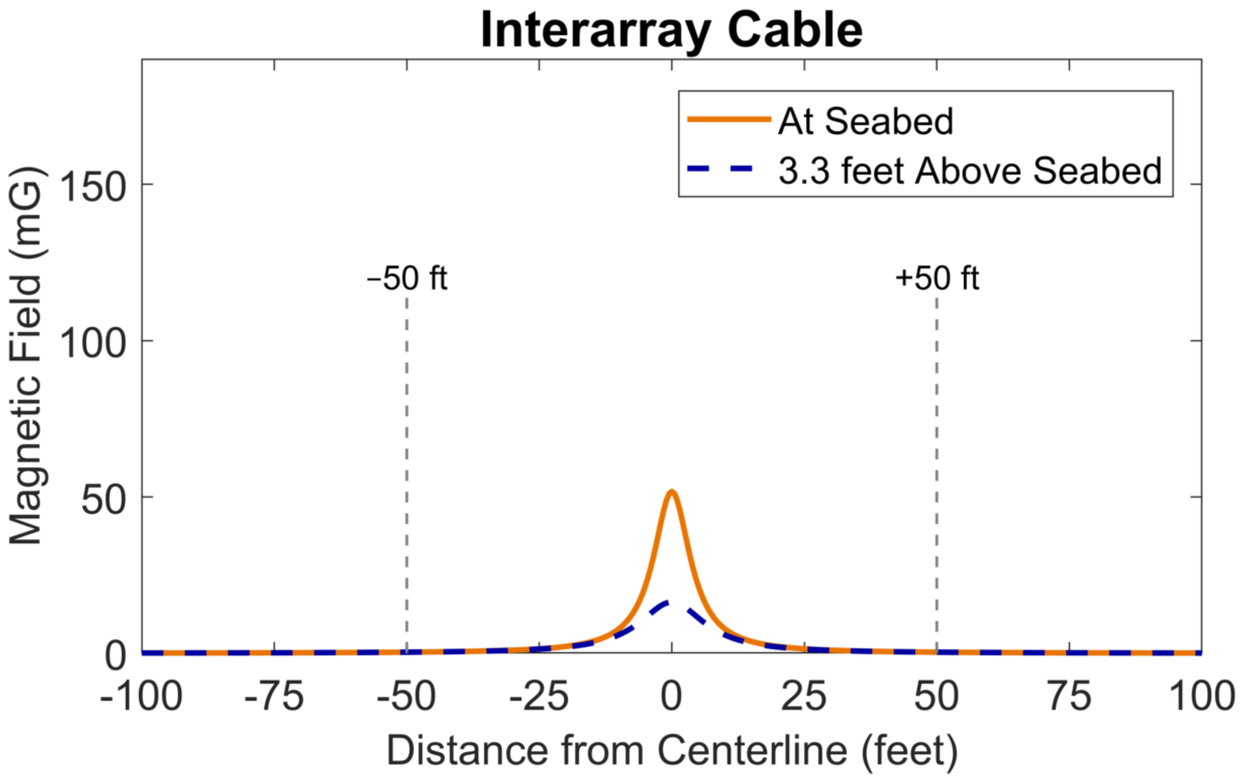

Figure C-3. Calculated magnetic-field levels in seawater above the interarray cable for a 4-ft (1.2 m) burial depth and average loading.

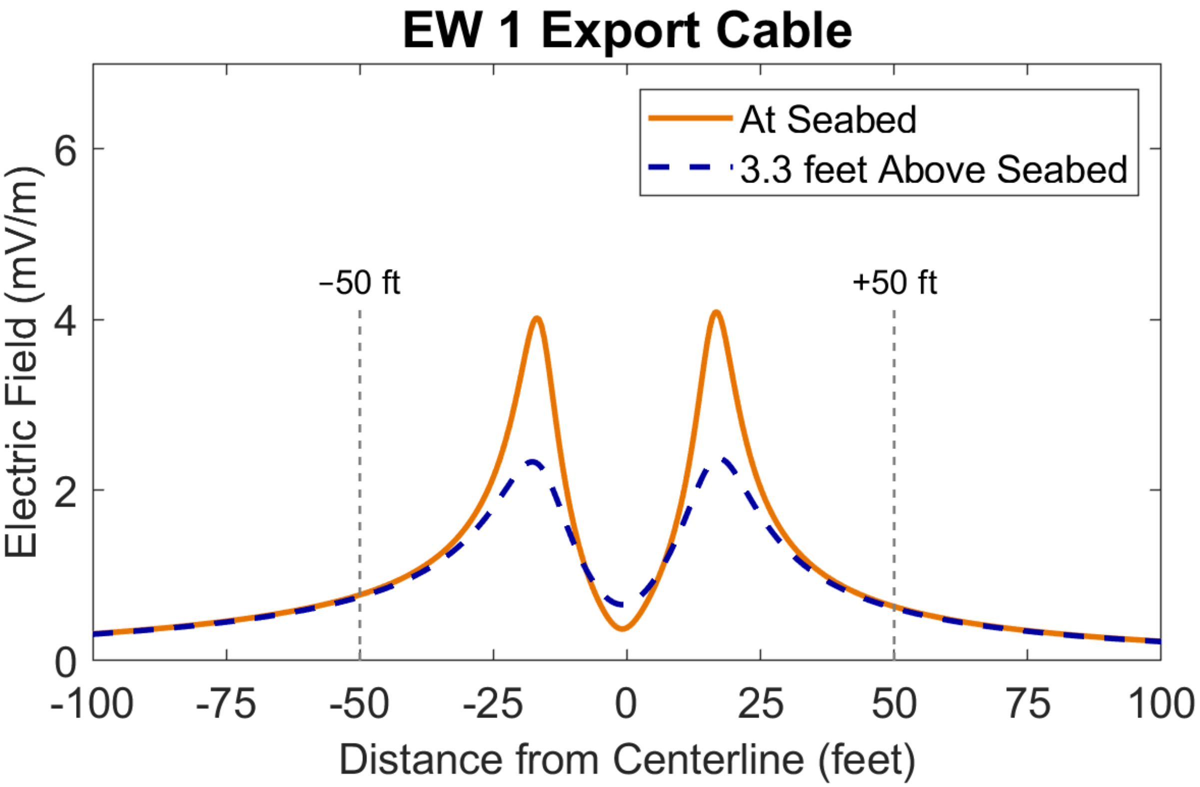

Figure C-4. Calculated electric-field levels in seawater above the EW 1 submarine export cable for a 4-ft (1.2 m) burial depth and average loading.

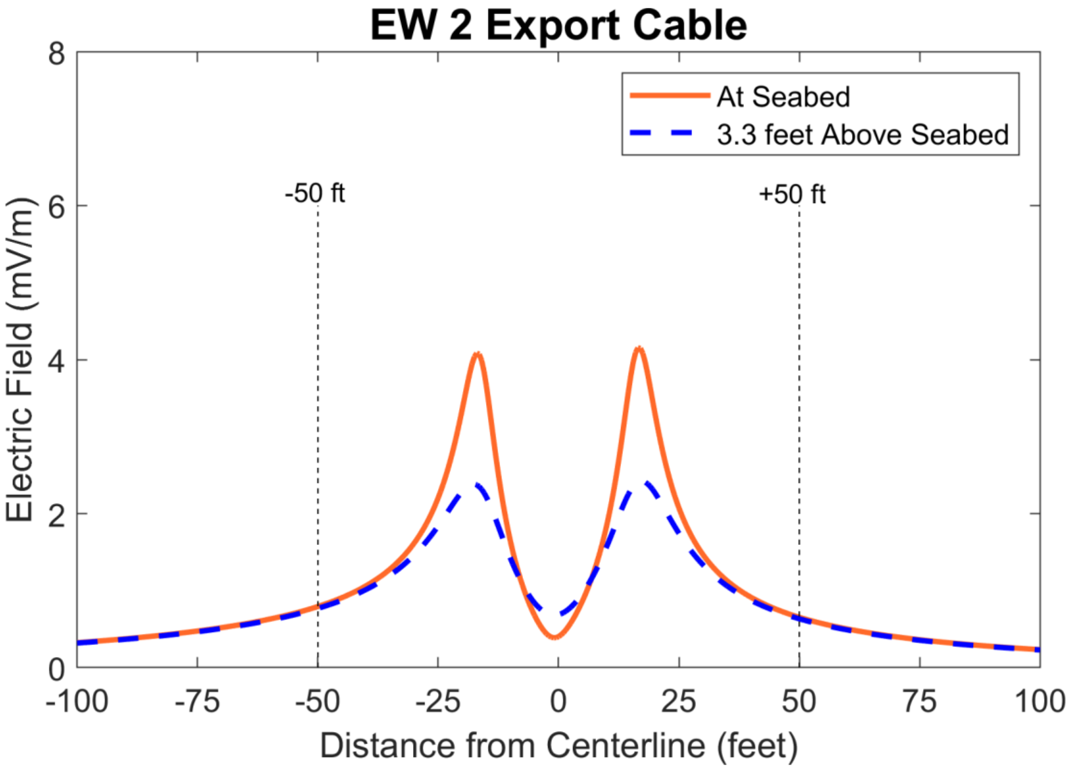

Figure C-5. Calculated electric-field levels in seawater above the EW 2 submarine export cable for a 4-ft (1.2 m) burial depth and average loading.

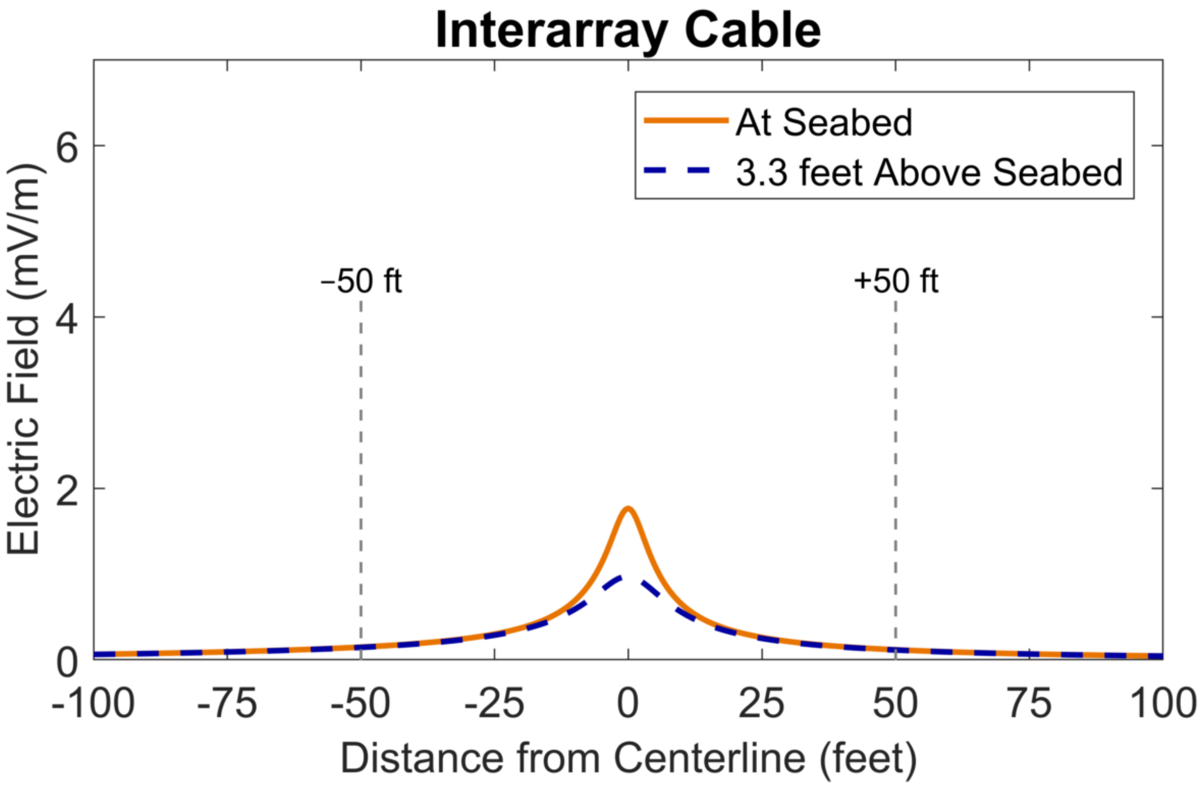

Figure C-6. Calculated electric-field levels in seawater above the interarray cable for a 4-ft (1.2 m) burial depth and average loading.