Electrical Engineering and Computer Science Practice

Ecological and Biological Sciences Practice

US Wind Maryland Offshore Wind Project

Offshore Electric- and Magnetic-Field Assessment

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Prepared for

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Acronyms and Abbreviations

µT	Microtesla
3D	3-dimensional
A	Ampere
AC	Alternating current
BOEM	Bureau of Ocean Energy Management
EMF	Electric and magnetic fields
FEA	Finite element analysis
ft	Feet
HDD	Horizontal directional drilling
Hz	Hertz
ICES	International Committee on Electromagnetic Safety
ICNIRP	International Commission on Non-Ionizing Radiation Protection
IEEE	Institute of Electrical and Electronics Engineers
km	Kilometer
kV	Kilovolt
Lease Area	Renewable Energy Lease Area OCS-A 0490
m	Meter
mG	Milligauss
mi	Mile
mm	Millimeter
MRE	Marine Renewable Energy
mT	Millitesla
mV/m	Millivolts per meter
MW	Megawatt
OCS	Outer Continental Shelf
OD	Outer diameter
OSS	Offshore substation
Project	Maryland Offshore Wind Project
XLPE	Cross-linked polyethylene
WTG	Wind turbine generator

Limitations

At the request of TRC Environmental Corporation (TRC), on behalf of US Wind, Inc. (US Wind), Exponent modeled the alternating current electric- and magnetic-field levels associated with the operation of the submarine cables proposed for the Maryland Offshore Wind Project (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 US Wind, TRC, and K2 Engineering, the engineering company contracted by US Wind to support development of the Project. We cannot verify the correctness of this input data and rely on US Wind, TRC, and K2 Engineering 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. US Wind and TRC have confirmed to Exponent that the data contained herein are not subject to Critical Energy Infrastructure Information restrictions.

The analyses 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 Project permitting 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.

Executive Summary

At the request of TRC Environmental Corporation (TRC), on behalf of US Wind Inc. (US Wind), Exponent calculated the alternating current electric and magnetic fields (EMF) associated with the operation of the Maryland Offshore Wind Project (the Project), an offshore wind energy project of up to approximately 2,000 megawatts of nameplate capacity within Lease Area OCS-A 0490. Electricity generated by offshore wind turbine generators (WTG) is proposed to be transmitted on Inter-array Cables to up to four Offshore Substations. Offshore submarine Export Cables would complete the connection to shore at a proposed landfall location at the 3R's Beach in the Delaware Seashore State Park and then through Indian River Bay to the point of interconnection.

This report summarizes the magnetic fields associated with the operation of the submarine transmission cables. Levels of EMF were calculated for the Inter-array Cables, Offshore Export Cables and Export Cables in Indian River Bay. These calculations were performed for two configurations: buried and beneath protective coverings. For purposes of this assessment, the Offshore Project Area is defined as the roughly 80,000-acre Lease Area where the Inter-array Cables, WTGs, and Offshore Substations will be installed, the Offshore Export Cable Corridor along which the Offshore Export Cables will be installed, and the Indian River Bay Export Cable Corridor.

Magnetic fields at the seabed and at a height of 1 m above seabed in the vicinity of the buried cables were assessed for the peak electricity generation (i.e., all WTGs producing maximum power), and transitory exposures at this peak loading were found to be below reported threshold levels for effects on the behavior of magnetosensitive marine organisms. Electric fields induced in seawater and in local electrosensitive marine organisms were assessed in the same areas, and were similarly found to be below reported detection thresholds. For these reasons, as well as those discussed in greater detail in the body of the report, neither induced electric fields nor magnetic fields associated with the operation of the Project cables are expected to affect the populations or distributions of fishes in the Offshore Project Area.

Average magnetic- and induced electric-field exposure for the medium term (i.e., over hours and days) was calculated for limited regions adjacent to the mattress- or rock-covered cables, where certain fish species may spend more time than near buried cables. The volume-averaged, magnetic-field magnitudes were calculated over these limited regions, where some species may likely be present, and were determined to be far below threshold levels at which longer-term exposures have been reported to affect the behavior or physiology of certain fish species.

These conclusions are consistent those of the U.S. Pacific Northwest National Laboratory's comprehensive review of the ecological impacts of Marine Renewable Energy development, which determined that "there has been no evidence to show that EMFs at the levels expected from MRE [Marine Renewable Energy] devices will cause an effect (whether negative or positive) on any species" (Copping et al., 2016). That conclusion was reaffirmed in the 2020 comprehensive review, which states, "To 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 and Hemery, 2020).

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

US Wind Inc. (US Wind), proposes to construct and operate the Maryland Offshore Wind Project (the Project), an offshore wind energy project of up to approximately 2,000 megawatts (MW) of nameplate capacity. The Offshore Substations (OSS), wind turbine generators (WTG), and Inter-array Cables would all be located in federal waters on the Outer Continental Shelf (OCS) in the Bureau of Ocean Energy Management (BOEM) Renewable Energy Lease Area OCS-A 0490 (Lease Area). The roughly 80,000-acre Lease Area is located approximately 11.5 miles (mi) (18.5 kilometers [km]) off the coast of Maryland. The Project includes MarWin, a wind farm of approximately 300 MW; Momentum Wind, consisting of approximately 808 MW; and build out of the remainder of the Lease Area to fulfill ongoing, government-sanctioned demands for offshore wind energy. Under the current Project Design Envelope (PDE), the Project is proposed to include a maximum of 121 WTGs, each with a maximum nameplate capacity of 18 MW, and collectively capable of producing up to approximately 2,000 MW of alternating current (AC) electricity. This offshore report includes an assessment of the offshore Inter-array Cables, Offshore Export Cables, and Export Cables in Indian River Bay.

Inter-array Cables would connect strings of four to six WTGs to an OSS. Up to 152 mi (245 km) of such Inter-array Cables will transmit power from the WTGs to the four OSSs at an operating voltage of 66 kilovolts (kV). At each OSS, the voltage would be stepped up from 66 kV to a planned operating voltage of 230–275 kV for transmission via the Offshore Export Cables.

Both cables designed for operation at 230-kV or 275-kV are currently within the PDE for the Offshore Export Cables. Up to four Offshore Export Cables would each transmit electricity from the OSSs to the planned landfall at 3R’s Beach in Delaware Seashore State Park, over a distance of approximately 13.8 mi (22.2 km).

To come ashore at the 3R’s Beach in Delaware Seashore State Park, each Offshore Export Cable would be installed by horizontal directional drilling (HDD) to minimize impacts to sensitive shore areas. Each HDD bore would extend approximately 1,600 feet (ft) (490 meters [m]) through to a transition vault installed below grade at the landfall location at 3R's Beach. From Delaware Seashore Stare Park, each of the four Export Cables would similarly be installed via HDD to Indian River Bay where the four cables (with a minimum spacing of 33 ft [10 m]) will traverse 10 mi (17 km) through the proposed Indian River Bay Export Cable Corridor to an HDD exit location at the landfall location near the point of interconnection.

Offshore Export Cables designed for operation at 230-kV or 275-kV are currently within the PDE. For the same power flow, a higher electrical current and hence higher magnetic fields would result for operation at 230 kV, and hence all calculations of the Export Cables in this report (both offshore and in Indian River Bay) assume an operating voltage of 230 kV.

An overview of the Offshore Project Area with the proposed location of the WTG array and potential Offshore Export Cable Corridor is provided in Figure 1. The Inter-array Cables, Offshore Export Cables, and Export Cables in Indian River Bay—where buried or otherwise protected— would be sources of magnetic and induced electric fields, described in the following sections.

This report summarizes the calculated AC magnetic-field and induced electric-field levels from the Inter-array cables, the Offshore Export Cables, and the Export Cables in Indian River Bay. An assessment of magnetic-field levels generated by the onshore portions of the Project is provided in a companion report titled *US Wind Maryland Offshore Wind Project: Onshore Magnetic Field Assessment*.

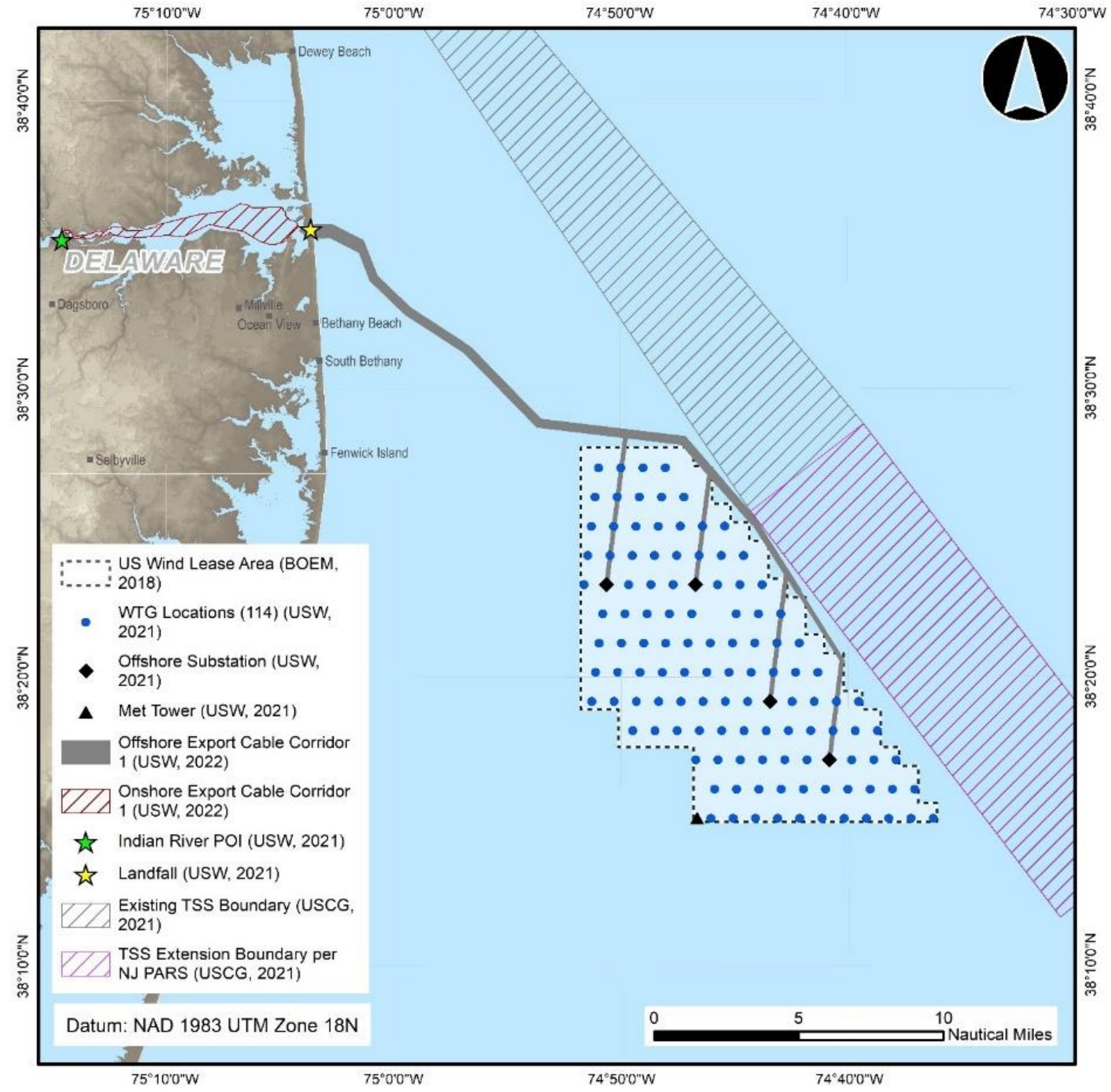

Figure 1. Geographic location of the proposed Offshore Project Area off the coast of Maryland and its Export Cable Corridor extending northwest toward a landfall location in the state of Delaware.

Magnetic Fields and Induced Electric Fields

The Project would transmit AC electricity from the Project WTGs to OSSs to landfall at a frequency of 60 Hertz (Hz), which means that it changes direction and intensity in a continuous cycle that repeats 60 times per second (i.e., they oscillate at this rate). Since the electricity is transmitted at a frequency of 60 Hz, the resulting EMF also would oscillate at the same 60-Hz frequency. This is the same as the electricity typically carried over distribution and transmission lines in our communities and that is used throughout modern life in our homes and businesses.

Magnetic Fields

Magnetic fields from the Project were reported as magnetic flux density in units of milligauss (mG), which is the unit of measure commonly used in North America. Elsewhere in the world, magnetic-field levels are often reported in units of microtesla (µT), where 1 µT is equal to 10 mG. The magnetic field created by the flow of current on the Project's cables will be highest directly above the buried submarine cables, and like magnetic fields from other sources, will decrease rapidly with distance.

Induced Electric Fields

The Project would produce electric fields due to the voltage applied to the electrical conductors of the Inter-array Cables and Offshore Export Cables. Since electric fields are effectively blocked by the cable construction, such as dielectric materials, the metallic sheaths, and the steel armoring of these cables, electric fields from voltage on the conductors would not be extend into the marine environment (*see* e.g., Snyder et al., 2019). The oscillating magnetic fields, however, would create (i.e., induce) weak electric fields in the water around the cables and in marine species near the cables. These induced electric fields, measured in units of millivolts per meter (mV/m), also would be highest immediately above the buried cables and the strength will decrease rapidly with distance from the source.

Magnetic- and Induced Electric-Field Calculations

Since the current (i.e., the load) carried by the cables depends on the speed of the wind, both magnetic-field and induced electric-field levels would vary as windspeed varies. Exponent therefore calculated magnetic and induced electric fields for estimated annual average load to provide typical field levels for average operating conditions as well as for peak load, which provides a conservative representation of the maximum field levels expected (i.e., when all wind turbines are generating electricity at their maximum capacity).

Electric- and Magnetic-Field Guidelines for Human Exposure

The states of Maryland and Delaware do not have any laws, regulations, or guidelines that limit 60-Hz magnetic fields from any type of electric transmission or distribution cables, either above ground, or underground, or offshore. Similarly, the federal government has no such laws, regulations, or guidelines regarding 60-Hz magnetic fields.

Since there are no governmental regulatory guidelines, magnetic-field levels were assessed in the context of the relevant human health exposure limits developed by scientific organizations based on reviews and evaluations of relevant health research. Both the International Commission on Non-Ionizing Radiation (ICNIRP) and the Institute of Electrical and Electronics Engineers' (IEEE) International Committee on Electromagnetic Safety (ICES) have conducted extensive reviews of the relevant research related to magnetic-field exposure and developed guidance for exposure based on that research (ICNIRP, 2010; ICES, 2019).

ICNIRP is an independent, non-profit scientific organization with the stated aim "… to protect people and the environment against adverse effects of non-ionizing radiation … To this end, ICNIRP develops and disseminates science-based advice on limiting exposure to non-ionizing radiation"[1] The Commission consists of international experts in fields such as biology, epidemiology, medicine, physics, and chemistry. These experts "… work together with and within ICNIRP to assess the risk of [non-ionizing radiation] exposure and provide exposure guidance,"[2] which is periodically published in guidelines, reviews, and statements that are publicly available.

ICES, operating under the oversight of the IEEE's Standards Association Board, is "… responsible for development of standards for the safe use of electromagnetic energy in the range of 0 Hz to 300 GHz [Gigahertz] relative to: the potential hazards of exposure of humans …, standards for products that emit electromagnetic energy by design or as a by-product of their operation, and standards for environmental limits." The Committee "strives to achieve consensus among all the stakeholders in the safe use of electromagnetic energy, thereby producing practical science-based standards that are readily accepted and applied."

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[1] https://www.icnirp.org/en/about-icnirp/aim-status-history/index.html

[2] *Ibid.*

The ICNIRP reference level limit for 60-Hz magnetic fields is 2,000 mG for the general public, while the ICES exposure reference level for the general public is 9,040 mG (ICNIRP, 2010; ICES, 2019).

Exposure of Fish and Other Species to Magnetic and Induced Electric Fields

Some species of environmental and ecological importance have specialized sensory receptors capable of detecting these electric and magnetic fields in the natural environment (*see* e.g., Taylor, 1986; Klimley, 1993; Lohmann et al., 1995; Hellinger and Hoffmann, 2012). The relevant evaluations presented herein include both potential transitory and longer-term exposure to magnetic and induced electric fields from the Project. The magnetic and induced electric fields detected by fish and other marine organisms generally are limited to frequencies between approximately 0 Hz[3] and 10 Hz (*see* e.g., Bedore and Kajiura, 2013; Snyder et al., 2019). The marine evaluation, beginning in the section titled *Description of Key Marine Communities in the Offshore Project Area*, addresses both potential transitory and longer-term exposure of fish and other species of interest in the Offshore Project Area.

Transitory Exposure

Demersal fish species that swim over the buried Project cables be exposed to magnetic and induced electric fields. Exposure from this swimming activity is transitory, so this evaluation focuses on whether these species can detect these fields, and if so, whether detection results in individual or population-level behavioral or physiological effects. Field levels were calculated at peak loading and at a height of 3.3 ft (1 m)[4] above the cables, which is the relevant reference location where most demersal fish species will experience transitory exposure. These values were compared to scientific literature to evaluate the possibility of detection and alternation of behavior.

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[3] A field that does not change significantly in time is called a static field or a 0-Hz field. The earth's geomagnetic field and the magnetic fields from permanent bar magnets are common examples of static magnetic fields.

[4] This height is consistent with recommendations in international exposure assessments (e.g., ICNIRP, 2010; ICES, 2019) and is meant to capture species swimming in close proximity to the seabed.

Longer Duration Exposure at Protective Coverings

As noted, exposure from swimming activity by demersal fish species is transitory, but in locations where the cables cannot be buried, the Project will use protective rock or mattresses to cover them. At these rock- or mattress-covered locations, magnetic- and induced electric-field levels will be higher since the depth of coverage at these locations is smaller than where the cable is buried under the seabed. These protective coverings result in hard-surface infrastructure that may attract some fish species for longer durations and can provide habitat for some species in areas where other hard-surface structures are scarce.

In areas with protective coverings, Exponent therefore calculated volume-average field levels as a conservative estimate of *average* exposure over hours and days (i.e., medium term) above rock- or mattress-covered cables. Average field levels were calculated in this manner because of the potential for some species that establish habitats in these areas to spend more time relatively close to these rock- or mattress-covered areas. Calculated volume-average field levels at average loading were compared to field levels reported in the scientific literature where physiologic responses were measured over longer periods than those used in typical acute behavioral studies.

EMF Calculations

Modeling Configurations

Exponent calculated the 60-Hz magnetic- and induced electric-fields from the three-phase, three-core submarine cables proposed for different segments of the Project and compared the results of these calculations to assessment criteria in order to evaluate potential effects on marine species. All of the AC cables are three-core cables (see Appendix A, Figure A-1) with the three conductors within each cable twisting helically around one another. Five representative cable configurations among three portions of the Project were modeled to represent the various offshore cables and installation methods, including:

1. Inter-array Cables
    - i. At a burial depth of 3.3 ft (1 m), and
    - ii. Where installed at the seabed with a 1-ft (0.3-m) thick protective covering.[5]
2. Offshore Export Cables[6]
    - i. At a burial depth of 3.3 ft (1 m), and at least a 100 ft (30.5 m) separation distance), and
    - ii. Where installed at the seabed with a 1-ft (0.3-m) thick protective covering and at least a 100 ft (30.5 m) separation distance.
3. Export Cables in Indian River Bay
    - i. The four Export Cables are to be installed parallel to one another with a minimum of 33 ft (10 m) center-to-center separation between cable conduits and buried 3.3 ft (1 m) beneath the seabed.

The PDE (*see* Maryland Offshore Wind Project, Construction and Operations Plan, Volume I, Project Information, Rev Nov 2022) indicates that minimum burial depths are proposed to range

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[5] Exponent understands that only Offshore Export Cables are expected to require portions with protective mattresses along the Offshore Export Cable Corridor where cable crossings or other obstacles may occur. However, magnetic fields around both Export Cables and Inter-array Cables with protective coverings were nevertheless calculated and presented in this report.

[6] Where the Export Cables transition from water to land and land to water at the 3R's Beach in Delaware Seashore State Park, the cables will be installed by HDD. In these portions of the Project, cables are expected to be installed at burial depths well in excess of 3.3 ft (1 m). Magnetic- and induced electric-field levels above the HDD portions will therefore be far lower than reported here, and thus were not modeled separately as part of this assessment.

from 3.3 ft to 6.6 ft (1 to 2 m) beneath the seabed. To conservatively overestimate EMF levels from buried cables, all calculations for the buried cables presented in this report were assessed at a 3.3 ft (1 m) burial depth. Further details of the cable parameters and associated modeling configurations are provided in Attachment A, Table A-1.

Loading Levels

As discussed above, both 230-kV and 275-kV cables are currently within the PDE, but operation at 230-kV will result in higher EMF levels, so all calculations assume operation at 230 kV. When operating at 230-kV, three of the four Offshore Export Cables will have a peak current of 1,200 Amperes (A), and one will have a peak current of 870 A. Average loading was based upon an estimated 40% capacity factor, so average current on three of the four Offshore Export Cables was assumed to be 480 A, and was assumed to be 348 A for the fourth cable. The peak and average loading of the Inter-array Cables was assumed to be 840 A and 336 A, respectively.

Methods for EMF Calculations

Exponent modeled the magnetic- and induced electric-field levels for each cable configuration with 3-dimensional (3D) finite element analysis (FEA) software. Models of each cable were constructed including the helically-twisting conductors within each cable and using conservative assumptions designed to ensure that the calculated levels overestimate the field levels that would be measured above the cables at any specified loading within the range of the Project's capacity. The calculated AC fields are presented at maximum loading (i.e., peak loading, which is the maximum Project capacity) and at the anticipated typical Project loading (i.e., average loading). To conservatively overestimate field levels from the Offshore Export Cables, only the higher loading level representative of three of the four cables (i.e., 1,200 A and 480 A for peak and average loading, respectively) were used. Where cables are expected to be separated from one another by sufficiently large distances such that they are not expected to interact (i.e., Inter-array Cables and Offshore Export Cables), models were created to calculate magnetic fields produced by an individual cable. These calculations were reported both at the seabed and at 3.3 ft (1 m) above the seabed. The four Offshore Export Cables at a minimum separation distance of 33 ft (10 m) in Indian River Bay were incorporated together in one model to capture any potential additive effects of magnetic fields from adjacent cables. In this model, three cables were assumed to carry the higher load (i.e., 1,200 A and 480 A for peak and average loading, respectively) and the fourth cable (assumed to be situated on the left-outside-edge of the cable grouping) was assumed to carry the lower load of 870 A and 348 A for peak and average loading, respectively. Additional details of modeling assumptions and methods are presented in Attachment B, and results of the calculations are presented in Attachment C.

EMF Calculation Results

While EMF was calculated throughout the vicinity of the Project components, the determination of the maximum magnetic fields and induced electric fields over the cables that may be detected by sensitive marine species is a focus of the assessment where cables are buried beneath the seabed. Where Project components may introduce new habitat (i.e., at protective mattresses or rock berms) the assessment focuses on the determination of volume-averaged magnetic and induced electric fields that may pose the potential for physiological effects from longer-term exposures to higher average fields.

EMF levels were calculated to be highest at the seabed immediately above the cable and decrease very rapidly with distance, either horizontally away from the cable or vertically through the water column. An example of the magnetic field and induced electric field from the 230-kV Offshore Export Cable when operated at peak loading and installed at a 3.3-ft (1-m) burial depth are shown below in Figure 2a and Figure 2b, respectively. At the seabed immediately above the cable the magnetic- and induced electric-field levels were 148 mG and 2.5 mV/m, respectively. Notably, however, is how rapidly both magnetic and induced electric fields decrease with distance. At a distance of 10 feet (3 m) horizontally from the cable, magnetic-field levels decrease to less than 1 mG and induced electric-field levels decrease to 0.1 mV/m or less.

EMF levels above the Export Cables in Indian River Bay were very similar; the 33-ft (10-m) minimum distance between cables means that there is minimal mutual interaction of the four adjacent cables. EMF levels above the Inter-array Cables were lower than the Offshore Export Cables both because of lower current flow, but also because the Inter-array Cables are smaller and therefore the three conductors within each cable can be bundled closer together.

At the seabed, the maximum calculated magnetic field at peak loading for cables installed at a buried depth of 3.3 ft (1 m) was 49 mG for the 66-kV Inter-array Cables, 148 mG for the 230-kV Offshore Export Cables, and 148 mG for the 230-kV Export Cables in Indian River Bay. The maximum electric field induced in seawater at the seabed for cables in these same conditions was 0.7 mV/m for the 66-kV Inter-array Cable, 2.5 mV/m for the 230-kV Offshore Export Cables, and 2.5 mV/m for 230-kV Export Cables in Indian River Bay.

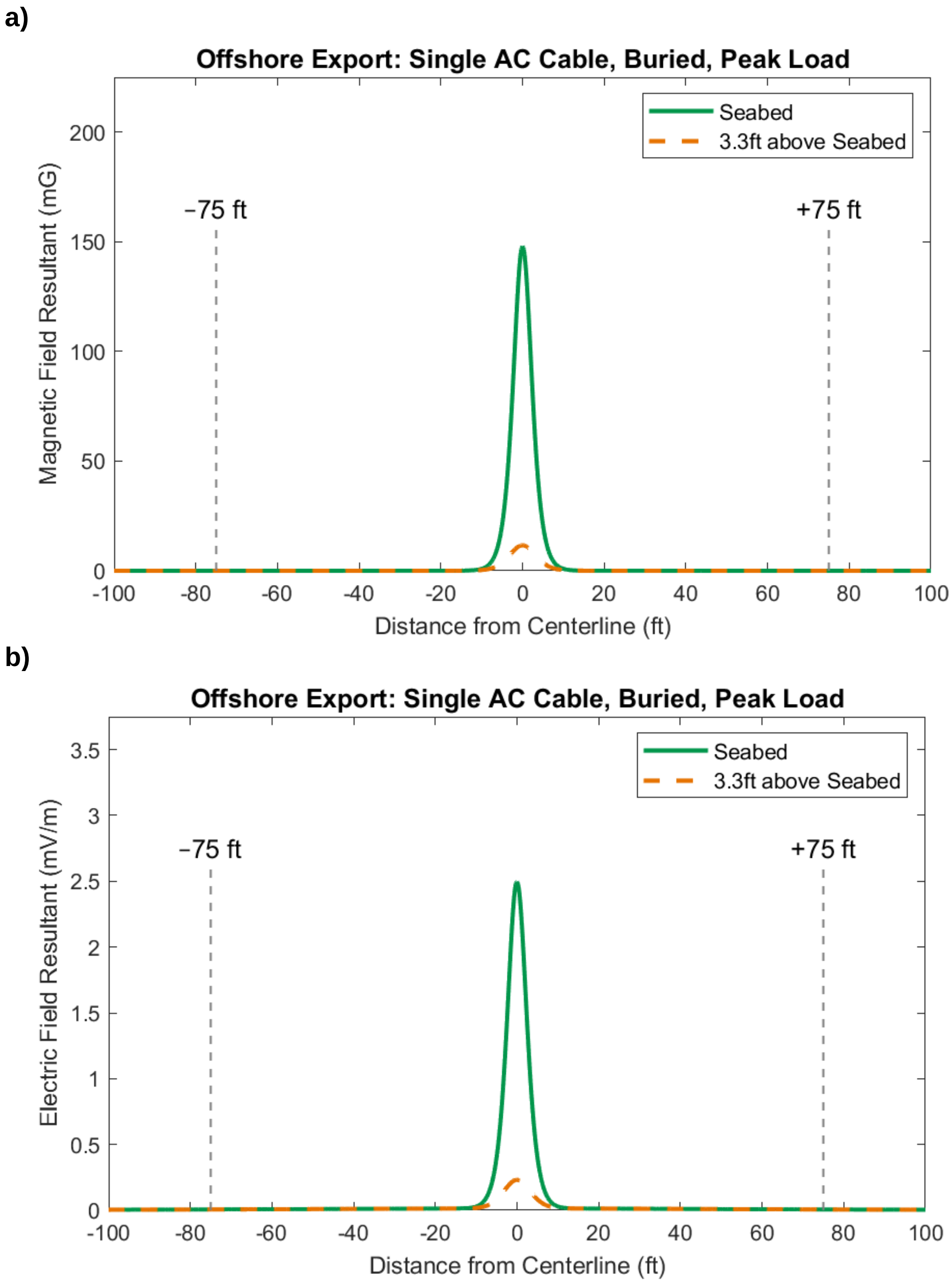

Figure 2. Calculated AC a) magnetic field and b) induced electric field during peak loading over one 230-kV Offshore Export Cable installed at a 3.3-ft (1-m) burial depth.

Calculated magnetic- and induced electric-field levels for all three cable types are shown below in Table 1, and quantify what the figures above show—that field levels decrease rapidly with distance. At a distance of 10 feet (3 m) horizontally from all cable types, the magnetic-field levels decrease to less than 1 mG and induced electric-field levels decrease to 0.1 mV/m or less.

Detailed results for the different cable configurations modeled in this assessment, including where covered in protective mattresses are provided in Attachment C. Magnetic-field calculations are presented in Table C-1 and Table C-2, Figure C-4 to Figure C-6, and Figure C-10 to Figure C-12. Induced electric-field calculations are presented in Table C-3 and Table C-4, Figure C-7 to Figure C-9, and Figure C-13 to Figure C-15.

Calculations of volume-averaged magnetic and induced electric fields also were performed in order to assess the fields that may be encountered for longer periods of time by some marine organisms that may inhabit the area over hard ground provided by protective coverings. The results of the volume-averaged calculations are included in Attachment D, Table D-1.

Table 1. Summary of calculated magnetic- and induced electric-field levels for 3.3-ft (1-m) burial depth and peak loading at specified horizontal distances*

		Magnetic Field (mG)			Electric Field (mV/m)[†]		
Cable Configuration	**Evaluation Height**	**Max**	**5 ft (1.5 m)**	**10 ft (3 m)**	**Max**	**5 ft (1.5 m)**	**10 ft (3 m)**
Inter-array Cable	At the seabed	49	4.0	0.1	0.7	0.1	< 0.1
	3.3 ft (1 m) above the seabed	2.1	0.5	< 0.1	< 0.1	< 0.1	< 0.1
Offshore Export Cable[‡]	At the seabed	148	21	0.9	2.5	0.4	< 0.1
	3.3 ft (1 m) above the seabed	12	3.7	0.3	0.2	0.1	< 0.1
Export Cables in Indian River Bay[‡,§]	At the seabed	148	21	0.9	2.5	0.4	< 0.1
	3.3 ft (1 m) above the seabed	12	3.8	0.3	0.2	0.1	< 0.1

* For the individual Inter-array and Offshore Export Cables, the horizontal distance is measured from the centerline of the cable.

[†] Induced electric fields in representative marine species of interest are lower than those presented here for induced electric fields in seawater.

[‡] Where cables are installed via HDD, the proposed burial depth will be approximately 6.6 ft (2 m) or greater. In this configuration, maximum calculated field levels above the cable will be lower than presented here.

[§] For the Export Cables in Indian River Bay, results at horizontal distances > 0 were provided relative to the outside cable with higher current (i.e., 1,200 A and 480 A for peak and average loading, respectively). Calculated magnetic-and induced-electric field levels near the cable carrying lower currents will be lower.

Description of Key Marine Communities in the Offshore Project Area

As previously noted, the Project will be sited approximately 11.5 mi (18.5 km) off the coast of Maryland, with up to 152 mi (245 km) of Inter-array Cable in federal waters and approximately 13.8 mi (22.2 km) of Offshore Export Cable running through coastal waters and Indian River Bay in Delaware. These cables are projected to intersect the habitats of numerous commercially- and ecologically-important marine species.

Important finfish[7] species that inhabit the Project Area and are considered likely to cross cable routes are listed in Table 2. Species were considered likely to inhabit or cross through cable routes if they were associated with a demersal habitat or if they are expected to occur in Indian River Bay because demersal (i.e., bottom-dwelling) finfish are most likely to encounter the highest EMF levels produced by cables (Bull and Helix, 2011). Pelagic finfish, in contrast, inhabit the upper reaches of the water column, which largely separates them from the highest EMF levels directly above the cables. The exception is in the shallower areas within Indian River Bay, where the demersal and pelagic habitats are compressed into each other and where pelagic finfish are more likely to swim near cable routes.

Table 2. Finfish species expected to inhabit the Project Area

Species	Habitat Association	EFH in Project Area	Commercial/Recreational Importance	Atlantic Ocean	Indian River Bay
American conger (*Conger oceanicus*)	Benthic				●
American eel (*Anguilla rostrata*)	Demersal			●	●
American sand lance (*Ammodytes americanus*)	Demersal				●
Atlantic butterfish (*Peprilus triacanthus*)	Demersal / Pelagic (spring to fall)	●	●	●	●
Atlantic cod (*Gadus morhua*)	Demersal	●	●	●	●
Atlantic croaker (*Micropogonias undulates*)	Demersal		●	●	●

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[7] The term finfish is used to distinguish these finfish species from the elasmobranchs, which are evaluated in Table 3.

Species	**Habitat Association**	**EFH in Project Area**	**Commercial/Recreational Importance**	**Atlantic Ocean**	**Indian River Bay**
Atlantic needlefish (*Stongylura marina*)	Demersal				●
Atlantic sturgeon (*Acipenser oxyrinchus oxyrinchus*)	Demersal			●	
Bergall (*Tautogolabrus adspersus*)	Demersal		●		●
Black drum (*Pogonias cromis*)	Demersal		●		●
Black sea bass *(Centropristis striata)*	Demersal	●	●	●	●
Feather blenny (*Hypsoblennius hentz*)	Demersal				●
Flathead grey mullet (*Mugil cephalus*)	Demersal		●		●
Fourspine stickleback (*Apeltes quadracus*)	Demersal				●
Gray snapper (*Lutjanus griseus*)	Demersal / Pelagic		●		●
Hogchoker (*Trinectes maculatus*)	Demersal				●
Little sculpin (*Myoxocephalus aenaeus*)	Demersal				●
Monkfish (*Lophius americanus*)	Demersal	●	●	●	
Mummichog (*Fundulus heteroclitus*)	Demersal			●	●
Naked goby (*Gobiosoma bosc*)	Demersal				●
Northern kingfish (*Menticirrhus saxatilis*)	Demersal				●
Northern pipefish (*Syngathus fuscus*)	Demersal				●
Northern puffer (*Sphoeroides maculatus*)	Demersal				●
Northern seahorse (*Hippocampus erectus*)	Demersal				●
Northern sea robin *(Prionotus carolinus)*	Demersal			●	●
Northern sennet (*Sphyraena borealis*)	Demersal				●
Northern stargazer (*Astroscopus guttatus*)	Demersal				●
Oyster toadfish (*Opsanus tau*)	Demersal				●
Pinfish (*Lagodon rhomboides*)	Demersal		●		●
Pollock (*Pollachius virens*)	Demersal	●	●		●

Species	Habitat Association	EFH in Project Area	Commercial/Recreational Importance	Atlantic Ocean	Indian River Bay
Red drum (*Sciaenops ocellatus*)	Demersal		●		●
Red hake (*Urophycis chuss*)	Demersal	●	●	●	●
Scup (*Stenotomus chrysops*)	Demersal (fall) / Pelagic	●	●	●	●
Seaboard goby (*Gobiosoma ginsburgi*)	Demersal				●
Sheepshead minnow (*Cyprinodon variegatus variegatus*)	Demersal				●
Shortnose sturgeon (*Acipenser brevirostrum*)	Demersal				
Silver hake (*Merluccius bilinearis*)	Demersal (night) / Pelagic (day)	●	●	●	
Silver perch (*Bairdiella chrysoura*)	Demersal				●
Smallmouth flounder (*Etropus microstomus*)	Demersal				●
Spot (*Leiostomus xanthurus*)	Demersal		●	●	●
Spotfin butterflyfish (*Chaetodon ocellatus*)	Demersal				●
Spotfin killifish (*Fundulus luciae*)	Demersal				●
Spotted hake (*Urophycis regia*)	Demersal			●	●
Spotted seatrout (*Cynoscion nebulosus*)	Demersal		●		●
Striped bass (*Morone saxatilis*)	Demersal		●		●
Striped cusk-eel (*Ophidion marginatum*)	Demersal				●
Striped sea robin (*Prionotus evolans*)	Demersal		●		●
Summer flounder (*Paralichthys dentatus*)	Demersal	●	●	●	●
Striped killifish (*Fundulus majalis*)	Demersal				●
Tautog (*Tautoga onitis*)	Demersal			●	
Three-spined stickleback (*Gasterosteus aculeatus*)	Benthopelagic				●
Weakfish (*Cynoscion regalis*)	Demersal			●	●
White mullet (*Mugil curema*)	Demersal				●
White perch (*Morone americana*)	Demersal		●		●

Species	Habitat Association	EFH in Project Area	Commercial/Recreational Importance	Atlantic Ocean	Indian River Bay
Windowpane flounder (*Scopthalmus aquosus*)	Demersal	●		●	●
Winter flounder (*Pseudopleuronectes americanus*)	Demersal	●	●	●	
Witch flounder (*Glytocephalus cynoglossus*)	Demersal	●		●	●
Yellowtail flounder (*limanda ferruginea*)	Demersal	●	●	●	
Alewife (*Alosa pseudoharengus*)	Pelagic		●	●	●
American shad (*Alosa sapidissima*)	Pelagic		●	●	●
Atlantic herring (*Clupea harengus*)	Pelagic	●	●	●	●
Atlantic menhaden (*Brevoortia tyrannus*)	Pelagic		●		●
Atlantic silverside (*Menidia menidia*)	Pelagic		●		●
Bay anchovy (*Anchoa mitchilli*)	Pelagic		●	●	●
Blueback herring (*Alosa aestivalis*)	Pelagic			●	●
Bluefin tuna (*Thunnus thynnus*)	Pelagic	●	●	●	●
Bluefish (*Pomatomus saltatrix*)	Pelagic	●	●	●	●
Broad striped anchovy (*Anchoa hepsetus*)	Pelagic			●	●
Crevalle jack (*Caranx hippos*)	Pelagic		●	●	●
Inland silverside (*Menidia beryllina*)	Pelagic				●
Inshore lizardfish (*Synodus foetens*)	Pelagic				●
Rainwater killifish (*Lucania parva*)	Pelagic				●
Rough silverside (*Membras martinica*)	Pelagic				●
Yellowfin tuna (*Thunnus albacares*)	Pelagic	●	●	●	●

Sources: Nelson and Monaco (2000); Able and Fahay (2010); USDOI and BOEM (2012); NOAA Fisheries (2021); Froese and Pauly (2022).

Several elasmobranch species, including skates, sharks, and dogfish, are also expected to inhabit the Project Area (Table 3). These species have cartilaginous skeletons and are known to be both magnetosensitive and electrosensitive. As with finfish species, elasmobranch species are considered likely to be exposed to cable EMF if they are either demersal or pelagic in shallow nearshore areas. Larger elasmobranchs, like sand tiger sharks (*Carcharias taurus*), frequently undergo long migrations that would take them out of the Project Area. Many elasmobranchs, however, exhibit smaller home ranges within coastal areas, increasing the likelihood of encountering the cable route.

Table 3. Elasmobranch species projected to inhabit the Project Area

Species	Habitat Association	EFH in Project Area	Commercial/ Recreational Importance	Atlantic Ocean	Indian River Bay
Atlantic angel shark (*Squantina dumeril*)	Demersal	●		●	
Clearnose skate (*Raja eglanteria*)	Demersal	●		●	●
Little skate (*Leucoraja erinacea*)	Demersal	●		●	
Smoothhound shark (*Mustelus canis*)	Demersal	●		●	●
Spiny dogfish (*Squalus acanthias*)	Demersal	●	●	●	
Winter skate (*Leucoraja ocellata*)	Demersal	●		●	●
Atlantic sharpnose shark (*Rhizoprionodon terraenovae*)	Pelagic	●		●	●
Sand tiger shark (*Carcharias taurus*)	Pelagic	●	●	●	●

Sources: Nelson and Monaco, 2000; Able and Fahay, 2010; USDOI and BOEM, 2012; NOAA Fisheries, 2021; Froese and Pauly, 2022.

Commercially important large invertebrates that inhabit the Project Area include bivalves and squid (Table 4); ecologically important invertebrates in the area are also likely to include crustaceans like crabs and lobsters. While bivalves may be sessile or immobile, crustaceans and squid will move and migrate through the Project Area and across cable routes. These differences result in different possible exposures: one transitory for mobile invertebrates that move through the Project Area and one longer-term for more immobile invertebrates that happen to inhabit sediments overlying the cable route. It should be noted, however, that the total area of sediment habit overlying the cable is a small percentage of the available sediment habitat in the coastal area.

Table 4. Large invertebrate species expected to inhabit the Project Area

Species	Habitat Association	EFH in Project Area	Commercial/Recreational Importance	Atlantic Ocean	Indian River Bay
Atlantic horseshoe crab (Limulus polyphemus)	Benthic		●	●	●
Atlantic surf clam (*Spisula solidissima*)	Benthic	●	●		●
Longfin inshore squid (*Doryteuthis pealeii*)	Pelagic	●		●	
Northern shortfin squid (*Illex illecebrosus*)	Demersal		●	●	●
Ocean quahog (*Artica islandica*)	Benthic	●			●

Sources: Nelson and Monaco, 2000; Able and Fahay, 2010; USDOI and BOEM, 2012; NOAA Fisheries, 2021; Froese and Pauly, 2022.

Several marine mammal and sea turtle species are commonly observed within the Project Area (Table 5). Marine mammals are federally protected under the Marine Mammal Protection Act, while the sea turtles commonly found in the Project Area are protected by the Endangered Species Act. These marine species are expected to have largely seasonal or intermittent presence in the Project Area as a result of these species' extensive migrations. In addition, these species breathe air and are therefore necessarily pelagic, only occasionally foraging along the sea bottom. Therefore, although they may encounter cable routes, any time these species spend in the areas with the highest EMF levels would be limited by the need to surface and breathe. Because of their extensive migrations, pelagic habitat, and air-breathing habits, these species will rarely, if ever, inhabit the benthic habitat directly over the Project cable route and thus a fuller assessment is not indicated.

Table 5. Marine mammals and sea turtles that commonly inhabit the Project Area

Common Name	Scientific Name	Stock	ESA/MMPA Status*	General Occurrence within the Project Area
Fin whale	*Balaenoptera physalus*	Western North Atlantic	E/DS	Common
Humpback whale	*Megaptera novaeangliae*	Gulf of Maine	Not Listed/Not Strategic	Common
Minke whale	*Balaenoptera acutorostrata*	Canadian East Coast	Not Listed/Not Strategic	Common
North Atlantic right whale	*Eubalaena glacialis*	Western North Atlantic	E/DS	Common

Common Name	Scientific Name	Stock	ESA/MMPA Status*	General Occurrence within the Project Area
Bottlenose dolphin	*Tursiops truncatus*	Western North Atlantic Northern Migratory Coastal	Not Listed/DS	Common
		Western North Atlantic Offshore	Not Listed/Not Strategic	
Short-beaked common dolphin	*Delphinus delphis*	Western North Atlantic	Not Listed/Not Strategic	Common
Loggerhead turtle	*Caretta*	--	Threatened	Common
Leatherback turtle	*Dermochelys coriacea*	--	Endangered	Common

* ESA= Endangered Species Act and MMPA= Marine Mammal Protection Act

Sensitivity of Finfish to AC EMF

Many fish species, including salmonids, tuna, eel, and mackerel, have the capability to detect variations in the earth's static (i.e., 0 Hz) geomagnetic field as a migratory cue. Some research has suggested that particles of magnetic material in these fishes' bones or organs, or both, allow them to detect and respond to these changes in the geomagnetic field (Hanson and Westerberg, 1987; Walker et al., 1988; Harrison et al., 2002; Tański et al., 2011). Detection of geomagnetic cues, however, are not used in isolation, but in concert with other environmental variables (e.g., temperature, light, water current strength and direction, and olfactory signals); in fact, a recent publication reports that magnetic field cues appear to be most often utilized as a "backup" to other environmental variables or otherwise present a lower priority cue when other variables are more readily interpreted (Johnsen et al., 2020).

Electrosensitivity, on the other hand, is comparatively rare in fish species. The ability to detect the low-frequency (i.e., generally 10 Hz or less) bioelectric fields produced by potential prey species and predators is mediated through specialized and sensitive electroreceptors (ampullae of Lorenzini). Within the Project Area, sturgeon species (family *Acipenseridae*) are the sole electrosensitive fish. Sturgeon are protected anadromous fish species that are regularly found in benthic habitats of estuaries and coastal environments along the Atlantic coast of the United States.

Laboratory Finfish Studies

Laboratory studies have been conducted with eel and salmon, migratory species known to utilize geomagnetic cues, to assess the potential effects of 60- to 75-Hz magnetic fields on swim behavior and orientation. When exposed to a 500-mG, 60-Hz magnetic field, both eel and salmon demonstrated no significant change in observed swimming behaviors (Richardson et al., 1976). As a result, the authors concluded that operating 60-Hz AC cables were not likely to alter the behavior or activity of either species under field conditions. More recently, researchers at the Marine Scotland Science Agency evaluated responses of European eel (*Anguilla anguilla*) and Atlantic salmon (*Salmo salar*) to 50-Hz AC magnetic fields up to 960 mG in strength. Armstrong et al. (2015) found that salmon exposed to magnetic fields between 1.3 and 950 mG exhibited no changes in swimming behaviors, indicating that salmon were unlikely to perceive or respond to 50-Hz AC magnetic fields. In a separate study, European eel were similarly exposed to a 960-mG, 50-Hz AC magnetic fields under laboratory conditions (Orpwood et al., 2015). The authors reported there were no observed effects on eel swim behavior, orientation, or passage through the tank system during this exposure. These controlled laboratory studies conducted with magnetosensitive eel and salmon suggest that 50- to 75-Hz magnetic fields have no effect on the behavior of magnetosensitive fish species, indicating that 50- to 75-Hz magnetic fields (such as those produced by the Project cables) are not easily detected by migratory fish species that utilize geomagnetic cues (Richardson et al., 1976; Armstrong et al., 2015; Orpwood et al., 2015).

In addition to research conducted with eel and salmon, the U.S. Department of Energy has conducted a series of laboratory studies examining the likelihood that 60-Hz AC magnetic-field sources, including transmission lines, are detectable by various finfish species. Researchers studied behavioral responses and tank distributions (relative to magnetic-field strength) of largemouth bass (*Micropterus salmoides*), the redear sunfish (*Lepomis microlophus*), and the magnetosensitive and electrosensitive pallid sturgeon (*Scaphirhynchus albus*). Research findings generally substantiate the results of the eel and salmon laboratory studies, in that 60-Hz AC magnetic fields did not affect observed fish behaviors. Largemouth bass exposed to a 24,500 mG, 60-Hz magnetic field exhibited no significant changes in fish behavior or swimming (Bevelhimer et al., 2015). In terms of tank distribution (which can be interpreted as attraction or repulsion to the AC magnetic fields), redear sunfish were significantly more likely to select shelters near the maximum tested magnetic-field strength of 1,657,800 mG, but resumed a normal distribution within the tank once the field was removed (Bevelhimer et al., 2015). Based on these findings, researchers concluded that their studies did not demonstrate that fish would detect or respond to AC magnetic fields at levels expected under environmental conditions. Bevelhimer et al. (2015) also examined the behaviors of magnetosensitive and electrosensitive pallid sturgeon when subjected to 60-Hz AC magnetic fields in a laboratory mesocosm. Constant magnetic-field strengths of approximately 18,000 to 24,500 mG were tested with no apparent effect on sturgeon swim behavior or distribution in the tanks, which indicates that the fish likely could not detect EMF from this source (Bevelhimer et al., 2015).

In conclusion, the scientific literature regarding laboratory-assessed behavioral effects of AC EMF on fish indicates that even magnetosensitive fish do not readily detect or alter their behavior in response to magnetic fields produced by 50/60-Hz AC cables. Moreover, when the field levels are increased to artificially high levels (i.e., over 1,000,000 mG and orders of magnitude higher than levels produced by submarine cables), behavioral effects observed in fish were minor and reversible.

Field Studies of Finfish

While field studies do not offer the same opportunity for in-depth behavioral observation as laboratory studies, surveys conducted in offshore marine environments allow for the assessment of regional distributions and populations of key species in relation to operating cables. A series of field surveys examining wild marine species populations were conducted at energized and unenergized AC submarine cable sites off the coast of California. The purpose of these surveys was to track fish populations and the presence or absence of species between 2010 and 2014 in order to assess whether energized cables (and accompanying EMF) had any *in situ* effects on natural populations of marine species.

AC magnetic-field levels were measured as a part of the research study and were determined to be between 730 and 1,100 mG at the energized cable site, depending on loading (Love et al., 2016). Researchers collected 3 years of observations of these surface-laid cables via both diver observation and video recording. Over 40 different fish species were recorded at field sites, including demersal halibut (*Paralichthys californicus*), sanddab flounder (*Citharichthys sordidus*), and seaperch (*Sebastes* spp). When energized cable sites were compared to unenergized sites, no differences in observed fish communities at the energized and unenergized cable sites were found (Love et al., 2016). Because of this, the authors concluded that the AC magnetic fields produced by the cable had no effect on fish presence or absence or localized distributions, but that the physical presence of the surface-laid cables did provide a more attractive habitat than the sediment sea bottom. Thus, these results indicate that the level of magnetic fields produced by a submarine AC cable do not affect either fish distributions or behavior, including for local flounder and other demersal fish species.

Additional information on the potential impacts of submarine AC cables on resident coastal fish populations can be interpreted from post-construction wind farm studies. It should be noted, however, that these generally focus on a larger footprint and results may integrate multiple variables. Yet, fish surveys conducted in the vicinity of wind farms should still have some power to detect changes in resident fish communities that could potentially result from operating submarine cables.

Recently, researchers have published the results of 7 years of surveys at the Block Island Wind Farm off the coast of Rhode Island to identify any changes in fish populations at the site. Data indicated that the numbers of hardground associated species, like black sea bass (*C. striata*) and Atlantic cod (*G. morhua),* increased in the wind farm vicinity, likely in response to the turbine structures (Wilber et al., 2022). Other fish species surveyed, including various flounder species, butterfish (*P. triacanthus*), and scup (*S. chrysops*), indicated that the presence of the wind farm and operating transmission cables had no effect on the catch of demersal fish species. Thus, researchers concluded that catches of fish were not significantly affected by the operating wind farm, except for increases observed in fish that are attracted to vertical structures (Wilber et al., 2022).

Similarly, Stenberg et al. (2011) assessed data collected over almost a decade that included both pre- and post-construction work at the Horns Rev Offshore Wind Farm site near Denmark and found “no general significant changes in the abundance or distribution patterns of pelagic and demersal fish”; fish species surveyed included several species similar to those expected to inhabit the Project Area, such as flatfish. It should be noted that there was a reported increase of hard-ground and reef-associated fish species, suggesting that the construction of vertical structures, in the form of turbine footings, may have either attracted or multiplied these species in the area (Stenberg et al., 2011)(Leonhard et al., 2011).

At the Thorntonbank Wind Farm in Belgium, fish surveys demonstrated some short-lived changes in the abundance of certain fish and invertebrate species, but these were theorized to be residual effects from the construction phase (Vandendriessche et al., 2015). Observed changes were ultimately determined to be temporary, and thus not related to on-going windfarm operations. Similarly, multiple fish survey methods were used to assess possible changes in fish communities in Lake Ontario following the installation of the Wolfe Island Wind Farm site, leading to the conclusion the submarine cables had "little to no effect … on local fish communities" (Dunlop et al., 2016). At the Nysted Wind Farm in Denmark researchers surveyed fish communities along the project cables, noting some "asymmetries in the catches" (i.e., fish were not caught in equivalent numbers on each side of the cable) (Dong Energy et al., 2006). Results mostly failed to correlate with the energy loading of the cables and therefore with magnetic-field strength; moreover, a lack of baseline and control data meant that changes in other physical conditions could not be ruled out as primary causes of observed effects.

Overall, results from these studies strongly indicate that operating windfarms and 50/60-Hz AC cables have not changed the distributions of resident fish populations, including demersal and sediment-dwelling species such as flounder. These results are in agreement with the results of the laboratory studies indicating no significant effects of AC EMF on fish species.

Electrosensitivity of Sturgeon Species

Electrosensitivity is relatively rare in fish species, with only a few known to be capable of detecting electric fields in addition to magnetic fields. While the majority of electrosensitive fish species do not reside in the Project Area, sturgeon are known to be electrosensitive and two species, shortnose and Atlantic sturgeon (*Acipenser brevirostrum* and *A. oxyrinchus oxyrinchus*) are expected to reside in the Project Area. Because of this, 50/60-Hz electric field detection thresholds of sturgeon associated were assessed in addition to magnetic-field detection levels. The detection abilities and responses of two different sturgeon species—sterlet (*A. ruthenus*) and Russian sturgeon (*A. gueldenstaedtii*)—were assessed using 50-Hz AC electric fields between 20 to 60 mV/m (Basov, 1999). Electric-field exposures of 20 mV/m resulted in minor changes to sturgeon orientation, as well as increased search and foraging behaviors near the power source, indicating that small behavioral changes may occur when sturgeon are in the vicinity of electric-field intensities of 20 mV/m at 50/60 Hz.

Sensitivity of Elasmobranchs to AC EMF

Because elasmobranch magneto-sensitivities and electro-sensitivities are attuned to the natural geomagnetic (i.e., 0 Hz) and bioelectric (i.e., <10 Hz) fields, much of the research into these species' detection abilities has centered on naturally-occurring fields and not EMF produced by 50/60-Hz AC cables. Basic research has demonstrated, however, that as the source frequency of the magnetic and electric fields increases from 0 Hz to above 10 Hz, elasmobranch detection sensitivity decreases (Andrianov et al., 1984). It has also been shown that at frequencies above 20 Hz, shark embryos cease responses to produced fields (Kempster et al., 2013). Based on this, it seems unlikely that elasmobranchs in the Project Area would be able to easily detect any EMF from the 50/60-Hz AC fields from Project cables.

This is supported by two separate laboratory studies conducted to assess the detection abilities and behavioral responses of elasmobranchs to 50/60-Hz AC fields. Researchers exposed juvenile thornback rays (*Raja clavata*) to a 4,500 mG, 50-Hz field to assess potential behavioral effects (Albert et al., 2022); however, exposures to this field had no significant effect on the vertical activity or horizontal activity of rays or their propensity to remain immobile, when compared to non-exposed rays. Similarly, catshark (*Cephaloscyllium isabellum*) were exposed to a 14,300 mG, 50-Hz field in the laboratory, together with an olfactory stimulant, in order to assess if the magnetic field altered response behaviors (Orr, 2016). Sharks demonstrated no change in behaviors when subjected to the AC magnetic field for 3 days, and exhibited no difficulty in appropriately responding to olfactory stimulants. Together, these studies indicate that 50/60-Hz EMF is not detected by elasmobranchs, even at relatively high field strengths.

Although field studies conducted at submarine cable and wind farm sites do not assess elasmobranch populations as regularly as fish or invertebrate populations, possibly due to these species' relatively low densities at such sites, Love et al. (2016) *did* specifically consider resident elasmobranchs. The authors' multi-year study at California submarine cable sites assessed elasmobranch populations and whether the produced magnetic fields were altering their distributions. Based on survey data, the researchers concluded that 60-Hz EMF had no effect on elasmobranchs and is "either unimportant to these organisms or that at least other environmental factors take precedence" (Love et al., 2016). Similarly, Wilber et al. (2022) surveyed populations of little skate (*L. erinacea)* and winter skate (*L. ocellata*) at the Block Island Wind Farm and found no effect of the operating wind farm on populations of these elasmobranch species.

Sensitivity of Large Invertebrates to AC EMF

As with finfish and elasmobranchs, laboratory research into the magnetosensitivity of large marine invertebrates has largely focused on static (0-Hz) magnetic fields. However, considering both the laboratory and field studies that have been conducted with 50/60 Hz fields allows for an assessment of the potential detection ability of large invertebrates, including cephalopods and large crustaceans like crab and lobster (which can provide a model for horseshoe crab).

Recently, researchers have examined the potential effects of exposure to 50-Hz AC magnetic fields on both the behavior and physiology of commercially-important crustacean and bivalve species. The exploration and sheltering behavior of juvenile European lobsters (*Homarus gammarus*) were observed in relation to a 2,300 mG, 50-Hz AC magnetic field for up to 1 week in the laboratory (Taormina et al., 2020). However, researchers observed no significant differences in either behavior or survival of lobsters exposed to AC EMF when compared to control lobsters. As such, authors concluded that “anthropogenic magnetic fields, at these intensities, do not significantly impact the behavior of juvenile European lobsters.” Additionally, the effects of 50-Hz AC magnetic fields on bivalve physiology have also been studied. Cockles (*Cerastoderma glaucum*) exposed to a 64,000 mG, 50-Hz magnetic field for 8 days were observed for changes in food consumption rate, oxygen consumption rate, ammonia excretion rate, and measures of oxidative stress (Jakubowska-Lehrmann et al., 2022). Exposure resulted in significantly different ammonia excretion rates, protein carbonyl levels (a biomarker of stress), and acetylcholinesterase concentrations in bivalves. The magnetic-field level tested was notably high and the authors reported that it would be “necessary to investigate lower values” to properly assess EMF levels produced by buried submarine cables (Jakubowska-Lehrmann et al., 2022).

Although a body of scientific literature exists documenting the responses of large crustaceans to both artificial sources of 0-Hz static fields and the earth’s geomagnetic field (Ugolini and Pezzani, 1995; Boles and Lohmann, 2003; Cain et al., 2005), information from these studies cannot be relied upon to predict effects from the Project’s 60-Hz AC sources of EMF. Unfortunately, relatively little laboratory research has been conducted on the behaviors and physiological responses of marine invertebrates to AC magnetic fields. A series of studies has been conducted to describe the effects of AC-generated EMF on the embryonic development of sea urchins (*Strongylocentrotus purpuratus*). Levin and Ernst (1995) examined the timing of embryonic cell division during exposure to AC magnetic fields. Field strengths of 3.4 millitesla (mT) (34,000 mG) changed the timing of cell division in developing embryos, but when the field strength was reduced by 50% (i.e., to 17,000 mG), embryonic cell division rates were unchanged versus unexposed controls (Levin and Ernst, 1995). More important, neither exposure caused an increase in embryonic mortality; however, minor developmental effects were observed in sea urchin (*S. purpuratus*) embryos when exposed to 500 mG and 1,000 mG 60-Hz magnetic fields (Zimmerman et al., 1990; Cameron et al., 1993).

Though some laboratory research concerning the effects of 60-Hz EMF on invertebrates suggested some physiological effects in developing invertebrate embryos, these are not expected to occur under field conditions in the Project Area. In the environment, invertebrate embryos are passively dispersed and experience naturally high mortality rates, meaning that the minor developmental delays observed during certain exposures to AC EMF under laboratory conditions would have no population-level impacts in the field. The fact that mortality rates were unaffected by EMF and that normal development was re-established following removal from EMF underscores the lack of significant physiological effects on invertebrate embryos. Moreover, recent research has focused on potential effects of AC EMF on the behavior and physiology of small sediment-dwelling worms, but overall, it was concluded that these organisms are not affected by such exposures (Jakubowska et al., 2019; Stankevičiūtė et al., 2019).

Evidence from Field Studies of Submarine Cables

The population-level field studies conducted at AC cable and wind farm sites provide some insight into potential effects on resident invertebrate species. Love et al. (2017a) recorded the presence of octopus and shrimp species during their multi-year survey of cable sites, and reported that the energized status of the cable had no apparent effect on localized distributions. In addition, because of the importance of commercially-harvested crustaceans, researchers at the University of California Santa Barbara conducted a series of field studies to specifically assess whether AC submarine cables impacted crab behavior and harvest. To assess whether 60-Hz

AC powered cables attract or repel crabs, cages containing rock crabs (*Metacarcinus anthonyi* and *Cancer productus*) were anchored along energized and unenergized cables; magnetic-field strengths in cages alongside energized cables ranged from 462 to 800 mG adjacent to the cable and decreased to 9 mG at the far end (Love et al., 2015). Crab position was observed during deployment, and based on this, it was concluded that crabs were neither attracted nor repelled by the magnetic fields generated by the cable. Additionally, studies were conducted on the ability of crabs to cross energized unburied cables at two sites near California and Washington, with maximum 60-Hz AC magnetic-field levels of 428 and 1,168 mG, respectively (Love et al., 2017b). Constructed cages allowed crabs to move to either side of the cable in order to determine if magnetic fields reduced the migratory potential of crustaceans. Researchers observed that both species of crabs freely crossed cable routes, demonstrating that energized submarine cables do not constitute a barrier to movement (Love et al., 2017b). Finally, Wilber et al. (2022) assessed longfin inshore squid (*D. pealeii*) populations at the Block Island Wind Farm site and found no effect of the operating wind farm on squid catch.

In all, the available laboratory and fields studies examining the ability of large invertebrates to detect AC magnetic fields all indicate that they are not capable of easily detecting AC magnetic fields at levels expected to occur at submarine cable sites.

Evaluation of EMF Exposures from Project Cables

Magnetic fields associated with the Project's submarine cables were calculated based on the PDE, comprising multiple proposed cable configurations and installation approaches. Results of these calculations are shown above in Table 1 and in Appendix C. The maximum magnetic-field levels calculated for cables buried to a depth of 3.3 ft (1 m) beneath the seabed during periods of peak loading were determined to be 148 mG at the seabed, decreasing to 12 mG at 3.3 ft (1 m) above the seabed directly over the Offshore Export Cable. These field values were approximately 3.4 and 42 times lower, respectively, than the 500-mG magnetic field that was demonstrated to have no behavioral effects on either Atlantic salmon or American eel. Magnetic-field levels from the Project were calculated to be multiple orders of magnitude lower than the field levels that result in significant changes in fish behavior (i.e., 1,657,800 mG for redear sunfish). In addition, the 60-Hz magnetic fields produced by the Project will be below the level of detection for multiple marine finfish species, based on the studies discussed above. Further, catsharks exposed to a 14,300, 50-Hz AC magnetic field in laboratory conditions by Orr (2016) did not exhibit behavioral changes, which suggests the fields could not be detected.

Where the Project submarine cables are buried to a depth of 3.3 ft (1 m) beneath the seabed, during periods of peak loading the Inter-array Cables, Offshore Export Cables, and Export Cables in Indian River Bay, were projected to produce maximum magnetic fields of 49, 148, and 148 mG, respectively, at the seabed directly above the cable. These results suggest that resident elasmobranchs will not detect the magnetic field from the Project.

The Love et al. (2015, 2017a) study data indicate that cephalopods and large crustaceans exposed to 60-Hz AC magnetic fields up to 1,158 mG is not associated with any changes in behavior or distribution. Among the Project cable segments evaluated as part of this assessment, the maximum magnetic field at peak loading is expected to be 148 mG at the seabed. This calculated value is approximately 7.9 times lower than those associated with no effects on caged crabs and populations of field invertebrate species. Although there are no studies that evaluate the detection ability of whelk species (i.e., conch), conch are a mollusk species related to bivalves and cephalopods. Neither bivalves nor cephalopods were significantly affected by exposure to 60-Hz AC magnetic field up to 1,168 mG. The effect of chronic magnetic-field exposure of sea snail, like whelk, is discussed below.

In summary, based on the available literature that indicates magnetic field produced by the Project will not be detected by either magnetosensitive fish or invertebrates, the Project is not expected to have any adverse effect on the population of fish in the Project Area or on their distribution.

Assessment of Induced Electric-Field Effects on Electrosensitive Finfish and Elasmobranchs

Exponent calculated induced electric fields from the Project in Atlantic sturgeon and dogfish models, which are summarized in Table 6. The Atlantic sturgeon was chosen because of its documented electrosensitivity, and relatively large size.[8] The dogfish was selected because of its residence in the Project Area and benthic habits. The Atlantic sturgeon was modeled as an ellipsoid at a 6-ft (1.8-m) length, with a maximum girth of 2.5 ft (0.8 m); the dogfish was also modeled as an ellipsoid, but at a 3.3-ft (1-m) length, with a maximum girth of 1.25 ft (0.4 m). Andrianov et al. (1984) determined that elasmobranchs can detect a 10-Hz, 1 mV/m electric field. Kempster et al. (2013) found that detection by elasmobranchs declines quickly as the frequency increases and ceases to detect the electric field when the frequency exceeds 20 Hz.

The maximum calculated value of induced electric field in this species is calculated to be 1.8 mV/m at the seabed over the Offshore Export Cable during periods of peak loading. The maximum calculated value of the induced electric field in this species was 1.8 mV/m at the seabed over the buried Offshore Export Cable during periods of peak loading. This value is approximately 11 times lower than the 20 mV/m electric field reported as the threshold for behavioral changes in Russian sturgeon and sterlet (Basov, 1999).

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[8] 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).

Table 6. Calculated induced electric fields in sturgeon and dogfish models at the seabed and 3.3 ft (1 m) above the seabed for peak loading and a 3.3-ft (1 m) cable burial depth

Cable Type	Evaluation Height	Induced Electric Field (mV/m), dogfish model	Induced Electric Field (mV/m), sturgeon model
Inter-array Cable	At the seabed	0.3	0.6
	3.3 feet (1 m) above the seabed	< 0.1	< 0.1
Offshore Export Cable	At the seabed	1.0	1.8
	3.3 feet (1 m) above the seabed	0.1	0.1
Export Cable in Indian River Bay*	At the seabed	1.0	1.8
	3.3 feet (1 m) above the seabed	0.1	0.1

* For the Export Cables in Indian River Bay, results were provided over the cables with higher current (i.e., 1,200 and 480 A for peak and average loading, respectively). Calculated induced-electric field levels above the cable carrying lower currents will be lower.

Assessment of Chronic EMF Exposure to Marine Species at Protected Cables

The construction of offshore windfarms adds valuable hardground habitat in coastal environments. Various structures, including turbine footings and mattresses, can be adopted as habitat by marine species that inhabit reef and other hardground habitats, especially when installed in areas that are dominated by soft sediment habitat (Quigel and Thornton, 1989; Petersen and Maim, 2006b). Hardground-associated species will be attracted to structures regardless of their ability to detect AC EMF, with a potential for long-term exposure different than the transitory detection-related behavioral effects of interest along the sediment-buried cable. Both finfish and invertebrate species are expected to congregate around rock- or mattress-protected cables and thus potentially could be incidentally exposed to variable levels of AC magnetic fields. The relevant research into the chronic effects of AC EMF on marine species has focused both on early developmental stages and juvenile and adult organisms. While embryonic exposure is less likely to occur under field conditions, given the largely passive dispersion of embryos, it does constitute a much more sensitive biological model for developmental effects.

Marine invertebrates have been utilized as model laboratory organisms to assess the potential developmental effects resulting from exposure to AC EMF. Purple sea urchin embryos have been exposed to a range of 60-Hz AC magnetic-field strengths over a series of studies: 500 mG (Cameron et al., 1993); 1,000 mG (Zimmerman et al., 1990); and 34,000 mG (Levin and Ernst, 1995). There was no effect on embryo survival, and only minor developmental effects were observed at these levels.

Similar research has also been conducted with fish embryos and larvae, and results also indicate that AC EMF is unlikely to cause chronic physiological effects. A lengthening of embryonic developmental time was observed for Japanese rice fish (*Oryzias latipes*) embryos exposed to a 1,000 mG, 60-Hz magnetic field (Cameron et al., 1985). The authors calculated this delay, however, to amount to about 18 hours, which they concluded to be unlikely to result in any long-term individual effects or impacts to populations. A similar delay in embryonic development was observed in zebrafish (*Danio rerio*) embryos exposed to a 10,000 mG, 50-Hz magnetic field (Skauli et al., 2000). More recently, additional studies with larval zebrafish indicated no effect of a 36-day, 10,000 mG exposure on hatching, growth rate, and larval mortality, although exposed embryos did absorb yolk sacs more rapidly (Fey et al., 2019). Rainbow trout larvae exposed to a 10,000 mG, 50-Hz magnetic field for 40 days did not exhibit decreased survival, despite evidence of cytotoxic and genotoxic responses (Stankevičiūtė et al., 2019).

While research suggests some physiological effects in marine embryos exposed to very high levels of AC magnetic fields, this type of exposure is not expected under field conditions, due to largely passive dispersal of embryos (Hoagstrom and Turner, 2015). Additionally, the naturally high mortality rates of embryonic and larval fish and invertebrates negates any potential impact on population levels. However, these results do provide important information because embryonic and larval stages are considered more sensitive to environmental stressors than juvenile and adult life stages.

The chronic effects of AC magnetic-field exposure have also been tested using adult fish and invertebrates, since differences in physiology preclude extrapolation from early life stages. A number of invertebrates, including bivalves, worms, and sea snails, have been assessed for potential long-term effects from chronic exposure to AC magnetic fields. While genotoxic and cytotoxic markers increased in Baltic clams (*Limecola balthica*) exposed to 10,000 mG, 50-Hz magnetic fields for 12 days, there was no effect on clam survival rates (Stankevičiūtė et al., 2019). As previously outlined, cockles exposed to 64,000 mG, 50-Hz magnetic fields for over 1 week exhibited increased ammonia excretion rates, protein carbonyl levels, and acetylcholinesterase concentrations (Jakubowska-Lehrmann et al., 2022). Interestingly, exposure to 1,000–5,000 mG, 50-Hz magnetic fields for up to 168 hours improved sea snail (*Onchidium struma*) immune response, likely a positive or beneficial effect for exposed snails (Zhang et al., 2020). Finally, though less relevant to understanding likely effects on large invertebrates, research has been conducted concerning the effects of chronic AC magnetic-field exposures on small, sediment-dwelling invertebrates, and found that AC magnetic fields did not cause behavioral or physiological changes (Jakubowska et al., 2019; Stankevičiūtė et al., 2019).

Studies have also been conducted with juvenile and adult fish to assess whether prolonged AC magnetic-field exposures result in biological or physiological changes. Li et al. (2015) exposed juvenile tilapia (*Oreochromis niloticus*) to 50-Hz magnetic fields between 300 and 2,000 mG for 1 month, examining fish growth and digestive activity. While there was a relationship between the magnitude of effects and the strength of the magnetic field, some exposures did result in reduced growth and reduced digestive enzyme function; however, once fish were removed from the field, the authors noted they were able to recover normal digestive function and growth (Li et al., 2015). Conversely, Cuppen et al. (2007) exposed goldfish to high frequency magnetic fields (200 Hz–5,000 Hz) between 1.5 mG and 500 mG and assessed fish immune response. Fish exposed to the magnetic fields expressed an increased immune response that led to better survival when fish were also exposed to pathogens (Cuppen et al., 2007). Finally, Nofouzi et al. (2015) intermittently exposed rainbow trout to 15-Hz magnetic fields between 1 mG and 500 mG for 2 months and determined that daily 1-hour exposures improved immune system activity, which may improve fish survival.

Evaluation of Chronic EMF Exposure at Mattress-Covered Areas

The maximum magnetic-field levels calculated for peak loading at 3.3 ft (1 m) above the unburied, mattress-covered areas along the cable route were 18 mG for the Inter-array Cables and 66 mG for both the Offshore Export Cables and the Export Cables in Indian River Bay. Based on the information from the available scientific literature, the calculated peak values were below the magnetic-field levels that cause physiological effects (i.e., from approximately 500 mG to greater than 10,000 mG). Because of this, it can be concluded that any hard-ground associated species expected to inhabit the Project mattresses are unlikely to experience adverse biological effects from these exposures. Moreover, given the relatively small areas expected to be mattress covered, the number of individual fish and invertebrates inhabiting these structures will be limited and very small.

As such, it can be reasonably determined that hardground-associated species that may inhabit these areas along the Project cables are not likely to be injured by magnetic fields.

Conclusions

Project-related AC magnetic-field values, calculated with conservative estimates, are well below relevant limits established by ICES and ICNIRP to protect the health and safety of the general public. These conservatively modeled values are also below levels linked to behavioral changes in marine organisms, and as such, are not expected to alter the populations of marine species that inhabit the Project Area.

While many marine species are sensitive to the static (0 Hz) geomagnetic field, these species do not readily perceive artificial 60-Hz magnetic fields in the environment. Therefore, information on the perceptibility and response of marine organisms to static magnetic fields cannot be used to assess effects from the Project's proposed AC cables. Thus, Exponent's assessment focused on studies conducted with 50-Hz and 60-Hz fields. Based on cable characteristics, Exponent developed conservative models of both the magnetic-field and induced electric-field levels at peak cable loading and provided results for these both at the seabed surface above the cable and at a height of 3.3 ft (1 m) above the seabed. These two evaluation heights (as well as calculations moving horizontally away from the cable) demonstrate the rate at which magnetic fields are reduced as distance from the cable increases. At the seabed above the buried cable, magnetic fields at peak loading are calculated to be 148 mG or lower, reducing to 12 mG or less within 3.3 ft (1 m) of the seabed. When compared to the magnetic-field levels reported in the scientific literature for fish, invertebrate, and elasmobranch species, the following conclusions could be made:

1. Magnetic-field levels, calculated at peak loading for the Project's cables, are well below those reported in the scientific literature to elicit behavioral responses in magnetosensitive fish species.
2. Based on fundamental biological research, elasmobranchs are not expected to detect 50/60 Hz magnetic fields produced by the Project's AC cables operating at peak loading.
3. Data from both laboratory and field surveys at submarine cable sites demonstrate that that the behavior and distribution of large invertebrates are unaffected by exposure to 60-Hz

magnetic fields; the presence of octopus at the same cable sites also suggested that cephalopods (including squid) also are not affected by AC magnetic fields.

4. The induced electric-field levels calculated using sturgeon and dogfish models are both below the published detection thresholds for electrosensitive species that may inhabit the Project Area.
5. For mattress-covered areas on the cable route, calculated magnetic-field levels are below chronic levels associated with physiological effects.

Thus, conservative modeling based on the Project's cable specifications and peak loading demonstrate that both magnetic- and induced electric-field levels generated by the Project's cables fall below the levels detectable by magnetosensitive and electrosensitive marine organisms. These conclusions align with the findings of a recent 2019 BOEM report evaluating the possibility that AC EMF generated by offshore wind farm cables could affect marine populations. This report found that for marine species of commercial and ecological importance in the southern New England area, no negative population effects are expected (Snyder et al., 2019). Since the behavior of marine species is not expected to be affected by magnetic and induced electric fields from the Project's cables, we conclude that the fields generated by the operating Project will not adversely impact populations of resident marine species.

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Attachment A

Cable Configurations and Burial Depths

Cable Configurations

The Project-related magnetic-field and induced electric-field levels were calculated for six different cable configurations as summarized in Table A-1. These six models comprise cables installations at two effective burial depths each for a single Inter-array Cable, a single Offshore Export Cable, and four parallel Export Cables in Indian River Bay. All modeled cables include three-phase conductors contained within a single outer jacket, as represented in the exemplar cross-sectional drawing shown in Figure A-1, in which various components of such cables are indicated.

As the Offshore Export Cables travel from the OSSs to the landfall location along the Offshore Export Cable Corridor, they will be buried to a target depth of 3.3 to 9.8 ft (1 to 3 m) beneath the seabed (*see* Figure A-1), and they will be separated from one another by a distance of at least 100 ft (30.5 m). A conservative model was developed using a burial depth of 3.3 ft (1 m) between the seabed and the top of the cable, where the Offshore Export Cable is buried beneath the seabed. Along short segments of the cable’s route, where it is not feasible to bury them (e.g., due to obstructions or cable crossings), the cables will be installed on the surface of the seabed and covered with rock berms or protective mattresses. We developed a model for locations where the cables are in a surface-laid configuration using an effective burial depth of 1 ft (0.3 m) between the surface of the protective mattress and the top of the cable. The protective mattresses were not modeled with material attributes contributing to the attenuation of magnetic fields, except for the minimum separation distance they will enforce between marine life and the outer jacket of the submarine cables.

The Export Cables in Indian River Bay and the Inter-array Cables will be buried to a target depth of 3.3 to 6.6 ft (1 to 2 m) beneath the seabed. Like the Offshore Export Cables, these will be conservatively modeled using a burial depth of 3.3 ft (1 m) between the seabed and the top of the cable along the majority of the cable route and using an effective burial depth of 1 ft (0.3 m) where the cables may be surface-laid and covered with rock berms or protective mattresses for short segments. Whereas the Inter-array Cables will be separated from one another by large distances, and thus are modeled individually like the Offshore Export Cables, the Export Cables in Indian River Bay will traverse the cable corridor through Indian River Bay separated from one another by 33–98 ft (10–30 m). To ensure the modeled configuration accurately captures the additive effects of overlapping magnetic fields from adjacent cables, a conservative model was developed for the Export Cables in Indian River Bay, using four cables with a minimum center-to-center separation distance of 33 ft (10 m).[9] Furthermore, one of the four Export Cables in Indian River Bay will have a lower loading value compared to the other three, as indicated in Table A-1 below.

Where the Offshore Export Cables extend from an offshore location near the proposed landing site at 3R's Beach to a transition vault installed below grade at the landfall location, they will be installed via HDD. The minimum separation distance between the cables is 49 ft (15 m), and the minimum burial depth below grade for each HDD duct is 8 ft (2.4 m). The significant lateral separation between ducts, and the increased burial depth compared to other Project cables, indicates the magnetic and induced electric fields for cables in the HDD ducts will be significantly less than those calculated for the Offshore Export Cables where they are buried to a depth of 3.3 ft (1 m) beneath the seabed; thus, EMF associated with cables installed via HDD were not modeled.

The size of the 230-kV and 275-kV cables are similar, so the factor that will most affect EMF levels is the current flowing through the cable. Assuming the same power flow, this results in higher electrical current for operation at 230 kV, and hence all calculations in this report assume an operating voltage of 230 kV for the Offshore Export Cable and Indian River Bay Export Cable. The maximum loading for the Offshore Export Cable will therefore occur at an operating voltage of 230 kV and would occur rarely (i.e., when the wind farm operates at its maximum total generating capacity). Peak loading for the Inter-array Cable at an operating voltage of 66 kV is determined by the highest per-phase conductor current being transmitted from a line of six WTGs, connected in series, each operating at its maximum total generating capacity of 18 MW. The average loading for these respective cables is determined by applying the same total power generation capacities, while utilizing the wind farm's assumed capacity factor of 40 percent.

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[9] Note that minimum cable separation distance will result in maximum EMF levels. At a greater separation distance, field levels would be similar to that presented herein.

Table A-1. Summary of offshore modeling configurations

Configuration	1a	1b	2a	2b	3a	3b
Description	Inter-Array Cable		Offshore Export Cable		Export Cable in Indian River Bay†	
Voltage	66 kV		230 kV			
Average Loading (per conductor)	336 A		480 A		480 A x 3 circuits 348 A x 1 circuit*	
Peak Loading (per conductor)	840A		1200 A		1200 A x 3 circuits 870 A x 1 circuit*	
Conductor Cross Section	800 mm^2		2500 mm^2		2500 mm^2	
Cable Type, Nominal Outer Diameter (OD)	3-core Cross-linked polyethylene (XLPE), 6.8-inch OD (172 millimeter [mm])		3-core XLPE, 12.2-inch OD (309.7 mm)			
Distance Between Conductor Centers within Cable	2.7-inches (68 mm)		4.7-inches (119 mm)			
Cable Pitch (i.e., helical twist)	7.5 ft (2.3 m)		10 ft (3 m)‡			
Minimum Horizontal Distance between Cables	Not Specified		100 ft (30.5 m)		33 ft (10 m)	
Installation Type	Buried	Surface-Laid§	Buried	Surface-Laid§	Buried	Surface-Laid§
Minimum Target Burial Depth to Top of Cable	3.3 ft (1 m)	1 ft (0.30 m)	3.3 ft (1 m)	1 ft (0.30 m)	3.3 ft (1 m)	1 ft (0.30 m)
Evaluation Heights	At the seabed and 3.3 ft (1 m) above the seabed**					

† The Export Cable in Indian River Bay consists of four Export Cables parallel to one another, separated by a center-to-center distance of 33 ft (10 m).

‡ Offshore Export Cables and Export Cables in Indian River Bay are conservatively modeled for a cable pitch of 10 ft (3 m). Magnetic- and induced electric-field levels would be expected to be lower for lower cable pitch (e.g., 8 ft [2.5 m]).

§ Where cables cannot be buried beneath the seabed, they will be protected with a post-lay rock cover (i.e., rock berms) or concrete mattresses, resulting in a total minimum effective burial depth of at least 12 inches (300 mm).

**Where covered by a rock berm or concrete mattress, the evaluation heights are at the top of the protective cover and at a height of 3.3 ft (1 m) above the protective cover.

* Among the four modeled Export Cables in Indian River Bay, the left-most cable is selected to carry the lower current load.

1	Conductor	Aluminium round stranded compacted longitudinal watertight
2	Conductor screen	Extruded semi-conductive XLPE
3	Insulation	Extruded XLPE
4	Insulation screen	Extruded semi-conductive XLPE
5	Bedding	Semi-conductive swelling tape
6	Metallic screen	Copper wire screen with copper-helix
7	Bedding	Swelling tape
8	Laminated sheath	Al-foil bonded to polymeric sheath
9	Polymeric sheath	HDPE, colour: black
10	Thin outer electrode	Semi-conducting PE skin layer, colour: black approx. thickness: 0.15 mm
11	Fibre optic cable	48 SM
12	Fillers and binder	Polypropylene threads and tapes
13	Bedding	Bedding tapes
14	Armouring	Round steel wires, galvanized
15	Serving	Bitumen impregnated Hessian tapes and Polypropylene threads

Figure A-1. Cross-section of an example 3-core submarine cable with helically-twisting conductors. Numbers on the righthand side identify various layers of the cable. (Source: Nexans)

Attachment B

Calculation Methods and Assumptions

Magnetic Fields and Induced Electric Fields in Seawater

US Wind, TRC, and K2 Management provided Exponent with data corresponding to the preliminary cable design characteristics and current loading for each of the proposed Project cable configurations modeled as part of this assessment. These input parameters were addressed in Attachment A, Table A-1, and related text. From these data, Exponent developed six offshore cable configuration models that were used for calculating the magnetic and induced electric fields generated by the cables.

Magnetic-field calculations were performed using data including current, burial depth, conductor configurations and the helical twisting of the conductors. As noted in the body of this report, the electric field associated with voltage applied to the conductors within the cables is entirely shielded by cable construction such as dielectric material, grounded metallic sheaths, and steel armoring around each cable. Magnetic fields, however, will induce a small electric field in the seawater, which may be detectable by certain electrosensitive marine organisms.

All calculations for the offshore cable models were performed using 3D FEA in COMSOL Multiphysics (version 6.0). These simulations employed the magnetic-field physics interface of COMSOL to solve the time-harmonic Maxwell-Ampere's Law for the magnetic fields generated by the Inter-Array Cables, the Offshore Export Cables, and the Export Cables in Indian River Bay. The FEA model was validated against a published reference (Pettersson and Schönborg, 1997) for the case of a straight section of helically-twisted, three-core, three-phase conductors. Pettersson and Schönborg (1997) also included a comparison to empirical measurements in their publication. The magnetic fields calculated for helically-twisted conductors, as will be installed in the Project, are more accurate and substantially lower than calculations of magnetic fields from conceptual cables that do not consider effects of helical-twist construction.

Inputs to the FEA models included the conductor geometry (e.g., the cable diameter, conductor spacing, and pitch of the helical twisting), the burial depth of the cable, the material properties of the seabed, the protective mattress covering, and the seawater.[10] In accordance with IEEE

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[10] Calculated magnetic-field levels in other common sediment types or in freshwater would not be substantially different from those calculated here.

Standard 644-2019 and IEEE Standard C95.3-2021 (IEEE, 2019, 2021), the magnetic-field levels offshore were calculated at the surface of the seabed, and at a height of 3.3 ft (1 m) above the seabed. The results of these calculations are reported in units of mG as the resultant root-mean-square flux density value. The material properties used in the models discussed herein include conductivity, relative permittivity, and relative permeability, as noted in Table B-1.

As discussed further in the Assessment Approach section below, the following assumptions were made when creating the cable models, and performing the associated calculations, to overestimate magnetic- or induced electric-field levels at any given loading level and burial depth: 1) magnetic-field levels were not attenuated by any surrounding material including the seabed, the earth, grout, rock berms, mattresses, or other materials; and 2) the magnetic field outside the cable was not reduced by cable armor (i.e., ferromagnetic shielding and induced eddy currents were not included). Additionally, modeling assumed that there was no unbalanced current on the phase conductors or currents flowing on the outer sheath of the cables.

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

Material	Conductivity (Siemens per meter)	Relative Permittivity	Relative Permeability	Reference
Seawater	5	72	1	Chave et al., 1990; Somaraju and Trumpf, 2006
Seabed	1.1	30	1	Cihlar and Ulaby, 1974; Hulbert et al., 1982; Chave et al., 1990
Concrete	0.04	200	1	Wilson, 1986

Electric Fields Induced in Marine Organisms

In addition to electric fields induced in seawater, the magnetic field from the Project cables also will induce weak electric fields in marine species in close proximity to the cables. Two species that may be capable of detecting these weak induced electric fields are the Atlantic sturgeon and the dogfish. Induced electric fields in these two species were calculated by modeling each as a homogeneous ellipsoid as first demonstrated for fish by Exponent (Normandeau Associates et al., 2011) consistent with the method described for humans in Standard IEEE C95.6-2002 (IEEE, 2002). Although a larger induced electric field would be present in larger animals, most of those species are not electrosensitive, so are less informative as a basis for comparison.

Assessment Approach

Two EMF assessment approaches were used by Exponent to evaluate different portions of the Project's submarine cables.

Buried Cables: The Inter-array Cables, Offshore Export Cables, and Export Cables in Indian River Bay generally will be buried beneath the sediment. Since these cables are buried, their physical presence will not alter the behavior of marine species (as they would if they were on the seabed). For buried transmission cables, the assessment was therefore performed to address whether EMF can be detected by marine species in the offshore environment. In the event such detection is possible, the assessment was performed to determine whether the level of detected EMF could affect or alter the behavior of these species—for example, with regard to migration, location preferences, or social behavior—thereby resulting in potentially deleterious population-level effects.

A transect perpendicular to the centerline of the cables at a distance 3.3 ft (1 m) above the seabed serves as a reference location in this analysis, relevant for species on the seabed and most mobile marine species above.[11] Magnetic- and induced electric-field levels associated with the transmission of electricity through the submarine cables were calculated along this transect, and these values were then compared to the detection thresholds of identified marine species similar to those expected to be present in the offshore Project Area to assess the likelihood that detection of these fields could lead to alterations of animal behavior.

Protective Coverings: The portion of the Project's submarine cables expected to be covered with rock berms or protective mattresses is proposed to comprise a small fraction of the total cable route. Unlike where Project cables will be buried beneath the seabed, where cables are installed under proactive coverings, a reef effect may be generated, as has been observed at other established wind farm sites (Petersen and Maim, 2006a).

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[11] This height is consistent with worldwide assessments (e.g., ICES, 2019 and ICNIRP, 2010) and is meant to capture species swimming in close proximity to the seabed.

In this situation, regardless of the presence of EMF, the physical structure of the protective mattresses or rock berms covering the cables will constitute new habitat features that are expected to attract certain marine species. Moreover, since such new habitat features will encourage some marine species to spend a greater fraction of time in proximity to EMF from the Project's cables, the assessment was performed not merely to determine the transitory level of EMF that may be *detected*, but rather to determine the likelihood that long-term exposure to EMF near these structures could have adverse population-level effects on those species.

To perform this assessment, magnetic- and induced electric-field levels were calculated throughout the region in the vicinity of the cables, and the volume average of these values was determined within a 1 cubic meter (m^3) region centered directly over the cable. These conservatively high, volume-average magnetic- and induced electric-field levels were then compared to those reported in the scientific literature where physiologic responses were studied over longer periods than are generally used for acute behavioral assessments.

Other Modeling Considerations

Cable Shielding Effects

The modeling approach used to calculate the maximum magnetic- and induced electric-field levels in this report was designed to produce conservative results based upon realistic parameters within the PDE. The models are not intended to account for the attenuation of magnetic fields due to conductor sheaths and outer steel cable armoring.

A previous study shows that flux shunting accounted for nearly a factor of 2 reduction in the magnetic-field level (Silva et al., 2006). The same study showed that a significantly smaller reduction in the magnetic-field level was attributable to eddy currents. Another study, commissioned by BOEM, involved post-construction EMF measurements above comparable AC three-core, XLPE submarine cables, and reported that "[t]he magnetic field produced by the [AC cable] was ~10 times lower than modeled values commissioned by the grid operator …" (Hutchison et al., 2018).[12] The modeling methodology applied in this EMF assessment is more

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[12] Note that while the Hutchison et al. (2018) report focused on submarine direct current transmission lines, a portion of the report also reported measurements around an AC transmission cable, which is referenced here.

sophisticated than that used in the modeling of the offshore submarine cables referenced by Hutchison et al. (2018) at least because the assessment presented herein includes the helical twisting of the conductors within each three-core submarine cable, and consequently results in lower calculated magnetic-field levels.

Unbalanced Currents and Ground Currents

Although unbalanced electrical currents flowing on the conductor sheaths and currents flowing on cable armoring may impact the actual magnetic field outside the cable, these factors are not accounted for in the modeling approach used to calculate the magnetic- and induced electric-field levels in this report. Such unbalanced currents can result when there is an unequal current flow among the three phases of an AC transmission line. Additionally, ground currents may flow along the armoring or sheaths when the ground potential at one end of a cable is not at the same electric potential as the other end of the cable. In the case of unbalanced current, the degree of such an imbalance among the currents flowing on the respective phase conductors can be at least partially controlled by system design and operation. In contrast, ground currents may be entirely unrelated to the transmission or generation of electricity by the Project. Consequently, these can be more challenging to control or predict. In the event that unbalanced phase currents and grounding-related currents occur in combination within a given cable, these can be viewed as a single-phase effective net current flowing along the cable. The reported measurement data reported by Hutchison et al. (2018) for an AC submarine cable indicated that the highest AC magnetic field (near to the cable itself) is produced predominantly as a result of the phase currents, but at greater distances away from the cable, unbalanced AC currents can have a much weaker, but non-negligible contribution to the AC magnetic field.

Attachment C

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

Project Cables

Models were created for six cable configurations, corresponding to three types of Project cables. With these models, AC magnetic-field and induced electric-field levels were calculated for each of the six cable configurations. As summarized in Attachment A, Table A-1, these configurations vary with respect to cable dimensions (including size and relative spacing of conductors within a cable), cable loading, number of and spacing between adjacent cables, and effective burial depth. A brief summary of the results is provided in the EMF Calculation Results section of this report. Further details of the calculated field levels for all configurations are provided below.

Figure C-1, Figure C-2, and Figure C-3 show the distribution of magnetic-field strength generated by the Project cables buried 3.3 ft (1 m) beneath the seabed in the space around the 66-kV Inter-array Cables, the 230-kV Offshore Export Cables, and the four adjacent 230-kV Export Cables in Indian River Bay, respectively. As evident from these figures, the calculated magnetic-field level is at a maximum directly above the buried cables and decreases rapidly with distance. For instance, the magnetic-field level at a height of 3.3 ft (1 m) above the seabed is 0.8 mG above an Inter-array Cable, 4.6 mG above an Offshore Export Cable, and 4.7 mG above one of the central cables among the set of four Export Cables in Indian River Bay. Calculated field levels for all configurations are far below the ICNIRP reference level of 2,000 mG and the ICES exposure reference level of 9,040 mG for exposure of the general public.

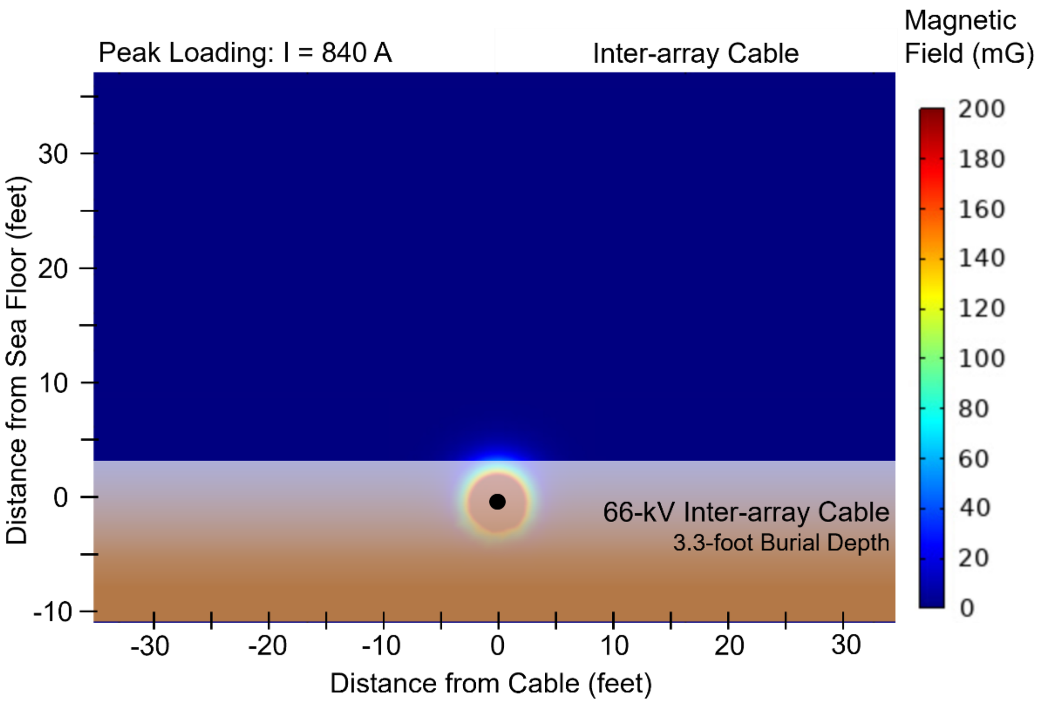

Figure C-1. Calculated AC magnetic-field levels during peak loading over one 66-kV Inter-array Cable installed at a burial depth of 3.3 ft (1 m) beneath the seabed.

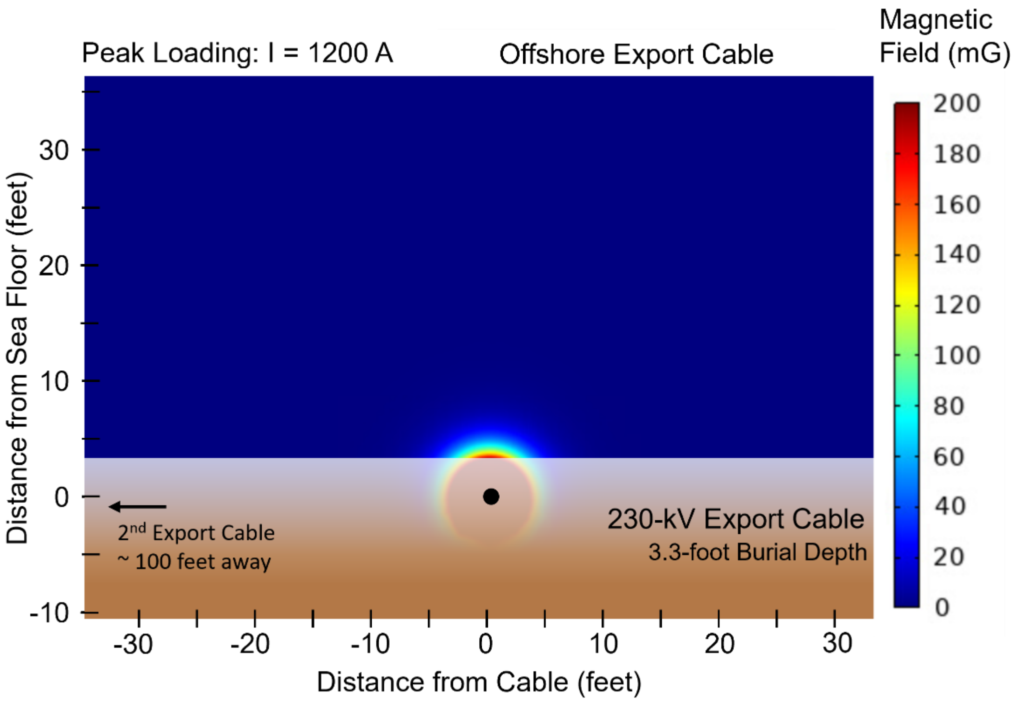

Figure C-2. Calculated AC magnetic-field levels during peak loading over one 230-kV Offshore Export Cable installed at a burial depth of 3.3 ft (1 m) beneath the seabed. As indicated in the figure, the nearest Offshore Export Cable is at least 100 ft (30.5 m) away and will not change the magnetic-field levels from those shown in this figure.

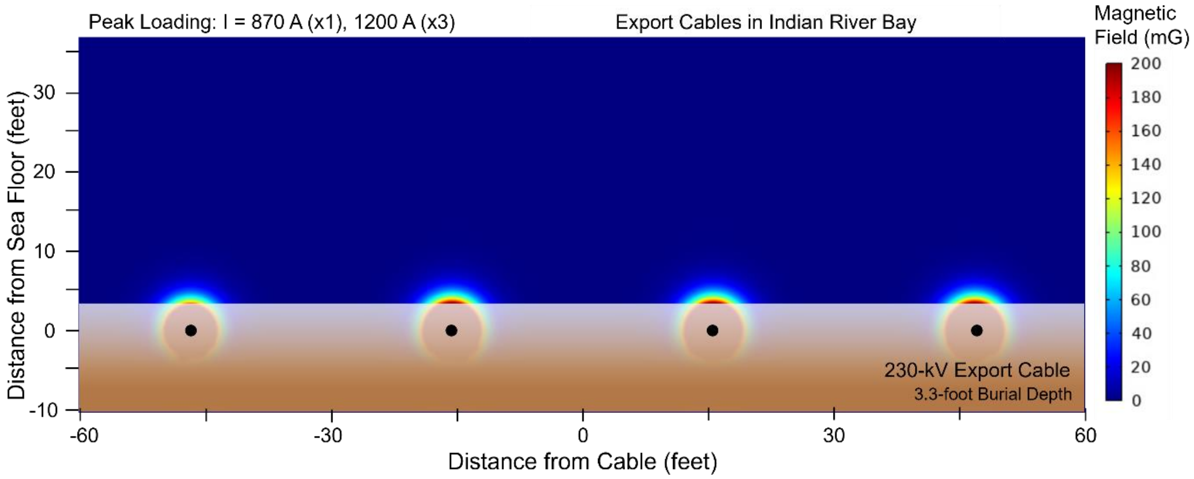

Figure C-3. Calculated AC magnetic-field levels during peak loading over four 230-kV Export Cables in Indian River Bay installed at a burial depth of 3.3 ft (1 m) beneath the seabed. The Export Cables are separated from one another by a center-to-center distance of 33 ft (10 m). The left-most cable has a peak loading (870 A) lower than the other three cables (1,200 A).

Cable Modeling Results

The calculated AC magnetic- and induced electric-field levels in seawater are provided in the tables and figures below for each of the six cable configurations summarized in Attachment A, Table A-1. In particular, the figures included below show the fields levels from one 66-kV Inter-array Cable, from one 230-kV Offshore Export Cable, and from a set of four 230-kV Export Cables in Indian River Bay, each modeled at a burial depth of 3.3 ft (1 m) beneath the seabed. Tables summarizing the calculated results for each of the six modeled configurations, for both average and peak loading, are also shown below:

- Table C-1 and Table C-2 summarize the results of calculated AC magnetic-field levels in seawater for each of the six modeled cable configurations for transects at the seabed and at a height of 3.3 ft (1 m) above the seabed, for both average and peak loading.
- Table C-3 and Table C-4 summarize the results of calculated AC electric-field levels induced in seawater for each of the six modeled cable configurations for transects at the seabed and at a height of 3.3 ft (1 m) above the seabed, for both average and peak loading.
- Table C-5 and Table C-6 summarize the results of calculated AC electric-field levels induced in representative marine species, for both average and peak loading.

The calculated AC field levels during periods of average loading are plotted as a function of horizontal distance from the cables, for each of the representative cable configurations. Figure C-4 through Figure C-6 show magnetic-field levels, and Figure C-7 through Figure C-9 show induced electric-field levels. Similarly, calculated field levels at peak loading are plotted in Figure C-10 through Figure C-15. These figures show the calculated results for configuration models in which cables are installed at a 3.3-ft (1-m) burial depth. The results for models incorporating this type of installation (i.e., buried cables) are considered to be representative of those encountered along most of the proposed cable route under typical loading.

Table C-1. Calculated AC magnetic-field levels (mG) over Project cables during average loading at specified horizontal distances

				AC Magnetic Field (mG)		
Cable	**Voltage**	**Installation Type**	**Location**	Max	**5 ft (1.5 m)***	**10 ft (3 m)***
Inter-Array Cable	66-kV	Buried (3.3 ft [1 m])	Seabed	20	1.6	< 0.1
			3.3 ft (1 m) above the seabed	0.8	0.2	< 0.1
		Mattress-Covered (1 ft [0.3 m])	Top of the protective cover	354	4.0	< 0.1
			3.3 ft (1 m) above the protective cover	7.3	0.9	< 0.1
Offshore Export Cable	230-kV	Buried (3.3 ft [1 m])	Seabed	59	8.4	0.4
			3.3 ft (1 m) above the seabed	4.6	1.5	0.1
		Mattress-Covered (1 ft [0.3 m])	Top of the protective cover	655	19	0.5
			3.3 ft (1 m) above the protective cover	26	5.2	0.3
Export Cables in Indian River Bay	230-kV	Buried (3.3 ft [1 m])	Seabed	59	8.4	0.4
			3.3 ft (1 m) above the seabed	4.7	1.5	0.1
		Mattress-Covered (1 ft [0.3 m])	Top of the protective cover	655	19	0.5
			3.3 ft (1 m) above the protective cover	26	5.3	0.3

* For the individual Inter-array and Offshore Export Cables, the horizontal distance is measured from the centerline of the cable. For the Export Cables in Indian River Bay, results at horizontal distances > 0 are provided relative to the outside cable with higher current (i.e., 1,200 and 480 A for peak and average loading, respectively). Calculated magnetic- and induced-electric field levels near the cable carrying lower currents will be lower.

Table C-2. Calculated AC magnetic-field levels (mG) over Project cables during peak loading at specified horizontal distances

Cable	Voltage	Installation Type	Location	AC Magnetic Field (mG)		
				Max	5 ft (1.5 m)*	10 ft (3 m)*
Inter-Array Cable	66-kV	Buried (3.3 ft [1 m])	Seabed	49	4.0	0.1
			3.3 ft (1 m) above the seabed	2.1	0.5	< 0.1
		Mattress-Covered (1 ft [0.3 m])	Top of the protective cover	884	10	0.1
			3.3 ft (1 m) above the protective cover	18	2.2	0.1
Offshore Export Cable	230-kV	Buried (3.3 ft [1 m])	Seabed	148	21	0.9
			3.3 ft (1 m) above the seabed	12	3.7	0.3
		Mattress-Covered (1 ft [0.3 m])	Top of the protective cover	1640	47	1.3
			3.3 ft (1 m) above the protective cover	66	13	0.7
Export Cables in Indian River Bay	230-kV	Buried (3.3 ft [1 m])	Seabed	148	21	0.9
			3.3 ft (1 m) above the seabed	12	3.8	0.3
		Mattress-Covered (1 ft [0.3 m])	Top of the protective cover	1640	47	1.4
			3.3 ft (1 m) above the protective cover	66	13	0.7

* For the individual Inter-array and Offshore Export Cables, the horizontal distance is measured from the centerline of the cable. For the Export Cables in Indian River Bay, results at horizontal distances > 0 are provided relative to the outside cable with higher current (i.e., 1,200 and 480 A for peak and average loading, respectively). Calculated magnetic- and induced-electric field levels near the cable carrying lower currents will be lower.

Table C-3. Calculated AC electric-field levels (mV/m) over Project cables during average loading at specified horizontal distances

				AC Magnetic Field (mG)		
Cable	**Voltage**	**Installation Type**	**Location**	**Max**	**5 ft (1.5 m)***	**10 ft (3 m)***
Inter-Array Cable	66-kV	Buried (3.3 ft [1 m])	Seabed	0.3	< 0.1	< 0.1
			3.3 ft (1 m) above the seabed	< 0.1	< 0.1	< 0.1
		Mattress-Covered (1 ft [0.3 m])	Top of protective the cover	3.2	0.1	< 0.1
			3.3 ft (1 m) above the protective cover	0.1	< 0.1	< 0.1
Offshore Export Cable	230-kV	Buried (3.3 ft [1 m])	Seabed	1.0	0.2	< 0.1
			3.3 ft (1 m) above the seabed	0.1	< 0.1	< 0.1
		Mattress-Covered (1 ft [0.3 m])	Top of protective cover	7.2	0.3	< 0.1
			3.3 ft (1 m) above the protective cover	0.5	0.1	< 0.1
Export Cables in Indian River Bay	230-kV	Buried (3.3 ft [1 m])	Seabed	1.0	0.2	< 0.1
			3.3 ft (1 m) above the seabed	0.1	< 0.1	< 0.1
		Mattress-Covered (1 ft [0.3 m])	Top of the protective cover	7.2	0.3	< 0.1
			3.3 ft (1 m) above the protective cover	0.5	0.1	< 0.1

* For the individual Inter-array and Offshore Export Cables, the horizontal distance is measured from the centerline of the cable. For the Export Cables in Indian River Bay, results at horizontal distances > 0 are provided relative to the outside cable with higher current (i.e., 1,200 and 480 A for peak and average loading, respectively). Calculated magnetic- and induced-electric field levels near the cable carrying lower currents will be lower.

Table C-4. Calculated AC electric-field levels (mV/m) over Project cables during peak loading at specified horizontal distances

Cable	Voltage	Installation Type	Location	AC Magnetic Field (mG)		
				Max	**5 ft (1.5 m)***	**10 ft (3 m)***
Inter-Array Cable	66-kV	Buried (3.3 ft [1 m])	Seabed	0.7	0.1	< 0.1
			3.3 ft (1 m) above the seabed	< 0.1	< 0.1	< 0.1
		Mattress-Covered (1 ft [0.3 m])	Top of protective the cover	7.9	0.1	< 0.1
			3.3 ft (1 m) above the protective cover	0.3	< 0.1	< 0.1
Offshore Export Cable	230-kV	Buried (3.3 ft [1 m])	Seabed	2.5	0.4	< 0.1
			3.3 ft (1 m) above the seabed	0.2	0.1	< 0.1
		Mattress-Covered (1 ft [0.3 m])	Top of protective cover	18	0.9	< 0.1
			3.3 ft (1 m) above the protective cover	1.2	0.3	< 0.1
Export Cables in Indian River Bay	230-kV	Buried (3.3 ft [1 m])	Seabed	2.5	0.4	< 0.1
			3.3 ft (1 m) above the seabed	0.2	0.1	< 0.1
		Mattress-Covered (1 ft [0.3 m])	Top of the protective cover	18	0.9	< 0.1
			3.3 ft (1 m) above the protective cover	1.2	0.3	< 0.1

* For the individual Inter-array and Offshore Export Cables, the horizontal distance is measured from the centerline of the cable. For the Export Cables in Indian River Bay, results at horizontal distances > 0 are provided relative to the outside cable with higher current (i.e., 1,200 and 480 A for peak and average loading, respectively). Calculated magnetic- and induced-electric field levels near the cable carrying lower currents will be lower.

Table C-5. Calculated AC electric-field levels (mV/m) induced in electrosensitive species during average loading

Cable	Voltage	Installation Type	Location	Induced AC Electric Fields (mV/m) in Electrosensitive Species	
				Dogfish	Sturgeon
Inter-Array Cable	66-kV	Buried (3.3 ft [1 m])	Seabed	0.1	0.2
			3.3 ft (1 m) above the seabed	< 0.1	< 0.1
		Mattress-Covered (1 ft [0.3 m])	Top of protective the cover	2.3	4.3
			3.3 ft (1 m) above the protective cover	< 0.1	0.1
Offshore Export Cable	230-kV	Buried (3.3 ft [1 m])	Seabed	0.4	0.7
			3.3 ft (1 m) above the seabed	< 0.1	0.1
		Mattress-Covered (1 ft [0.3 m])	Top of protective cover	4.3	8.0
			3.3 ft (1 m) above the protective cover	0.2	0.3
Export Cables in Indian River Bay*	230-kV	Buried (3.3 ft [1 m])	Seabed	0.4	0.7
			3.3 ft (1 m) above the seabed	< 0.1	0.1
		Mattress-Covered (1 ft [0.3 m])	Top of the protective cover	4.3	8.0
			3.3 ft (1 m) above the protective cover	0.2	0.3

* For the Export Cables in Indian River Bay, results are provided for the outside cable with higher current (i.e., 1,200 and 480 A for peak and average loading, respectively). Calculated induced electric-field levels near the cable carrying lower currents will be lower.

Table C-6. Calculated AC electric-field levels (mV/m) induced in electrosensitive species during peak loading

Cable	Voltage	Installation Type	Location	Induced AC Electric Fields (mV/m) in Electrosensitive Species	
				Dogfish	Sturgeon
Inter-Array Cables	66-kV	Buried (3.3 ft [1 m])	Seabed	0.3	0.6
			3.3 ft (1 m) above the seabed	< 0.1	< 0.1
		Mattress-Covered (1 ft [0.3 m])	Top of protective the cover	5.7	11
			3.3 ft (1 m) above the protective cover	0.1	0.2
Offshore Export Cable	230-kV	Buried (3.3 ft [1 m])	Seabed	1.0	1.8
			3.3 ft (1 m) above the seabed	0.1	0.1
		Mattress-Covered (1 ft [0.3 m])	Top of protective cover	11	20
			3.3 ft (1 m) above the protective cover	0.4	0.8
Export Cables in Indian River Bay*	230-kV	Buried (3.3 ft [1 m])	Seabed	1.0	1.8
			3.3 ft (1m) above the seabed	0.1	0.1
		Mattress-Covered (1 ft [0.3 m])	Top of the protective cover	11	20
			3.3 ft (1 m) above the protective cover	0.4	0.8

* For the Export Cables in Indian River Bay, results are provided for the outside cable with higher current (i.e., 1,200 and 480 A for peak and average loading, respectively). Calculated induced electric-field levels near the cable carrying lower currents will be lower.

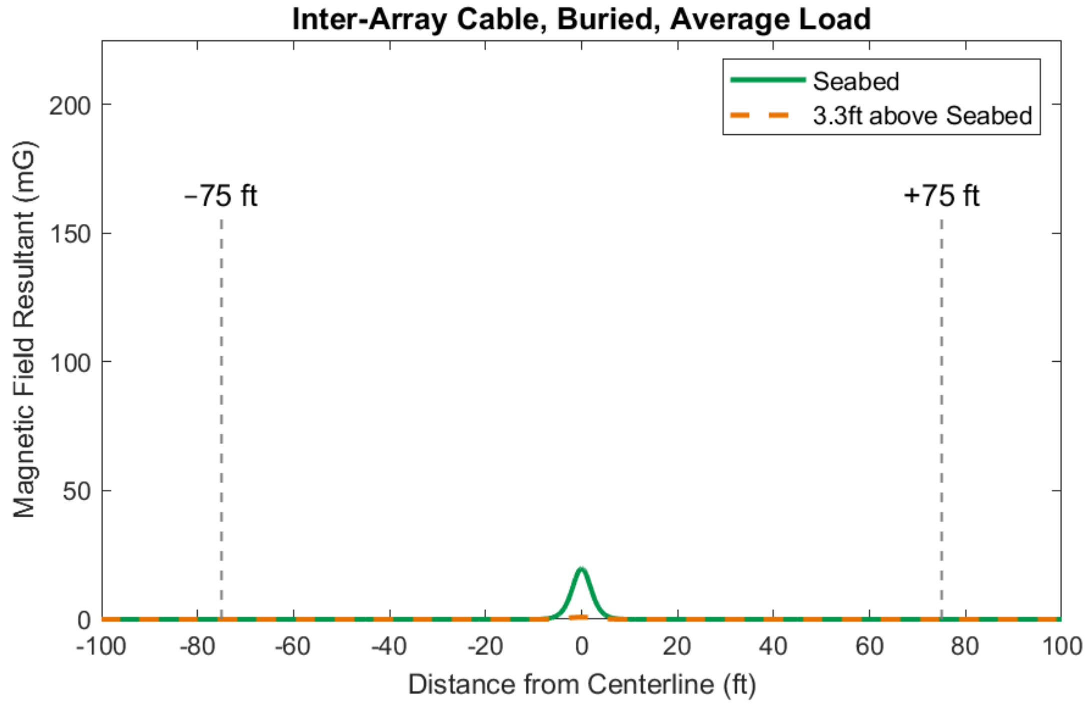

Figure C-4. Calculated AC magnetic-field levels during average loading over one 66-kV Inter-array Cable installed at a 3.3-ft (1-m) burial depth.

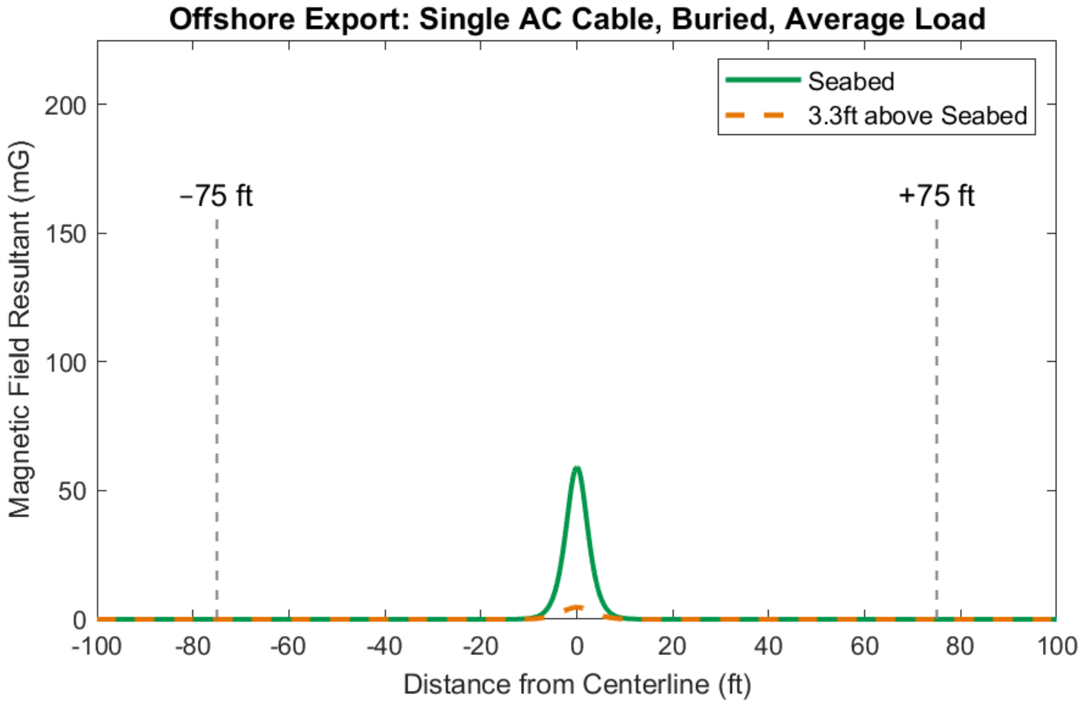

Figure C-5. Calculated AC magnetic-field levels during average loading over one 230-kV Offshore Export Cable installed at a 3.3-ft (1-m) burial depth.

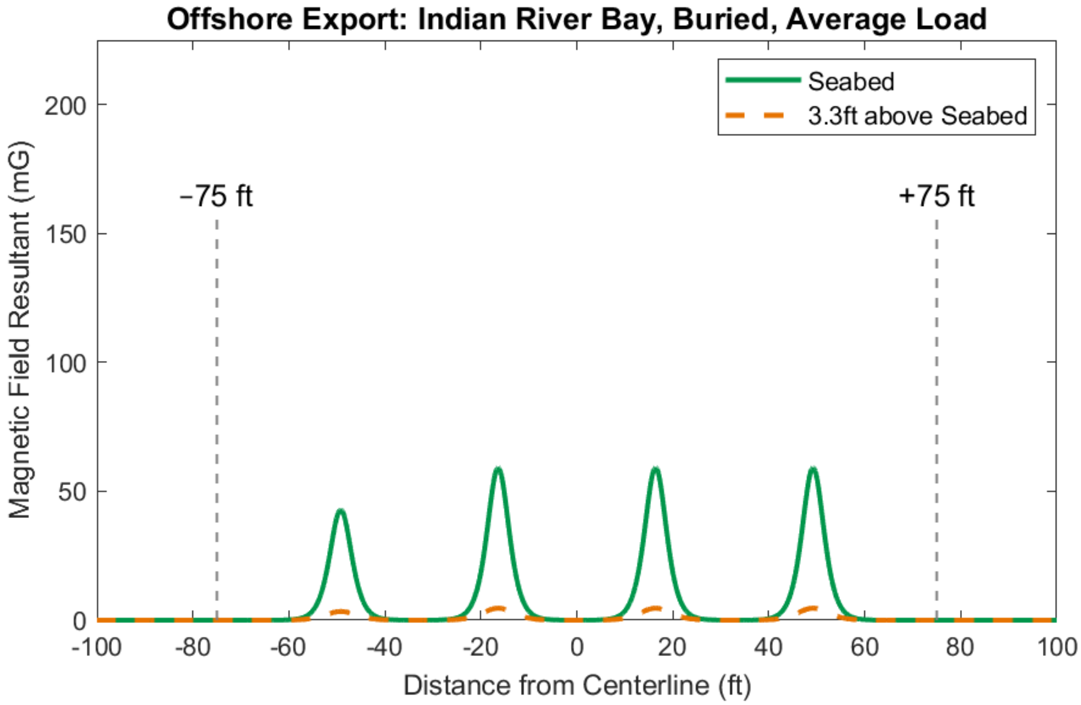

Figure C-6. Calculated AC magnetic-field levels during average loading over four 230-kV Export Cables in Indian River Bay installed at a 3.3-ft (1-m) burial depth.

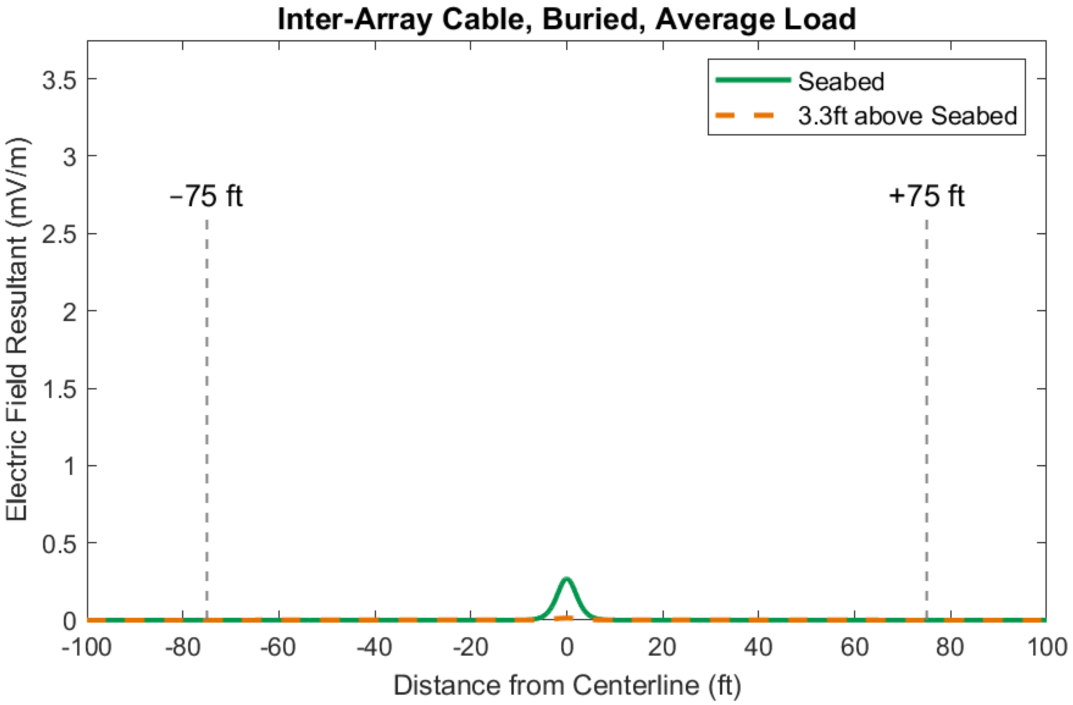

Figure C-7. Calculated induced AC electric-field levels during average loading over one 66-kV Inter-array Cable installed at a 3.3-ft (1-m) burial depth.

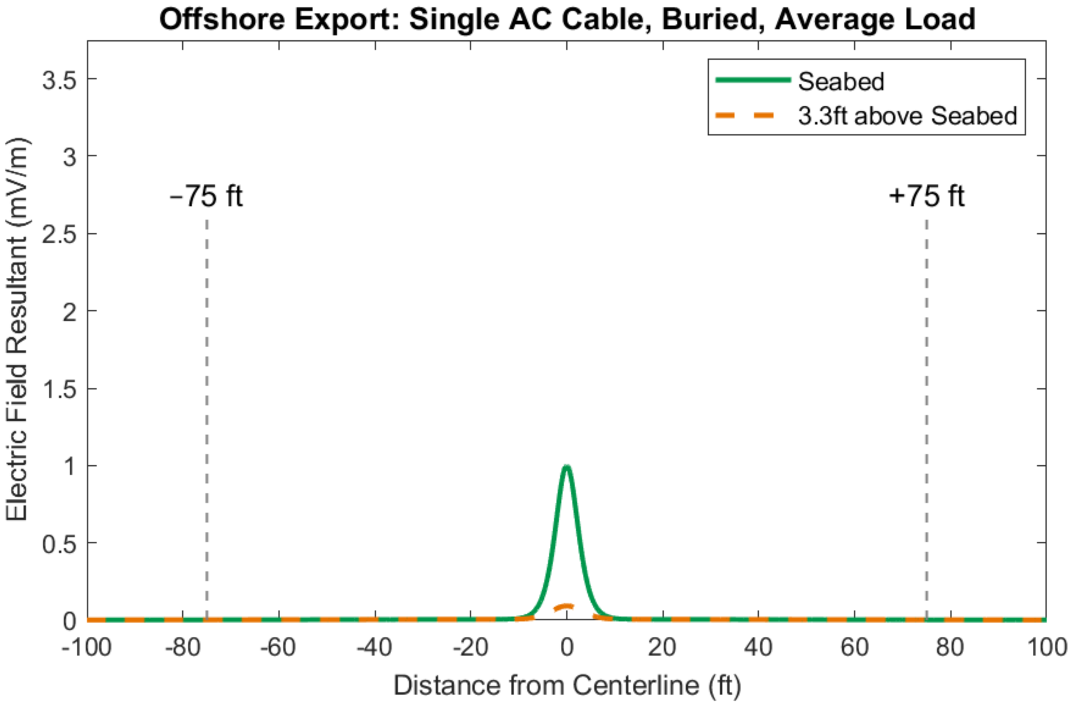

Figure C-8. Calculated induced AC electric-field levels during average loading over one 230-kV Offshore Export Cable installed at a 3.3-ft (1-m) burial depth.

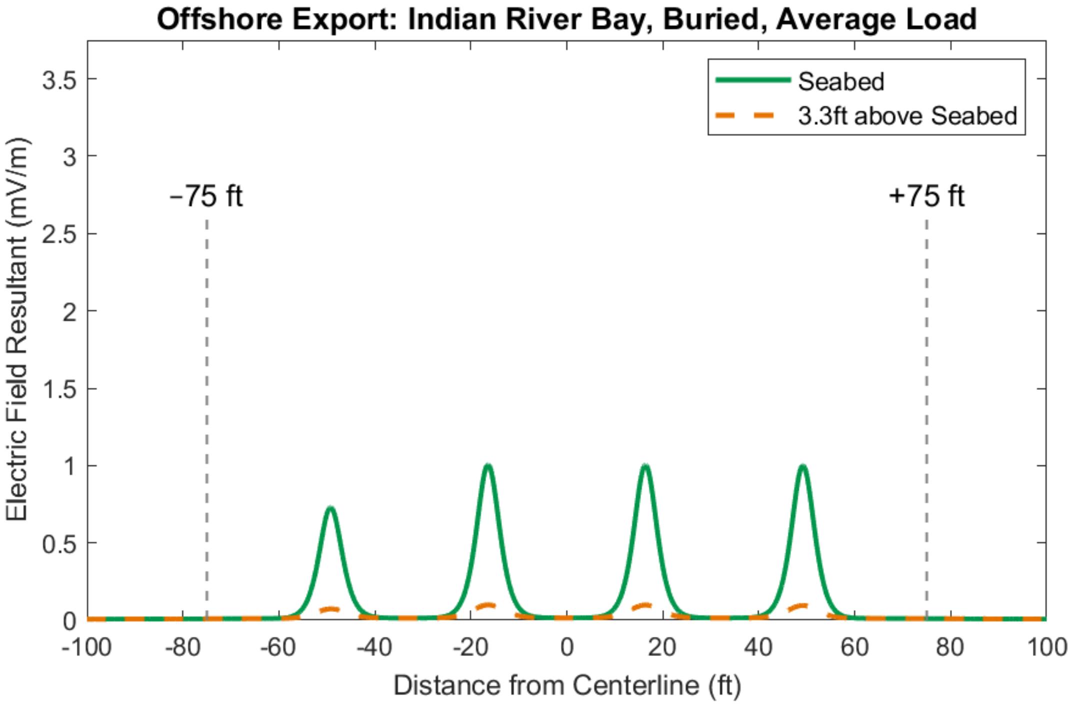

Figure C-9. Calculated induced AC electric-field levels during average loading over four 230-kV Export Cables in Indian River Bay installed at a 3.3-ft (1-m) burial depth.

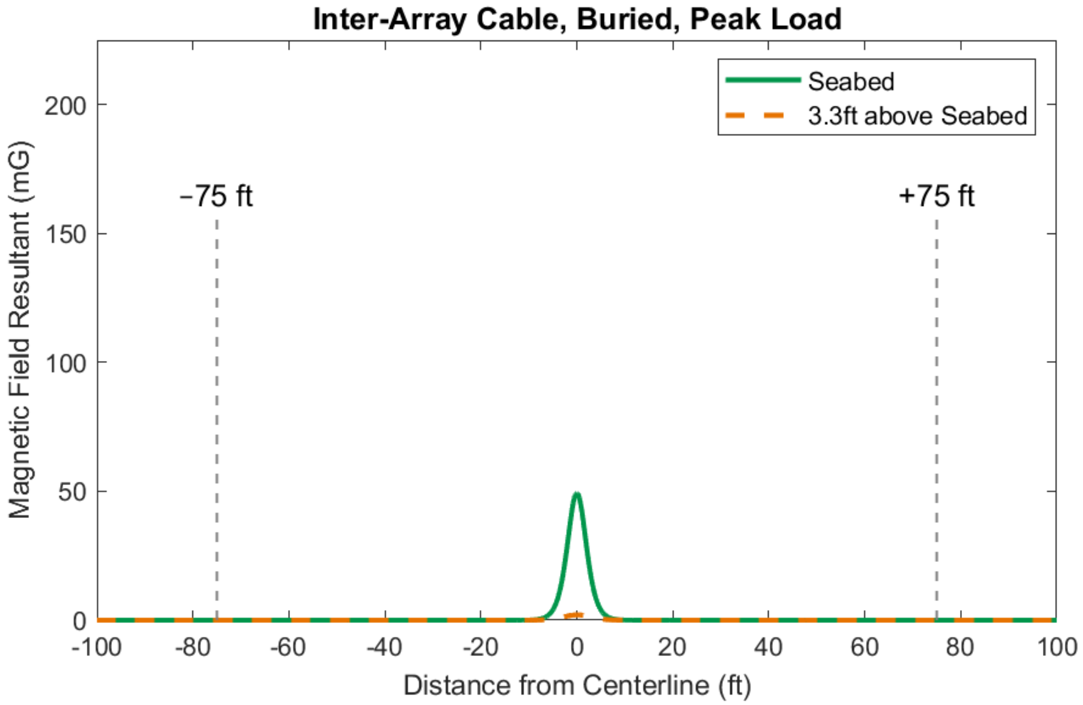

Figure C-10. Calculated AC magnetic-field levels during peak loading over one 66-kV Inter-array Cable installed at a 3.3-ft (1-m) burial depth.

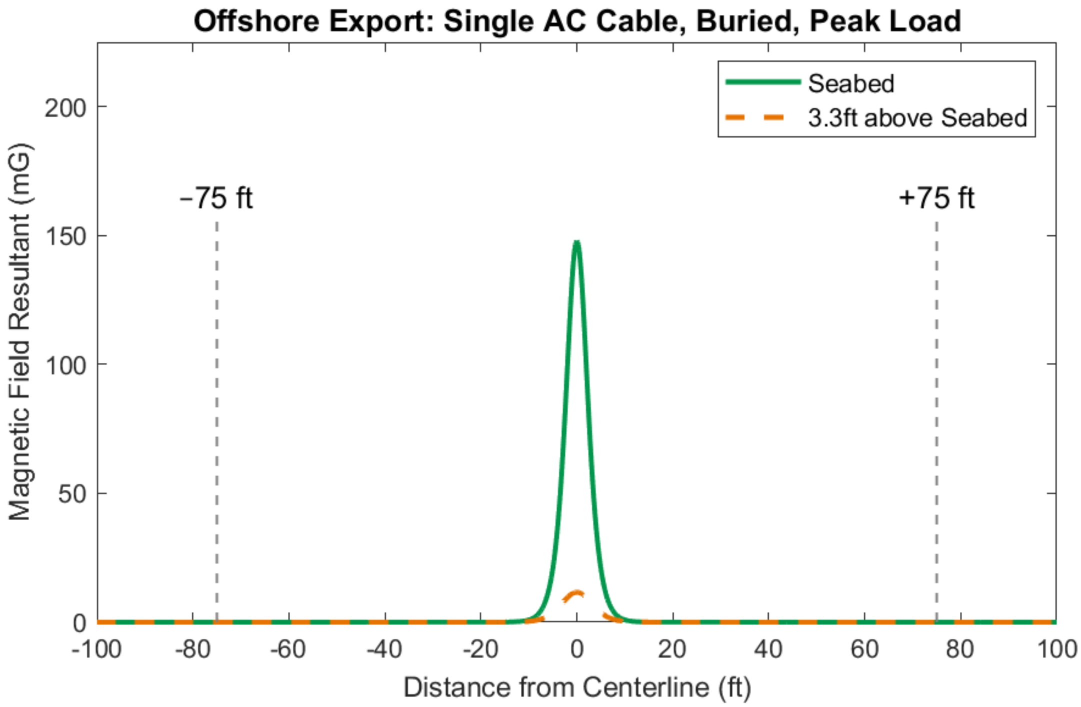

Figure C-11. Calculated AC magnetic-field levels during peak loading over one 230-kV Offshore Export Cable installed at a 3.3-ft (1-m) burial depth.

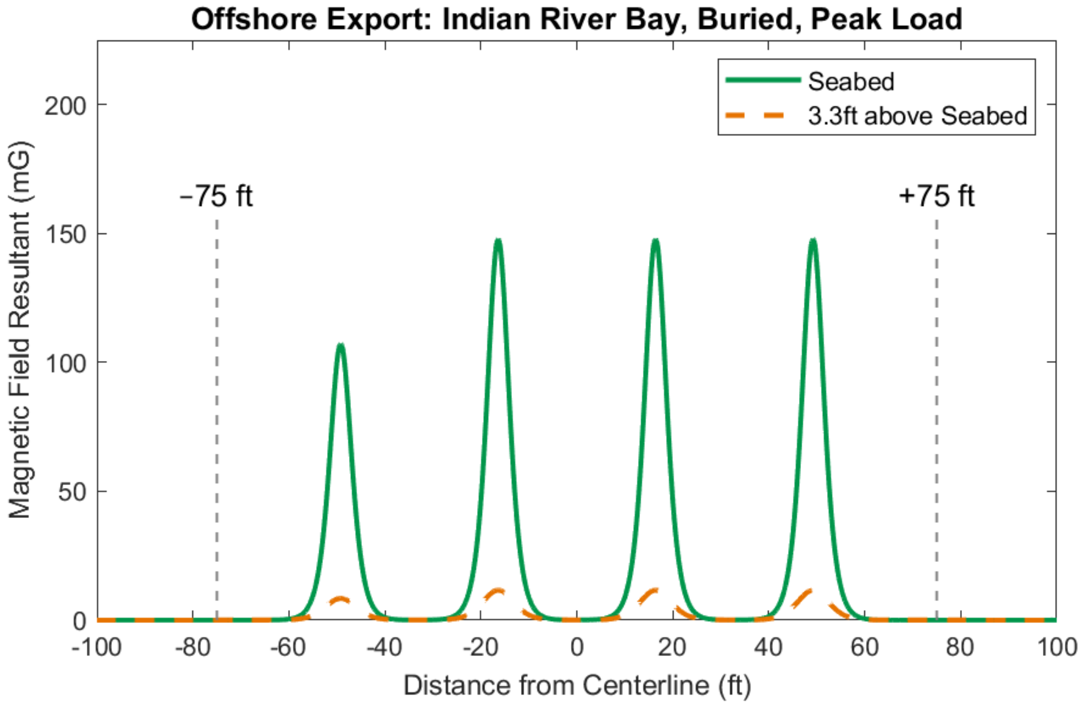

Figure C-12. Calculated AC magnetic-field levels during peak loading over four 230-kV Export Cables in Indian River Bay installed at a 3.3-ft (1-m) burial depth.

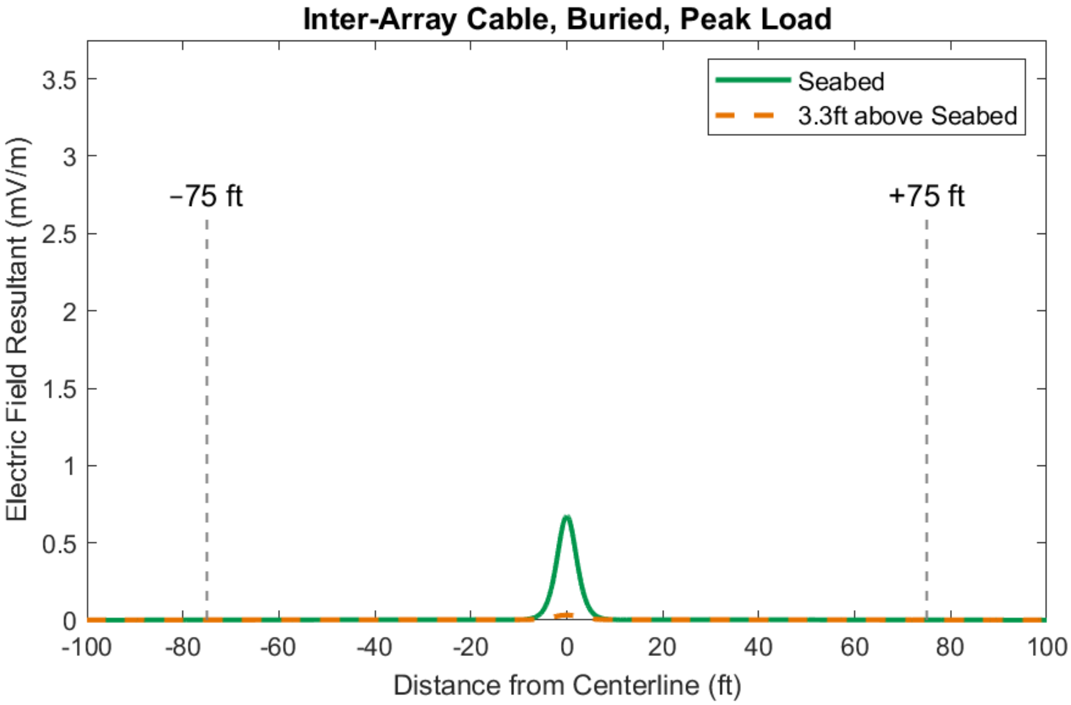

Figure C-13. Calculated induced AC electric-field levels during peak loading over one 66-kV Inter-array Cable installed at a 3.3-ft (1-m) burial depth.

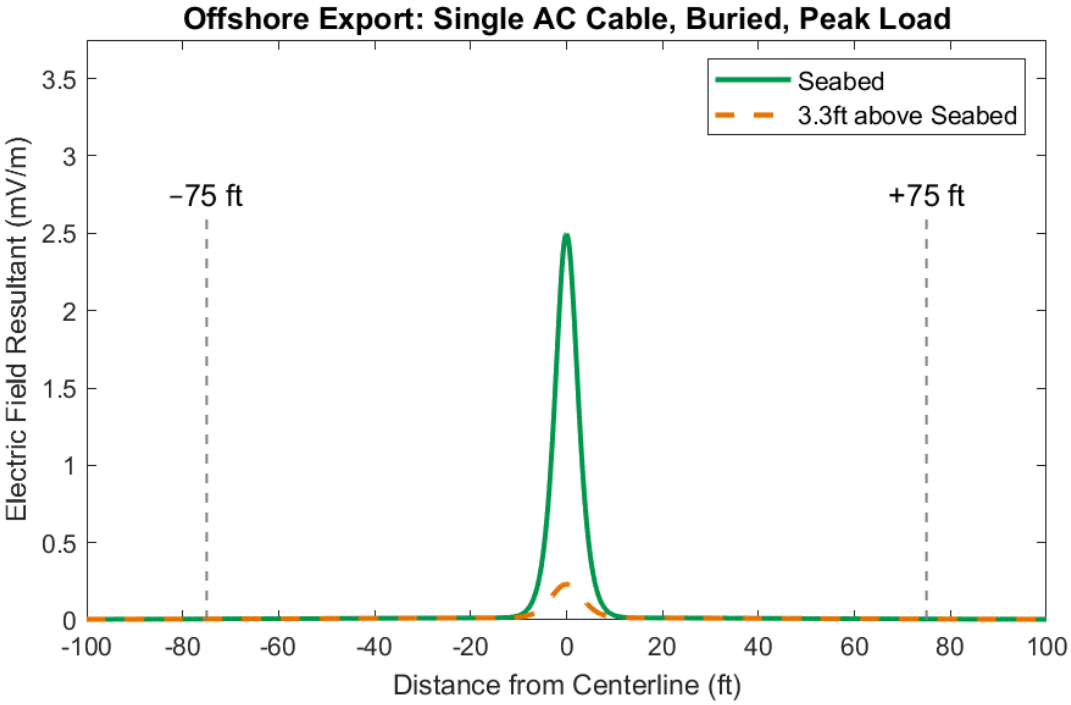

Figure C-14. Calculated induced AC electric-field levels during peak loading over one 230-kV Offshore Export Cable installed at a 3.3-ft (1-m) burial depth.

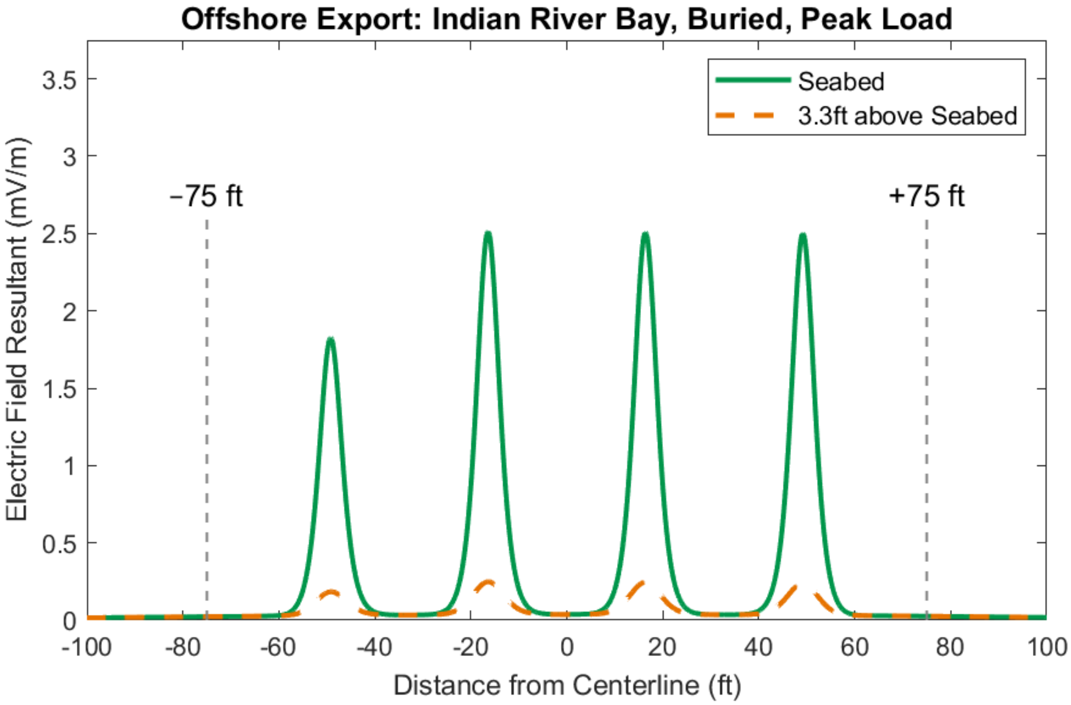

Figure C-15. Calculated induced AC electric-field levels during peak loading over four 230-kV Export Cables in Indian River Bay installed at a 3.3-ft (1-m) burial depth.

Attachment D

Calculated Volume-Averaged EMF Levels for Cables with Protective Coverings

The calculated results of AC magnetic and induced electric fields for points in space above the Project cables are reported in Attachment C. Calculations of volume-averaged magnetic and induced electric fields also were performed in order to assess the fields that may be encountered by some marine organisms that may inhabit the area for longer periods of time over hard ground provided by protective coverings, such as rock berms or protective mattresses covering segments of surface-laid cables. The volume over which these calculations were averaged is represented by a cubic 3.3-ft (1-m) region of space, extending vertically from the top of the protective covering. The results of the volume-averaged calculations are included in Table D-1 below.

Table D-1. Calculated volume-averaged AC magnetic-fields (mG) and induced electric-fields (mV/m) above Project cables with protective covers.

	Average Loading		Peak Loading	
Volume of Water*	**Magnetic-Field (mG)**	**Electric Field (mV/m)***	**Magnetic-Field (mG)**	**Electric Field (mV/m)**
Inter-array Cable	58	0.7	146	1.7
Offshore Export Cable	139	2.0	347	5.0
Export Cables in Indian River Bay	139	2.0	347	5.0

* Volume corresponds to a 3.3-ft (1-m) sided cube, centered above circuit centerline of an Inter-array Cable or an Offshore Export Cable, or directly above the centerline of the center-right circuit among the set of four Export Cables in Indian River Bay. The bottom of the cube is positioned 3.3-ft (1-m) above the seabed.