Electrical Engineering and Computer Science Practice

Ecological and Biological Sciences Practice

Revolution Wind Farm

Offshore Electric- and Magnetic-Field Assessment

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Acronyms and Abbreviations

µT	Microtesla
A	Ampere
AC	Alternating current
BOEM	Bureau of Ocean Energy Management
DC	Direct current
EMF	Electric and magnetic fields
HDD	Horizontal directional drilling
Hz	Hertz
IAC	Inter-Array Cable
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 0486
m	Meter
mi	Mile
mG	Milligauss
mm	Millimeter
mT	Millitesla
mV/m	Millivolts per meter
MW	Megawatt
OCS	Outer Continental Shelf
OD	Outer diameter
Orsted	Orsted US Wind Power, LLC
OSS	Offshore substation
OSS-Link Cable	Offshore substation interconnector cable
Project	Revolution Wind Farm project
Revolution Wind	Revolution Wind, LLC.
RWEC	Revolution Wind Export Cable

RWEC Landfall Cables	RWECs connecting the offshore exit pit to the TJBs at shore landings
RWF	Revolution Wind Farm
TJB	Transition joint bay
VHB	Vanasse Hangen Brustlin, Inc.
WTG	Wind turbine generator

Limitations

At the request of Vanasse Hangen Brustlin, Inc. (VHB) and Revolution Wind, LLC. (Revolution Wind)[1], Exponent modeled the electric- and magnetic-field levels associated with the operation of the submarine cables proposed for the Revolution Wind Farm 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 VHB and Revolution Wind. We cannot verify the correctness of this input data and rely on VHB and Revolution Wind 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 Revolution Wind Farm Project remains fully with the client. VHB has 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.

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[1] Revolution Wind is a 50/50 joint venture between Orsted North America Inc. and Eversource Investment LLC.

Executive Summary

At the request of Vanasse Hangen Brustlin, Inc. (VHB) and Revolution Wind, LLC. (Revolution Wind)[2], Exponent calculated the magnetic fields and induced electric fields associated with the operation of submarine cables that are proposed to convey electricity generated by the Revolution Wind Farm Project (Project). Field levels were calculated for the submarine Inter-Array Cables (IAC) connecting individual wind turbine generators (WTG) and offshore substations (OSS), and for the submarine Revolution Wind Export Cables (RWEC) running between the offshore substations and the proposed Landfall Work Area in North Kingstown, Rhode Island.

The buried (or otherwise protected) submarine cables, as well as cables passing through the water column at WTGs and OSSs, will be sources of electric and magnetic fields (EMF) in the marine environment. The proximity and likely duration of exposure of marine species to Project EMF at these installations will be different from the buried cables, so EMF for these Project elements are reviewed separately.

Over the buried cables, the focus of the assessment is on behavioral reactions of marine species to 60-Hertz alternating current (AC) EMF in the offshore environment. The magnetic fields and induced electric fields are calculated for comparison to the detection thresholds of various local electrosensitive marine organisms to assess the likelihood of detection or alteration of animal behavior.

Calculated magnetic-field levels above the buried cables were found to be below reported thresholds for effects on the behavior of magnetosensitive marine organisms and calculated induced electric-field levels were found to be below reported detection thresholds of local electrosensitive marine organisms.

In contrast to the buried cables, the WTGs and OSSs are relatively large structures and are expected to attract some species to this habitat (i.e., a reef effect), as has been observed at other established wind farm sites. Since the physical vertical structure of the WTGs and OSSs will

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[2] Revolution Wind is a 50/50 joint venture between Orsted North America Inc. and Eversource Investment LLC.

attract some species to this new habitat for a relatively greater period of time, regardless of the presence of EMF, the focus of the assessment is on the potential for any adverse effect of more chronic exposure to EMF.

Computational modeling of the proposed installations indicates that the AC magnetic fields and induced electric fields will be confined to a relatively small region immediately surrounding the cables and associated infrastructure. Modeling results indicate that the average magnetic-field strengths at the OSSs and WTGs are far below levels associated with documented chronic effects on fish. These findings concur with the conclusions of a 2016 comprehensive review by the U.S. Pacific Northwest National Laboratory of the ecological impacts of Marine Renewable Energy development, which concluded 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 " 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 et al., 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

Revolution Wind, LLC. (Revolution Wind), a 50/50 joint venture between Orsted North America Inc., and Eversource Investment LLC, proposes to construct and operate the Revolution Wind Farm Project (Project). The wind farm portion of the Project (RWF) will be located in federal waters on the Outer Continental Shelf (OCS) in the designated Bureau of Ocean Energy Management (BOEM) Renewable Energy Lease Area OCS-A 0486 (Lease Area). The Lease Area is approximately 20 statute miles (mi) (17.4 nautical miles; 30 kilometers [km]) south of the coast of Rhode Island. Other components of the Project will be located in state waters of Rhode Island and onshore in North Kingstown, Rhode Island. The Project is proposed to be comprised of up to 100 wind turbine generators (WTG) and will be capable of producing up to 880 megawatts (MW) of electricity.

Electricity from the WTGs will be carried at a voltage of 66 kilovolts (kV) over approximately 155 mi (250 km) of Inter-Array Cables (IAC), and will be collected at up to two offshore substations (OSS). The two substations will be connected by an approximately 9 mi (14.5 km) OSS-Interconnector Cable (OSS-Link Cable). At the offshore substations, the voltage will be increased to 275 kV and will connect to a new substation in North Kingstown, Rhode Island, via the Revolution Wind Export Cables (RWEC)—a pair of 275-kV 3-core submarine cables (approximately 50 mi [80 km]).

Where the RWECs makes landfall at Quonset Point in North Kingstown, Rhode Island, the RWECs will be spliced to slightly larger 3-core cables (RWEC Landfall Cables), which will be installed via horizontal directional drilling (HDD) to transition joint bays (TJBs) within the Landfall Work Area.[3] At the TJBs, the RWEC Landfall Cables will be spliced to single-core Onshore Transmission Cables and will transition to an onshore underground duct bank to a new onshore substation sited adjacent to the existing Davisville Substation. Figure 1 provides an overview of the offshore Project Area with the proposed location of the RWF and potential

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[3] Hereafter all references to RWEC Landfall Cables will refer to cables installed between the offshore exit pit and TJBs installed via HDD .

RWEC routes. Note that while other portions of the Construction and Operations Plan refer to the RWEC routes on the outer continental shelf and in Rhode Island waters (RWEC-OCS and RWEC-RI, respectively), the assessment in this report does not depend on location, so the discussion below refers to the RWECs as covering both portions.

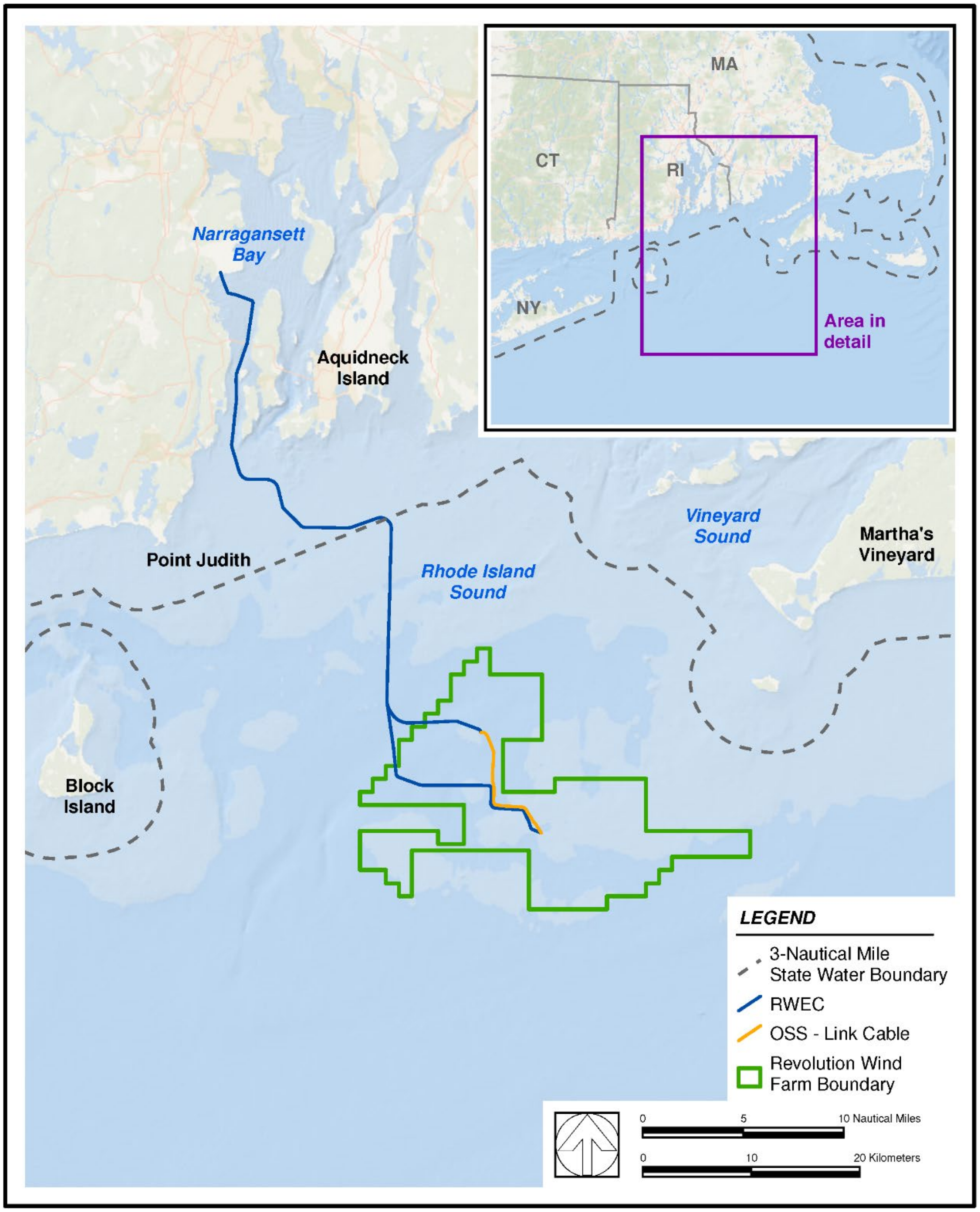

Figure 1. Overview of the proposed RWF and RWEC routes.

Each of the electrical elements for the Project, including the IACs and RWECs—where buried or otherwise protected and at the WTGs and the OSSs—will be sources of magnetic and induced electric fields. This report summarizes the 60-Hertz (Hz) magnetic and induced electric fields produced by these submarine cables in the offshore portion of the proposed route, as well as by a representative WTG and OSS.[4] An assessment of the magnetic fields associated with the Onshore Transmission Cables between the TJBs and the new onshore substation is provided in the companion report titled *Revolution Wind Farm Onshore Magnetic-Field Assessment* (Exponent, 2020).

Magnetic Fields and Induced Electric Fields

Magnetic fields are associated with electricity flowing through the submarine cables and are reported as magnetic flux density in units of milligauss (mG), where 1 Gauss is equal to 1,000 mG. Magnetic fields are also reported as microtesla (μT), where 1 mG is equal to 0.1 μT.

The strongest magnetic field will occur at the surface of the steel armoring around the submarine cable and will decrease rapidly with distance. While an electric field is created by the voltage applied to the conductors inside the cable, it is entirely shielded from the marine environment by grounded metallic sheaths and steel armoring around the cable (Snyder et al., 2019). The magnetic field, however, will induce a weak electric field in the seawater around the cables and in nearby marine species. This induced electric field will vary in strength with the flow of electricity on the cable and, like the magnetic field, will decrease rapidly with distance. Induced electric fields in the marine environment are measured in units of millivolts per meter (mV/m).

The magnetic fields and induced electric fields around the conductors will vary depending on load current—expressed in units of amperes (A). Since load current on the conductors will vary with varying power generation (dependent upon the speed of the wind and operational status), measurements or calculations of these fields represent only a snapshot of conditions at one moment in time. On a given day, throughout a week, or over the course of months or years, the

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[4] The Project also includes an Offshore OSS-Link Cable (approximately 9 miles [14.5 km]) and slightly larger diameter RWEC Landfall Cables, described in greater detail below.

magnetic- and induced electric-field levels will also vary. To account for this variability, calculations are performed for annual average load and peak load of the Project, which will provide the average and maximum field levels expected for the proposed Project. Annual average loading and annual peak loading were used to calculate magnetic and induced electric fields in this report.

Electric and Magnetic Field Exposures and Guidelines

Human Exposure

The federal government has not enacted any limits for electric fields or magnetic fields from land- or marine-based transmission cables or other sources of 60-Hz fields. Similarly, the State of Rhode Island also has not established any limits or guidelines for exposure. While land-based exposure to electric and magnetic fields (EMF) from transmission cables is relatively common, marine-based submarine cables provide limited opportunity for persons to come in close proximity to them, although limited exposure is possible for those who may be scuba diving at the seabed directly over the cables.

Two international organizations provide guidance on human exposure to magnetic fields. This guidance is the result of extensive review and evaluation of relevant research of health and safety issues, and the limits they propose are designed to protect health and safety of persons in an occupational setting and for the general public. The International Committee on Electromagnetic Safety (ICES), which operates "under the rules and oversight of the Institute of Electrical and Electronics Engineers (IEEE) Standards Association Board,"[5] developed an exposure reference level limit to 60-Hz magnetic fields of 9,040 mG for the general public (ICES, 2019). The International Commission on Non-Ionizing Radiation (ICNIRP), an independent organization that provides scientific advice and guidance on the health and environmental effects of non-ionizing radiation, determined a reference level limit of 2,000 mG for whole-body exposure to 60-Hz magnetic fields (ICNIRP, 2010). The limits for both ICES and ICNIRP for electric-field exposure are roughly one million times higher than those expected from induced electric fields, so human exposure to electric fields is not discussed further in this

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[5] http://www.ices-emfsafety.org/

report.

Exposure of Marine Species

Both magnetic fields and induced electric fields from submarine cables are of environmental and ecological interest because research shows that some marine species have specialized sensory receptors that are capable of detecting magnetic fields or electric fields, or both, in the natural environment (e.g., Taylor, 1986; Klimley, 1993; Lohmann et al., 1995; Hellinger and Hoffmann, 2012). Generally, the fields detected by marine organisms are within a very limited frequency range, which includes the static magnetic field of the earth (frequency of ~0 Hz), the near 0-Hz induced electric fields produced by ocean currents and fish movement in the earth's static magnetic field, and the electric fields produced by biological processes of fish with frequencies from 0 Hz to about 10 Hz (Bedore and Kajiura, 2013; Snyder et al., 2019).

Assessment Approach

Exponent used two separate assessment approaches for evaluating the different Project elements with respect to EMF exposure of marine species.

Buried Cables: Where cables are buried, the interaction of interest will be whether or not EMF can be detected by sensitive species, and if detected, whether these fields are likely to affect or alter the behavior of these species in a way that could have potentially deleterious population-level effects. To perform this assessment, the magnetic-field and induced electric-field levels associated with the submarine cables are calculated at a height of 3.3 feet (1 meter [m]) above the seabed as relevant reference locations for most mobile marine species above the seabed.[6] The calculated field levels are then compared to the detection thresholds of various marine species expected to be in the Project Area (e.g., sharks; fish, including key groundfish species; and larger crustaceans, such as crabs and lobsters) to assess the likelihood of detection or alteration of animal behavior.

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

OSSs, WTGs, and Cables Covered with Protective Mattresses: In contrast to the buried cables, the OSSs and WTGs are relatively large structures (at least 36 feet in diameter [11 m]),[7] and the portion of these structures above seabed will introduce a new habitat, as will the small portion of cables to be covered by protective mattresses or rock berms (estimated to be approximately 10% of the total route). These new habitats will attract certain species, regardless of the presence of magnetic and induced electric fields. The assessment of exposure at these new habitats is different than at other locations since the new habitats may encourage certain fish and shark species to spend a greater amount of time relatively close to these structures. Since marine species swimming near these portions of the Project would be expected to move freely throughout the environment around these structures from top to bottom, a conservative estimate of average exposure over a medium term (hours, days) was obtained by calculating the average EMF level in a volume of the water column adjacent to these structures or above the mattress-protected cables. These field levels were compared to those reported in the scientific literature where physiologic responses were measured over longer periods than are typically used for acute behavioral studies.

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[7] The cited dimensions are for monopile structures. Piled jacket foundations with smaller diameter legs also may be considered for the OSSs, but would have cables separated by far greater distances, so the monopile structures were evaluated as the option that would result in the highest EMF levels.

Cable Configurations and Calculation Methods

Project Cables

Exponent calculated the 60-Hz fields from the various submarine cables proposed for different portions of the Project and compared the calculated levels to assessment criteria to evaluate potential effects on marine species.

Three cable configurations are proposed as part of the Project (detailed descriptions of the cable configurations are provided in Attachment A):[8]

1. IACs (66 kV) are proposed to be installed between WTGs and between WTGs and the OSSs;
2. RWECs (275 kV, double-circuit) are proposed to run from the OSSs to the Landfall Work Area in North Kingston, Rhode Island;[9] and,
3. Where the RWECs are installed between the exit pit to and the TJBs at shore landings, slightly larger cables (referred to as RWEC Landfall Cables) will be installed by HDD.

For most of the route, the cables will be buried to a target burial depth of 4 to 6 feet (1.2 m to 1.8 m) beneath the seabed (see Attachment A, Figure A-1); however, *for the calculations, a conservative burial depth of 3.3 feet (1 m) has been assumed*. Where it is impracticable to bury the cables, they may lie upon the surface of the seabed for short areas and will be covered with protective concrete mattresses or rock berms. The protective coverings for these short surface-laid installations will be at least 1 foot (0.3 m) thick. At the Landfall Work Area, the RWECs will be spliced to two slightly larger RWEC Landfall Cables for installation via HDD. At the offshore exit pit transition to the HDD (over a few tens of feet) the burial depth may less than 15 feet (4.6 m) and is conservatively modeled at the same minimum depth of 3.3 feet (1 m) as the RWECs and IACs.

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[8] The substation itself is expected to be a minimum of 82 feet (25 m) above mean sea level, so will not be a source of EMF in the marine environment.

[9] Interconnector Cables may also be installed in the Offshore Interconnector Cable Corridor–approximately 9 miles (15 km)–if two OSSs are constructed. The Interconnector Cables are proposed to be the same as the RWECs, so are not discussed separately.

Evaluations of field levels at these minimum heights are designed to describe the likeliest exposure zone for demersal fish. A detailed table summarizing the modeling inputs for each of these cable configurations is shown in Attachment A, Table A-1.

Modeling Methods

Exponent modeled the magnetic- and induced electric-field levels for each cable configuration, 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. In addition to using a conservative minimum target burial for all cases, these conservative models assume no shielding effect of cable sheathing or armoring as well as no field reduction due to helical twisting of conductors within the cables. As discussed in Snyder et al. (2019), each of these factors will reduce the magnetic field compared to those calculated in this report. The induced electric- and magnetic-field levels reported below therefore provide conservative upper bounds on the expected field levels surrounding the cables. Additional discussion of these factors is presented in Attachment B.

The RWECs are proposed to be separated by at least 160 feet (50 m), so were modeled in isolation from one another. In contrast, the IACs and RWEC Landfall Cables are proposed to be closer together with minimum separation distances of 9.2 feet (2.8 m) and 49 feet (15 m) respectively, so models of these two configurations included both cables together to account for the potential additive effects of two closely-spaced cables.[10] More detailed descriptions of the calculation methods for magnetic fields and induced electric fields within marine organisms are provided in Attachment B.

WTGs and OSSs

Exponent also modeled magnetic- and induced electric-field levels from the WTGs and OSSs (each supported on 36-foot [11-m] diameter monopile or piled jacket foundations).[11] The WTGs

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[10] At the TJBs on land, the separation distance will be somewhat less (23 to 33 feet [7 to 10 m]). Therefore, the RWEC Landfall Cables were conservatively modeled using a separation distance of 16 feet (5 m) to conservatively overestimate field levels.

[11] Magnetic and induced-electric field levels around larger monopiles (e.g., 39 feet [12 m] or 49 feet [15m]) are expected to be similar to or lower than modeled here because cables would be spaced further apart.

and OSSs will have the various IACs and RWECs distributed around the circumference of the foundations,[12] and are modeled to approach the WTGs or OSSs at a burial depth of 3.3 feet (1 m). At the base of WTGs or OSS structures, individual cables will be pulled from the base of the foundation to the top of the structure through pre-installed black steel j-tubes inside the structure.[13]

Modeling Geometry for WTGs and OSSs

At any individual WTG, a maximum of three IACs will be present, and each will have an approach angle relative to one another of not less than 70 degrees. At the OSSs, the RWECs, the OSS-Link Cable, and up to six IACs will be spaced around the circumference of the monopile with a minimum approach angle of 23 degrees. Electrical current from the WTGs or OSSs flows down the cables inside the monopile wall within the j-tubes. The cables exit the j-tubes at a maximum height of approximately 16 feet (5 m) above seabed, and enter the seabed at an angle of approximately 45 degrees from the vertical, separating from one another radially as illustrated in Figure 3. As the cables exit the monopile they will form a partial “skirt” and a sheltered area, which some marine species may utilize as habitat. At the base of the WTG shown in Figure 2a, the minimum horizontal distance between the cables exiting the j-tubes is approximately 20 feet (6 m). In Figure 2b, the minimum horizontal distance between adjacent j-tubes at the base of the OSS is approximately 6.6 feet (2 m).

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[12] The piled jacket foundations will be installed as four-legs to support rectangular-shaped OSS platforms. The leg supports at seabed will be separated by 120 ft x 110 ft (37 m x 34 m). The separation of IACs, OSS-Link Cable, and RWEC on piled jacket foundations will be greater compared to separation around monopile foundations. Therefore, expected levels of magnetic and induced electric fields are expected to be similar to or greater around monopile foundations compared to piled jacket foundations.

[13] The diameter of each j-tube is approximately 2.5 times the diameter of the cable.

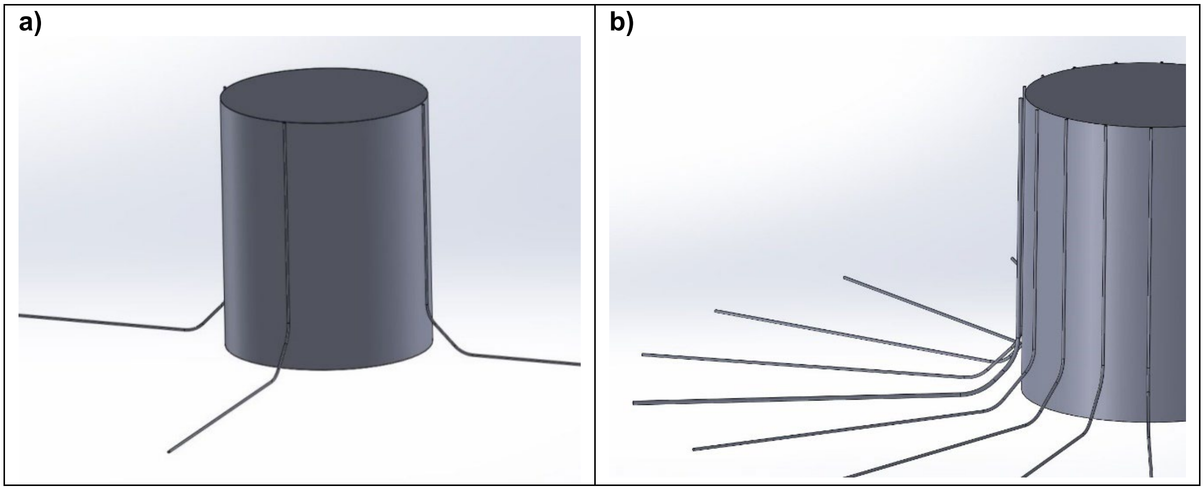

Figure 2. Indicative illustration of the geometry of cables connecting to a) a WTG and b) an OSS.

Modeling Methods

All calculations for the WTGs and OSSs were performed using the same methods that was used to the model the EMF from the IACs, RWECs, and RWEC Landfall Cables. In contrast to the relatively simple cable geometry, however, the models of the WTGs and particularly the OSS are substantially more complex. As shown in Figure 2, the separation of the cables away from the OSS monopile and their radial divergence requires a significantly larger modeling domain. Similar to the calculations of individual cables, the modeling approach at the WTGs and OSSs includes a number of factors that will reduce the magnetic-field level compared to those calculated in this report (Snyder et al., 2019). The induced electric- and magnetic-field levels reported below therefore provide conservative upper bounds on the expected field levels surrounding the cables. A more detailed description of the calculation methods is provided in Attachment B.

Calculated Magnetic and Induced Electric Fields

Fields from Project Cables

The magnetic-field and induced electric-field levels calculated for five offshore cable configurations are summarized in Attachment A, Table A-1. The cables in these five configurations vary in size, loading, and effective burial depth. The calculated field levels at a height of 3.3 feet (1 m) above the seabed for a 3.3-foot (1 m) burial depth and average loading are summarized below. Calculated field levels for the surface-laid installations, for peak loading, and calculations of field levels for all configurations at the seabed are provided in Attachment C.

Magnetic-field levels summarized below are compared to limits on human exposure and both magnetic-field and induced electric-field levels are compared with relevant detection thresholds for marine species in subsequent sections of this report.

Magnetic-Field Levels

The calculated magnetic-field levels above the 275-kV RWECs, 66-kV IACs, and 275-kV RWEC Landfall Cables for a 3.3-foot (1 m) burial depth and average loading are plotted in Figure 3, Figure 4, and Figure 5, respectively. The calculated magnetic field at a height of 3.3 feet (1 m) above the seabed is highest directly above the buried cables (IACs, 17 mG; RWECs, 41 mG; and RWEC Landfall Cables, 39 mG) and decreases rapidly with distance.[14] All calculated field levels are well 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.

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[14] RWEC Landfall Cables and IACs are conservatively modeled in locations where the distance between any two respective cables is at a minimum (<20 feet). As shown in Attachment C, similar to the RWECs, calculated magnetic-field levels from the RWEC Landfall Cables and IACs also decrease rapidly with distance, but the presence of a second cable in relatively close proximity makes it appear that field levels decrease more slowly with distance than the RWECs (see e.g., Table 1).

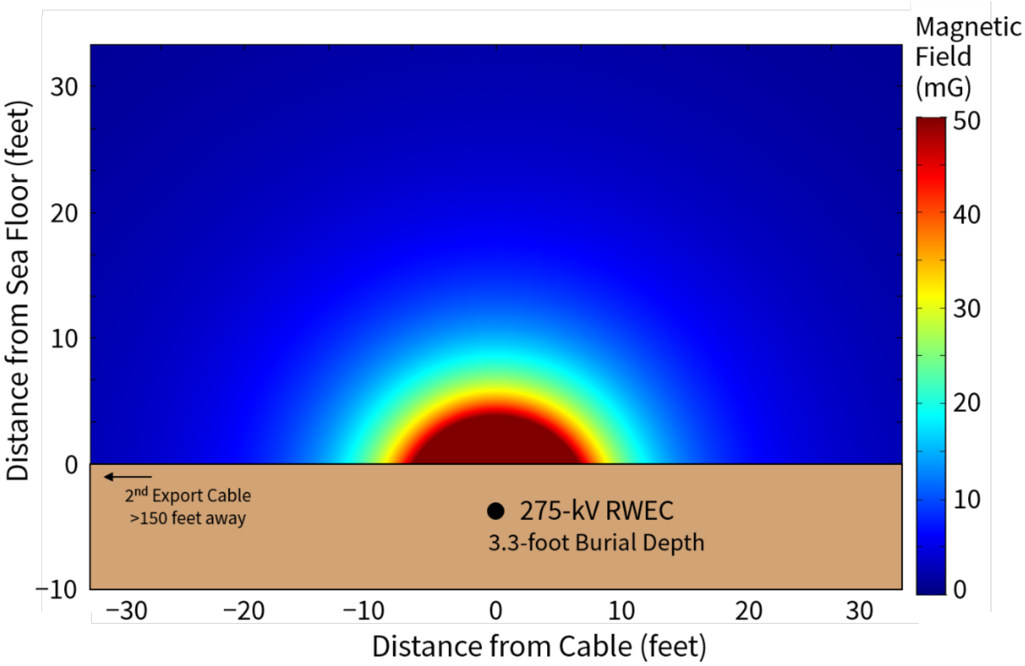

Figure 3. Calculated magnetic-field levels in seawater above the 275-kV RWEC for a 3.3-foot (1 m) burial depth and average loading.

As indicated in the figure, the second RWEC is more than 150 feet away and is not expected to change the magnetic-field levels from those shown here.

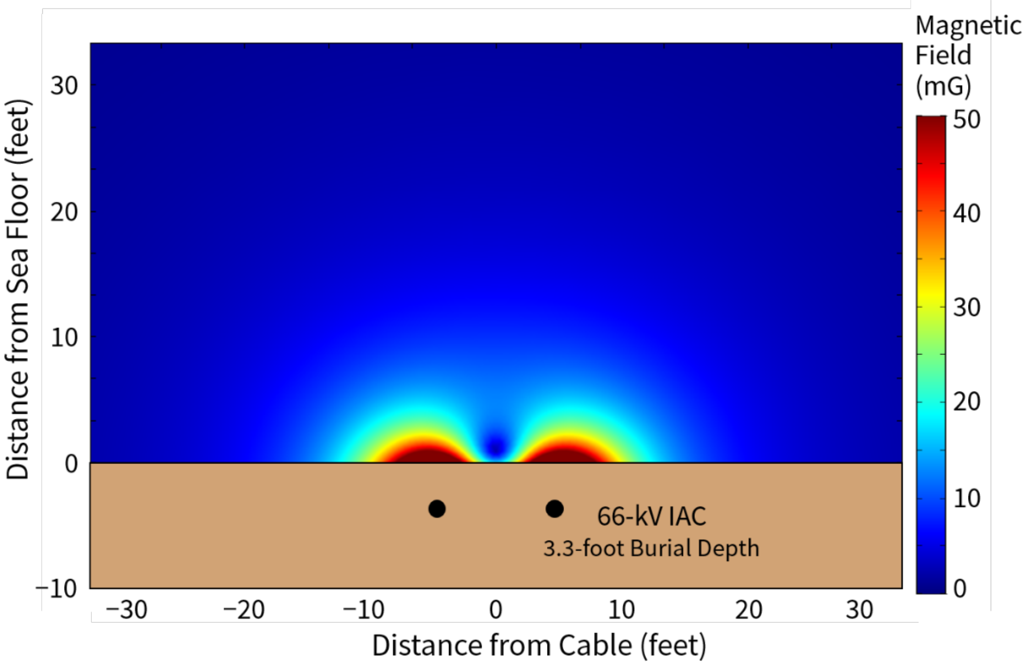

Figure 4. Calculated magnetic-field levels in seawater above the two 66-kV IACs for a 3.3-foot (1 m) burial depth and average loading.

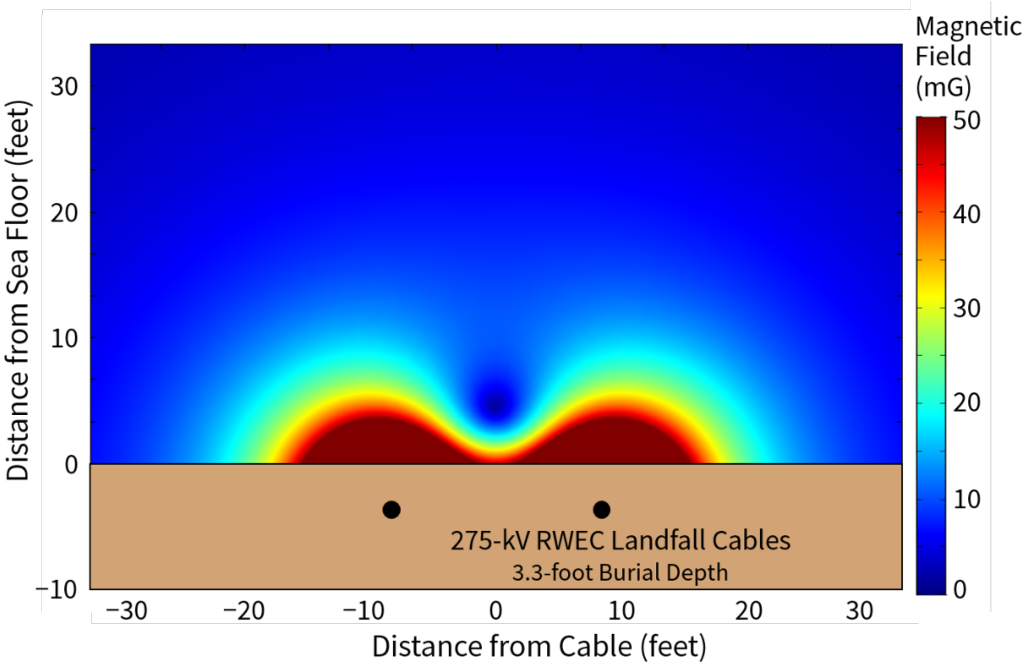

Figure 5. Calculated magnetic-field levels in seawater above the two 275-kV RWEC Landfall Cables for a 3.3-foot (1 m) burial depth and average loading.

A summary of calculated magnetic-field levels at the seabed is shown in Table 1 for each of the cable configurations at a 3.3-foot burial depth and average loading. Where the cables may potentially be laid on the seabed for short distances and covered by protective concrete mattresses or rock berms, the field levels would be higher, but also will decrease very rapidly with distance. For horizontal distances beyond 30 feet from the cables (including where covered by protective mattresses), the magnetic-field levels for all configurations are calculated to be 5.6 mG or less for average loading, and 7.9 mG or less for peak loading.[15]

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[15] At the seabed, the highest calculated magnetic field for any configuration was 1071 mG at average loading and 1529 mG at peak loading. At a height of 3.3 feet (1 m) above the seabed, the highest calculated magnetic-field level for any configuration was 91 mG at average loading and 130 mG at peak loading. All these maxima occurred directly above the 275-kV RWECs where for limited distances the cables potentially may be laid on the seabed and covered by protective concrete mattress or rock berms. These highest calculated levels are still well below the ICNIRP and ICES limits for exposure of the general public. See Attachment C for calculated field levels for all modeled cable configurations.

Table 1. Calculated magnetic-field levels (mG) at 3.3 feet (1m) above the seabed for a 3.3-foot (1 m) burial depth and average loading

	Horizontal Distance from Cable*		
Configuration	**Max**	**±10 feet**	**±30 feet**
IACs	17	12	1.7
RWECs	41	13	2.1
RWEC Landfall Cables	39	38	5.2

* Two cables are modeled for each cable type. The distance between the two RWECs is >150 feet, while the distance between any two IACs and between the two RWEC Landfall Cables is <20 feet. Horizontal distance is measured from the center of the RWEC or from the centerline of the two modeled IACs and RWEC Landfall Cables.

Electric-Field Levels Induced in Seawater

The electric fields calculated to be induced in seawater at a height of 3.3 feet (1 m) above the seabed are summarized in Table 2 for the three cable types at average loading. Induced electric-field levels in seawater were calculated to be 2.8 mV/m or less for each of these configurations and decrease rapidly with distance.[16] For short distances where the cables potentially may be laid on the seabed and covered by protective concrete mattresses or rock berms, the field levels would be higher, but also will decrease very rapidly with distance. For horizontal distances beyond 30 feet (~9 m) from the buried cables, the induced electric-field levels for all configurations were calculated to be 1.2 mV/m or less for average loading, and 1.7 mV/m or less for peak loading. [17]

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[16] RWEC Landfall Cables and IACs are conservatively modeled in locations where the distance between any two respective cables is at a minimum (<20 feet). As shown in Attachment C, similar to the RWECs, calculated magnetic-field levels from the RWEC Landfall Cables and IACs also decrease rapidly with distance, but the presence of a second cable in relatively close proximity makes it appear that field levels decrease more slowly with distance than the RWECs (see e.g., Table 1).

[17] At the sea bed, the highest induced electric field for any configuration was calculated to be 13 mV/m at average loading and 18 mV/m at peak loading. At a height of 3.3 feet (1 m) above the seabed, the highest induced electric-field level for any configuration was calculated to be 3.5 mV/m at average loading and 4.9 mV/m at peak loading. All these maxima occurred directly above the 275-kV RWECs where the cables may potentially be laid on the seabed for short distances and covered by a protective concrete mattress or rock berms. These highest calculated levels are still well below the ICNIRP and ICES limits for exposure of the general public. See Attachment C for calculated field levels for all modeled cable configurations.

Table 2. Calculated induced electric-field levels (mV/m) at 3.3 feet (1 m) above the seabed for a 3.3-foot (1 m) burial depth and average loading

	Horizontal Distance from Cable*		
Configuration	**Max**	**±10 feet**	**±30 feet**
IACs	1.3	1.1	0.4
RWECs	2.3	1.3	0.5
RWEC Landfall Cables	2.8	2.8	1.1

* Two cables are modeled for each cable type. The distance between the two RWECs is >150 feet, while the distance between any two IACs and between the two RWEC Landfall Cables is <20 feet. Horizontal distance is measured from the center of the RWECs or from the centerline of the two modeled IACs and RWEC Landfall Cables.

Electric-Field Levels Induced in Marine Organisms

The calculated electric fields induced in marine organisms at the seabed are summarized in Table 3 for each of the primary cable configurations at a 3.3-foot (1 m) burial depth and average loading. At average loading, the calculated electric-field levels induced in marine organisms are 0.5 mV/m or less. The electric field that is calculated to be induced in marine organisms scales linearly with the magnetic-field levels and also will decrease rapidly with distance from the cables. Within a horizontal distance of 30 feet from the buried cables, calculated induced electric-field levels in marine organisms at the seabed fall to 0.1 mV/m or less for all cable configurations.

Table 3. Calculated electric-field levels (mV/m) induced in marine organisms at 3.3 feet (1 m) above the seabed for a 3.3-foot (1 m) burial depth and average loading

Configuration	Dogfish	Sturgeon
IACs	0.1	0.2
RWECs	0.3	0.5
RWEC Landfall Cables	0.3	0.5

WTGs and OSSs

The calculated magnetic-field and induced electric-field levels for the individual cables discussed above decrease very rapidly with distance and the calculated magnetic-field and induced electric-field levels from cables coming together at the WTG and OSS systems are similar—the calculated field levels are highest in the immediate vicinity of the cables and decrease rapidly with distance.

OSSs

The magnetic field from the cables on the OSS monopile foundation is shown in Figure 6, which is a 3-dimensional plot of the magnetic field across the entire modeling domain. A vertical plane cutting through the center of the plot passes through the RWEC and one passes through an IAC to show how the field level varies with height above the seabed around the two modeled cable types. In addition, a horizontal plane cutting through the modeling domain at the seabed shows how the magnetic-field level changes with distance from the OSS monopile foundation. This figure also shows visually that the fields from one transmission cable are not calculated to substantially change the field levels at an adjacent cable. The maximum calculated field level over a single cable at the OSS (at the same specified distance from the cable) is within 1% of the maximum calculated field level listed above in Table 1 and Table 2 (at similar distances from the cables).

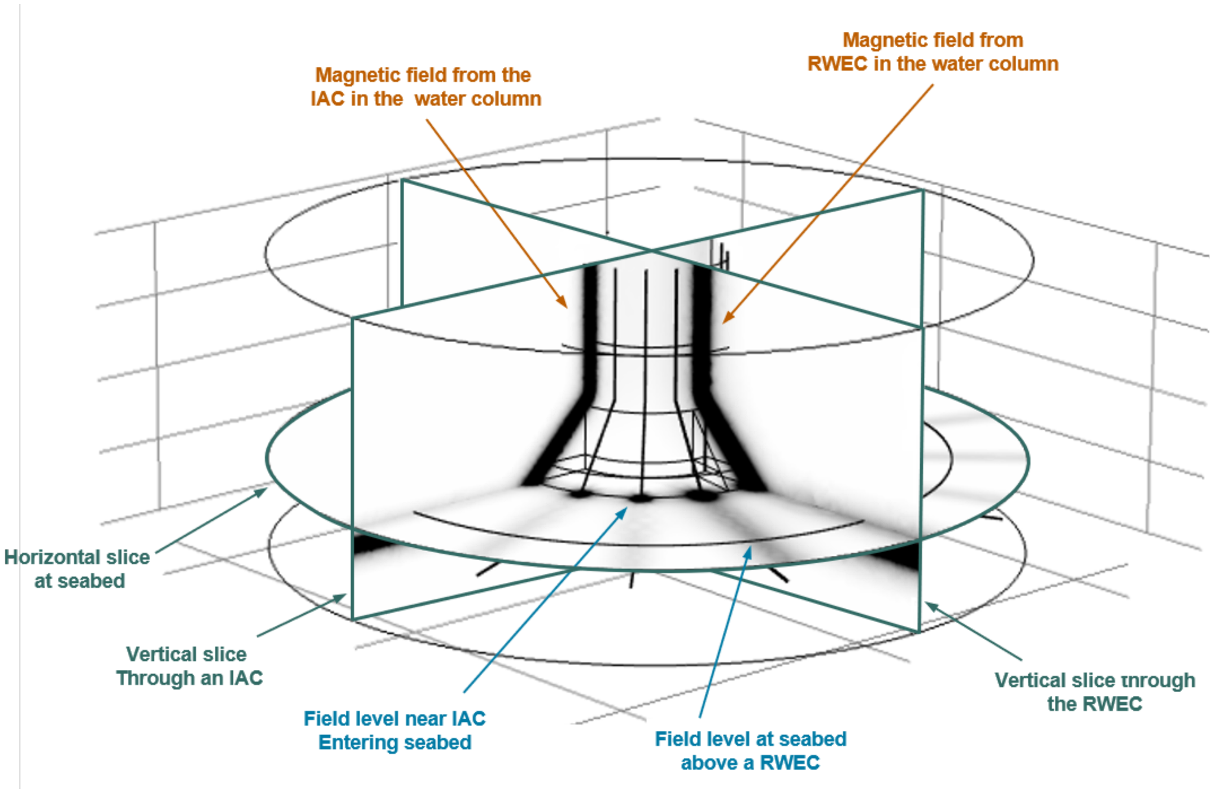

Figure 6. Visual comparison of modeled magnetic fields around the RWEC and IACs attached to the OSS.

The density of the shading around representative cables describes the relative strength of the calculated magnetic field.

The assessment of fields around the OSS was performed for three separate volumes of seawater where some marine species might spend more time than above buried cables in other locations. For this reason, the field levels in the seawater around the OSS were calculated as the average within each of the three volumes. The first is the volume of water within 6.6 feet (2 m) of the monopile above where the j-tubes exit the monopile; species such as pelagic reef fish are expected to aggregate here. The second is in the volume of water beneath the skirt region below where the cables exit the j-tubes; this area is also expected to provide structure for reef-associated fish. The third is the volume of water beneath the skirt region where the cables exit the j-tubes and less than 3.3 feet (1 m) above the seabed expected to be inhabited by shelter-seeking benthic species.

WTGs

The calculated magnetic fields around the outer surface of the WTGs are qualitatively similar to those outside the OSS, but somewhat lower because no Export Cable connects to WTGs. In addition, a maximum of three cables attach to a WTG and the center-center spacing between the three IACs is much greater than at the OSS (20 feet [6 m] at the WTG compared to 6.6 feet [2 m] at the OSS), so the small overlap in the field from adjacent cables is even less. The volume-averaged magnetic- and induced electric-field level in these portions of the monopile for both the OSS and WTG are summarized in Table 4.

Table 4. Calculated volume-averaged induced electric-field (mV/m) and magnetic-field levels (mG) around the OSS and WTGs

	OSS		WTG	
Volume of Water	**Magnetic-Field (mG)**	**Electric Field (mV/m)**	**Magnetic-Field (mG)**	**Electric Field (mV/m)**
Above j-tubes	44	3.1	23	1.0
Skirt region	245	6.3	89	1.7
Skirt region <3.3 feet (1 m) above the seabed	157	4.9	56	1.3

Evaluation of EMF Exposure to Large Invertebrates in the Project Area

The RWF will be sited approximately 14.8 mi (23.8 km) southeast of Block Island, Rhode Island. The transmission cable linking the offshore site is expected to transect the habitat of a number of large invertebrate species including epibenthic crustaceans, bivalves, and squid. In addition, sediments in this area contain communities of small burrowing invertebrates, called infauna, that can constitute an important food source for fish and larger invertebrates.

In the proposed Project Area, there is habitat supporting two squid species of commercial importance—longfin squid and northern shortfin squid (Table 5). Both species of squid are found in large schools across many types of coastal and deep-water benthic habitats. Squid also exhibit seasonal migrations that could result in occasional crossings of the cable route. In addition, epibenthic crustaceans such as crab and lobster also inhabit the region. These crustaceans also commonly exhibit seasonal migrations or significant local movement and are known to utilize a range of bottom substrates. Given this, it is likely that individuals of these species will periodically encounter cable routes.

A number of bivalves (clams, mussels, scallops) are found in coastal Rhode Island, and commercially-important bivalve species in the Project Area include the Atlantic sea scallop, the Atlantic surf clam, and the quahog clam (Table 5). Unlike large crustaceans and squid, however, these species are mainly found burrowed into muddy substrates, and do not exhibit the same migratory behaviors as the larger mobile invertebrates. Because of this, bivalve populations outside the sediments along the submarine cable route would not be exposed to the operational cable, given their restricted movement. Similarly, sediment infauna move only small distances, if at all, indicating that communities of these sediment-swelling invertebrates outside the cable route will not move into the cable area.

Table 5. Important large invertebrate species expected to inhabit the Project Area

Species	Preferred Habitat
Atlantic sea scallop (Placopecten magellanicus)	Associated with sand, gravel, shells, and other rocky habitat
Atlantic surfclam (Spisula solidissima)	Burrows in medium-grained sand and finer substrates usually at depths between 26 to 216 feet (8 to 66 m)
Longfin inshore squid (Doryteuthis pealeii)	Benthopelagic in inshore areas and to the outer continental shelf
Northern shortfin squid (Illex illecebrosus)	Found over various bottom substrates from coastal areas throughout the continental shelf
Ocean quahog (Arctica islandica)	Sandy substrates, generally at depths between 82 and 200 feet (25 and 61 m)

Magnetosensitivity in Large Marine Invertebrates

Although a body of scientific literature exists documenting the responses of large crustaceans to static and geomagnetic fields (Ugolini and Pezzani 1995; Boles and Lohmann, 2003; Cain et al., 2005), information from these studies cannot be relied upon to predict effects from 60-Hz alternating current (AC) power sources.

Recently, researchers exposed juvenile European lobsters (*Homarus gammarus*) to 50-Hz AC magnetic fields up to 2,300 mG for 1 week in a laboratory setting and recorded exploration and sheltering behaviors (Taormina et al., 2020). During this time, lobsters exhibited no significant differences in behaviors or survival due to the prolonged exposure to these AC magnetic fields. Because of this, authors concluded that “anthropogenic magnetic fields, at these intensities, do not significantly impact the behavior of juvenile European lobsters.” The potential effect of AC magnetic fields on bivalve physiology has also been assessed. Cockles (*Cerastoderma glaucum*) were exposed to 64,000 mG 50-Hz magnetic fields for 8 days while endpoints including food consumption rate, oxygen consumption rate, ammonia excretion rate, and measures of oxidative stress were measured (Jakubowski-Lehrmann et al., 2022). Although ammonia excretion rates, protein carbonyl levels (a biomarker of stress), and acetylcholinesterase concentrations were significantly altered by the exposure, these responses were relatively minor and occurred following exposure to a magnetic field level much higher than those expected at AC cable sites.

A series of studies have been conducted to describe the effects of AC-generated EMF on the embryonic development of sea urchins (*Strongylocentrotus purpuratus*). Levine 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%, 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). Conversely, Ueno et al. (1986) exposed giant axons excised from lobsters to determine how magnetic fields might impact nervous system function in crustaceans. No effects of nerve function or potential were observed, even at magnetic fields as strong as 8,000,000 mG produced by a 50-Hz power source (Ueno et al., 1986).

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 indicated 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

Because of the lack of laboratory-derived information regarding the behavioral responses and possible population-level effects, field studies conducted at submarine AC cable sites that assess effects on resident populations of large invertebrates can be used to evaluate potential impacts on species in the Project Area. Recently, scientists have conducted a number of field studies with different crab species at cable sites off the coasts of California and Washington; these studies were designed to evaluate if the presence of the cables impacts the behavior and movement of crustaceans. In addition, large-scale field surveys have been conducted to track the presence and abundance of both crustacean and octopus species at AC cable sites. Taken together, the results from these field studies provide key data regarding effects because they are conducted under more realistic conditions than laboratory studies.

Two species of rock crabs (*Metacarcinus anthonyi* and *Cancer productus*) were caged along unburied 60-Hz AC cables, using a study design that allowed for observation of individual crab distribution relative to both energized and unenergized cables. Along the energized cable, measured magnetic fields were determined to be between 462 and 800 mG, decreasing to 9 mG at the distant side of the cages (Love et al., 2015). As such, crabs were provided a wide range of magnetic-field levels to potentially affect crab distribution. Over four observation times, data indicated that crabs were neither more or less likely to be found either close to the cable or at the distal end of the cages. As such, it was concluded that the presence of the magnetic fields did not result in crab distributions that significantly differed from those around the unenergized cable (Love et al., 2015). As a result, this research provides a strong indication that crabs and other large crustaceans do not exhibit altered behaviors when exposed to 60-Hz EMF as generated by AC submarine cables.

Another series of field surveys were conducted to assess the potential impact of submarine AC cables on the harvest of commercially important crab species off the coasts of Washington and California. This study focused on the ability of crabs (*Metacarcinus magister* in Washington and *Cancer productus* in California) to freely pass across 60-Hz submarine cable routes, which has implications for crab harvest and regional population distributions. Measurements of magnetic-field strengths indicated that the California cable carried a greater electric current than those studied in Puget Sound, producing magnetic fields up to 1,168 mG versus 428 mG (Love et al., 2017a). Specialized experimental units were used to determine whether cables were a barrier to the movement of trapped local crabs. Researchers observed that both species of crabs freely crossed cable routes, demonstrating that energized submarine cables do not constitute a barrier to movement. Taken together, these surveys provide important evidence that energized submarine 60-Hz AC cables do not affect regional populations and distributions of large crustaceans. Moreover, this finding is corroborated by a 2018 report detailing a recent field study with American lobsters (*Homarus americanus*) conducted at a DC submarine cable site that also carried measurable AC currents off the Atlantic coast of the United States. Lobsters were enclosed in mesh cages and behavioral responses were recorded. Although some changes in lobster activity were noted, specifically in regard to number of turns, there was no evidence that either the DC or AC magnetic and electric fields (1.3 mG and 0.76 mV/m, respectively) produced by the cable acted as a barrier to lobster movement (Hutchison et al., 2018).

In addition to crab studies, Love et al. (2017b) also conducted a multi-year survey at energized and unenergized AC submarine cable sites to determine the numbers and types of fish and invertebrate species at these sites. Common large invertebrate species observed included both a crustacean species (*Pandalus platyceros* shrimp) and an octopus (*Octopus rubescens*). Based on two years of data, shrimp and octopus were observed along both energized and unenergized cables at equivalent rates. Although invertebrate communities at all cable sites differed from that of natural sedimented areas, the authors concluded that these differences were a result of the physical presence of the unburied cable structure, and not the EMF produced by the cable (Love et al., 2017b). Given this, the Love et al. (2017b) study provides further evidence that EMF produced by 60-Hz AC cables (730 to 1,100 mG) does not affect the behavior of large, mobile crustaceans and cephalopods like octopus and squid.

Evaluation of EMF Levels Produced by the Project Cables

Overall, data from fields studies indicate that 60-Hz AC submarine cables are unlikely to alter the behaviors and distributions of large marine invertebrates. For instance, crab movement and migration were reported to be unaffected by magnetic fields between 138 and 1,168 mG (Love et al., 2015, 2017b). In addition, localized cephalopod distributions were not altered by 730 to 1,100 mG magnetic fields produced by 60-Hz AC cables (Love et al., 2017b). For the Project cables, the modeled magnetic-field strength at peak loading is 210 mG at the seabed above the RWEC, which is lower than the magnetic-field levels associated with no effects on cephalopod and crustacean distributions. As such, evidence from a series of field surveys demonstrates that the behavior and distributions of large crustacean and cephalopod invertebrates would not be altered by magnetic-field levels projected for Project cables.

Evaluation of EMF Exposure to Finfish in the Project Area

A diverse collection of fish species has demonstrated magnetosensitivity, including salmonids, tuna, herrings, carp, and mackerel. This ability to detect and respond to changes in the earth's geomagnetic field may be related to particles of magnetite found in the bones and organs of various species (Harrison et al., 2002), the presence of which allows these various species of fish to monitor geomagnetic fields (Hanson and Westerberg, 1987; Walker et al., 1998; Tański et al., 2011). These geomagnetic cues, however, are likely used together with other environmental variables (temperature, light, current strength and direction, and olfactory signals) to accomplish large-scale fish migrations.

In contrast to magnetosensitivity, only a select few species of fish are capable of detecting low-level electric fields, via specialized and sensitive electroreceptors (ampullae of Lorenzini). Electrosensitive fish include sturgeon species (family Acipenseridae); these are mostly anadromous fish that regularly inhabit estuaries and coastal environments along the Atlantic coast of the United States during different stages of their life. Their ability to detect electric fields is most likely used to locate prey items, which generate low-level, low frequency electric fields.

Important Finfish Species Residing in the Project Area

The coastal Rhode Island region supports a diversity of finfish[18] species, many of which are important commercially-harvested species. The proposed Project Area is expected to fall within the habitat range for a number of these species (Table 6). Because the behaviors and habitats of these species affect the likelihood of encountering elevated EMF along the proposed cable route, these attributes are also presented. Most notably, demersal and bottom-dwelling fish are generally understood to most frequently inhabit the areas closest to the cable route; hence, these species have the greatest chance of exposure to EMF produced by the operating cable (Bull and

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

Helix, 2011). On the other hand, pelagic or surface-dwelling species live in the upper portions of the water column and will therefore generally inhabit areas more distant from the cable route. This habitat preference decreases the probability that highly migratory or pelagic species would regularly encounter EMF produced by the submarine cables.

Table 6. Finfish species expected to inhabit the Project Area

Species	Demersal or Pelagic?	Size (at maturity)*	Size (common length)*
Albacore tuna (Thunnus alalunga)	Pelagic	85	100
Atlantic butterfish (Peprilus triacanthus)	Pelagic/Benthopelagic	12	20
Atlantic cod (Gadus morhua)	Demersal/Benthic	63	Not reported
Atlantic herring (Clupea harengus)	Pelagic	17	30
Atlantic mackerel (Scomber scombrus)	Pelagic	29	30
Atlantic wolffish (Anarhichas lupus)	Demersal/Benthic	60	Not reported
Black sea bass (Centropristis striata)	Reef-associated	19.1	30
Bluefin tuna (Thunnus thynnus)	Pelagic	97	200
Bluefish (Pomatomus saltatrix)	Pelagic	30	60
Haddock (Melanogrammus aeglefinus)	Demersal/Benthic	35	35
Monkfish (Lophius americanus)	Demersal/Benthic	47	90
Ocean pout (Zoarces americanus)	Demersal	28.8	110 (max length)
Pollock (Pollachius virens)	Demersal/Benthic	39.1	60
Red hake (Urophycis chuss)	Demersal/Benthic	26	Not reported
Scup (Stenotomus chrysops)	Demersal/Benthic	16	25
Silver hake (Merluccius bilinearis)	Demersal/Benthic	23	37
Skipjack tuna (Katsuwonus pelamis)	Pelagic	40	80
Summer flounder (Paralichthys dentatus)	Demersal/Benthic	28	Not reported
White hake (Urophycis tenuis)	Demersal/Benthic	46	70
Windowpane flounder (Scophthalmus aquosus)	Demersal/Benthic	22	Not reported
Winter flounder (Pseudopleuronectes americanus)	Demersal/Benthic	27	Not reported

Species	Demersal or Pelagic?	Size (at maturity)*	Size (common length)*
Yellowfin tuna (Thunnus albacares)	Pelagic	103	150
Yellowtail flounder (Limanda ferruginea)	Demersal/Benthic	30	Not reported

* Information from fishbase.org (all sizes in centimeters)

The majority of scientific literature concerning the effects of magnetic field exposure on fish species has utilized static DC power sources; only a few studies have assessed the potential effects associated with AC magnetic fields, and many of those have examined low frequency sources (i.e., ~10 Hz). This is likely because naturally occurring EMF are static (like the geomagnetic field) or low frequency (like the fields produced by organisms swimming through the geomagnetic field). Thus, in order to evaluate the potential for population-level impacts from 60-Hz AC submarine cables, research related to 50/60-Hz EMF has been reviewed, and used to predict the general behavioral responses of magnetosensitive fish residing in the Project Area. Given that magnetosensitivity in finfish evolved in response to a common environmental signal—the geomagnetic field—these findings can be used to predict the responses of fish within the Project Area. Since most fish are expected to only be exposed to cable-associated EMF for a short period of time while swimming through the cable route, this review focuses on the behaviors and responses associated with transitory EMF exposure, and not potential physiological responses that may result from more chronic, long-term exposures.

Behavioral Responses to EMF from 50- and 60-Hz AC Sources

Overall, the available laboratory-generated research regarding the effects of 50- or 60-Hz EMF on fish behavior does not indicate that produced fields will affect fish orientation and behavior. A series of laboratory studies were conducted in 1970 to determine the effect of 60-75 Hz magnetic fields on magnetosensitive Atlantic salmon (*Salmo salar*) and American eel (*Anguilla rostrata*). When exposed to a 500-mG magnetic field, neither species demonstrated any significant change in swimming behaviors, leading the authors to conclude that EMF produced by 60-Hz AC cables is not likely to alter the behavior or activity of either species (Richardson et al., 1976). These findings were confirmed by more recent studies conducted by the Marine Scotland Science Agency (Armstrong et al., 2015; Orpwood et al., 2015). These studies evaluated the responses of European eel (*A. anguilla*) and Atlantic salmon to magnetic fields up to 960 mG, produced by a 50-Hz AC power source. Specifically, salmon were exposed to magnetic fields between 1.3 and 950 mG, resulting in no significant change in salmon swimming or behavior (Armstrong et al., 2015). European eel were similarly exposed to a 960 mG magnetic field, with no observed effects on eel swim behavior, orientation, or passage through the tank system (Orpwood et al., 2015). Overall, these controlled laboratory studies conducted with eel and salmon support the conclusion that EMF produced by 50- to 75-Hz AC cables do not alter the behavior of magnetosensitive fish species, indicating that high frequency EMF are not easily detected by magnetosensitive migratory fish species (Richardson et al., 1976; Armstrong et al., 2015; Orpwood et al., 2015).

Researchers at the U.S. Department of Energy's Oak Ridge Laboratory also conducted a series of studies with freshwater fish species, including largemouth bass (*Micropterus salmoides*), the redear sunfish (*Lepomis microlophus*), and the magnetosensitive and electrosensitive pallid sturgeon (*Scaphirhynchus albus*); individuals of these species were exposed to variable strengths of magnetic fields produced by an AC electromagnet. Overall, findings for these studies corroborate the lack of behavioral effects found in experiments with salmon and eel. For instance, redear sunfish were observed to rest in shelters nearest to a magnetic-field source at maximum strength (1,657,800 mG); however, once the field was discontinued, fish resumed a normal distribution and there were no observed long-term effects on exposed fish (Bevelhimer et al., 2013). Largemouth bass exposed to a 24,500 mG magnetic field from a 60-Hz AC power source exhibited no significant changes in fish behavior or swimming, leading the researchers to conclude their study did not support an effect of fish behaviors from EMF produced by transmission cables (Bevelhimer et al., 2015). Finally, researchers utilized a more complex mesocosm chamber to gauge if exposure to AC EMF had an effect on pallid sturgeon behavior. 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 sturgeon were unable to detect magnetic fields of these strengths (Bevelhimer et al., 2015).

In conclusion, the scientific literature regarding laboratory-assessed behavioral effects of AC EMF on fish indicates that 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 magnetic field is increased high enough for fish to detect (i.e., over 1,000,000 mG and orders of magnitude higher than levels produced by submarine cables), behavioral effects observed in fish are minor and reversible, suggesting even these are unlikely to result in population-level effects.

Field Studies of Finfish Distribution around Submarine Cables

In addition to controlled laboratory studies, a number of field surveys have been conducted at both submarine cable and offshore windfarm sites in order to assess the potential effects of AC EMF and wind energy generation on resident finfish population. While these types of studies do not offer the same level of refined behavioral observation that laboratory studies do, they allow for assessment of regional distributions and populations of key species, which are important metrics for understanding the likelihood of impacts from a harvestability standpoint.

Researchers at the Marine Science Institute at the University of California, Santa Barbara, and the BOEM conducted a series of surveys between 2010 and 2014 to track fish populations at both energized and unenergized 60-Hz submarine cables off the California coast. These studies were designed to assess whether EMF produced by the energized cable had any *in situ* effects on the distribution of marine species. Along the energized cable, magnetic fields were measured to be between 730 to 1,100 mG (Love et al., 2016). Over 3 years of observations, researchers identified more than 40 different fish species at field sites, including demersal halibut (*Paralichthys californicus*), sanddab (*Citharichthys sordidus*), and seaperch (*Sebastes* spp). No differences in fish communities at the energized and unenergized cable sites were noted, indicating that EMF had no effect on fish distributions, although the physical structure of the unburied cables did attract a higher number of fish versus sediment bottoms, creating a "reef effect" (Love et al., 2016). Thus, the study results demonstrate that magnetic fields produced by an AC cable do not alter fish distributions or behavior.

Additionally, multiple fish surveys have been conducted at existing offshore windfarm sites; data from those with AC transmission cables can be used to predict *in situ* effects on fish distribution. Overall, results from these studies strongly indicate that operating windfarms and cables have not changed the distributions of resident fish populations. Nearly 10 years of pre- and post-operational data from the Horns Rev Offshore Wind Farm site near Denmark indicate "no general significant changes in the abundance or distribution patterns of pelagic and demersal fish" (Leonhard et al., 2011), including species similar to those expected to inhabit the Project Area, such as various flatfish species. Researchers did note an increase in fish species associated with hard ground and vertical features, especially around turbine footings (Leonhard et al., 2011). 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. Assessment of data from these surveys led to the conclusion the submarine cables had "little to no effect … on local fish communities" (Dunlop et al., 2016).

At the Thorntonbank Wind Farm in Belgium, fish surveys demonstrated some short-lived changes in the abundance of certain fish and invertebrate species (Vandendriessche et al., 2015). These were temporary, however, indicating that these alterations were not related to the cables' magnetic fields, but may have been a result of lingering construction-phase effects (Vandendriessche et al., 2015). Conversely, at the Nysted Wind Farm in Denmark, researchers noted some "asymmetries in the catches" along the project cables (Vattenfall and Skov-og, 2006). These minor effects on distribution mostly failed to correlate with the energy loading of the cables, indicating that they also were unrelated to magnetic-field strength. The authors also noted that a lack of baseline data precluded a fuller assessment of possible effects, and that a change in physical conditions of the sediment over the cable route due to jet plowing could not be ruled out (Vattenfall and Skov-og, 2006).

Overall, these field surveys at either submarine AC cable sites or offshore wind farm sites demonstrated that 50/60-Hz magnetic fields do not significantly affect fish distributions. This is in agreement with the results of the laboratory studies indicating no significant effects of AC EMF on fish species.

Electrosensitivity of Sturgeon Species

Only a few fish species are capable of detecting electric fields in addition to magnetic fields, and the majority of these do not reside in the Project Area, although, the endangered Atlantic sturgeon, which inhabits the Project Area, is known to be electrosensitive. Hence, the detection thresholds of sturgeon for electric fields associated with 50/60-Hz power sources were assessed based on available information from the scientific literature. Basov (1999) tested the detection abilities and responses of two different sturgeon species—sterlet (*Acipenser ruthenus*) and

Russian sturgeon (*Acipenser gueldenstaedtii*)—using 50-Hz AC electric fields between 20 to 60 mV/m (Basov,1999). Exposure to the 20 mV/m electric fields caused minor changes to sturgeon orientation, as well as increased search and foraging behaviors near the power source. This study suggests that small behavioral changes may occur when sturgeon are in the vicinity of electric-field intensities of 20 mV/m at 50/60 Hz.

Evaluation of EMF Exposure from the Project Cables

The magnetic fields calculated based on projected cable configurations and burial depths proposed for the Project are presented in Table 7. At peak loading, magnetic-field levels were determined to be 58 mG at 3.3 feet (1 m) above the seabed directly over the RWEC. This value is approximately 8.6 times lower than the 500-mG magnetic field that was demonstrated to have no behavioral effects on either Atlantic salmon or American eel. Field strengths associated with significant changes in fish behavior are multiple orders of magnitude higher (i.e., 1,657,800 mG for redear sunfish) than those expected at the Project cables. These studies of multiple fish species indicate that the magnetic fields produced by the Project cables will be below the level of detection for marine finfish species.

In addition to magnetic-field levels, induced electric-field strengths, based on a model of an Atlantic sturgeon, were calculated (Table 7). The Atlantic sturgeon was selected as a model species due to its electrosensitivity and was modeled as an ellipsoid 6 feet (1.8 m) in length with a maximum girth of 2.5 feet (0.8 m).[19] The maximum value for buried cables (0.7 mV/m at peak loading) is projected to occur along the RWECs and RWEC Landfall Cables. This maximum calculated induced electric-field strength is more than 25 times lower than the 20 mV/m electric field reported as the threshold for behavioral changes in Russian sturgeon and sterlet (Basov et al., 1999). Modeled induced electric fields in seawater also are predicted to be below this reported detection threshold level (Table 2). As such, there is no indication that EMF from the Project cables would be detectable by resident magnetosensitive and electrosensitive finfish

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[19] 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).

species. Because of this, the operating cables therefore are not expected to affect the populations or distributions of finfish in the Project Area.

Table 7. Calculated maximum magnetic field and induced electric field (using sturgeon model) at 3.3 feet (1 m) above seabed for 3.3-foot (1 m) burial depth and <u>peak loading</u>

Cable Type	Magnetic Field (mG)	Induced Electric Field (mV/m) Seawater	Induced Electric Field (mV/m) Sturgeon Model
IAC	24	1.8	0.3
RWEC	58	3.2	0.7
RWEC Landfall Cable	55	4.0	0.7

Assessment of EMF Exposure to Elasmobranchs in the Project Area

In contrast to finfish, elasmobranchs are cartilaginous fish; the group includes skates, sharks, and rays. These species are common in coastal marine environments and exhibit both magnetosensitivity and electrosensitivity. Elasmobranchs' abilities to detect low frequency electric fields in the approximate 1 to 10-Hz ranges assists in the capture of prey, which produce low frequency electric fields (Bedore and Kajiura, 2013).

Elasmobranch Species Residing in the Project Area

At least 13 different shark, skate, and dogfish species are expected to inhabit various parts of the Project Area (Table 8). Some species, like the large pelagic sharks, have large ranges across a wide range of water depths, and therefore the Project Area is only a minor portion of their total habitat. On the other hand, smaller benthic elasmobranchs like skates and dogfish have small ranges, and together with their demersal habits, are more likely to have more frequent contact with the Project's cable routes.

Table 8. Elasmobranch species projected to inhabit the Project Area

Species	Demersal or Pelagic	Size (at first reproduction)*	Size (common length)*
Basking Shark (Cetorhinus maximus)	Pelagic	500	700
Blue shark (Prionace glauca)	Pelagic	206	335
Common Thresher Shark (Alopias vulpinus)	Pelagic	303	450
Dusky shark (Carcharhinus obscurus)	Pelagic	220	250
Little Skate (Leucoraja erinacea)	Demersal/ Benthic	32	
Sand tiger shark (Carcharias Taurus)	Pelagic	220	250
Sandbar Shark (Carcharhinus plumbeus)	Benthopelagic	126	200
Shortfin Mako Shark (Isurus oxyrinchus)	Pelagic	278	270
Smooth Dogfish (Mustelus canis)	Demersal/ Benthic	102	100

Species	Demersal or Pelagic	Size (at first reproduction)*	Size (common length)*
Spiny Dogfish (Squalus acanthias)	Demersal/ Benthic	81	100
Tiger Shark (Galeocerdo cuvieri)	Pelagic/ Benthopelagic	210	500
White Shark (Carcharodon carcharias)	Pelagic	450	Not reported
Winter Skate (Leucoraja ocellata)	Demersal/ Benthic	73	Not reported

* Information from fishbase.org (all sizes in centimeters)

Magnetosensitivity and Electrosensitivity of Elasmobranchs

Laboratory studies assessing the EMF detection abilities of elasmobranch species have largely evaluated low frequency EMF (~10 Hz or less). Given that elasmobranch prey items produce bioelectric fields within this range, this focus is not surprising. Available research, however, also indicates that the EMF detection ability of elasmobranchs decreases as the frequency increases of the field approaches 20 Hz. For example, as researchers increased the EMF source frequency from 1 Hz to 10 Hz, they noted that this resulted in a 100-fold decrease in the detection threshold of skates (i.e., a recorded increase of 0.01 mV/m to 1 mV/m) (Andrianov et al., 1984). Additionally, bamboo shark embryos showed the strongest responses when exposed to electric fields produced at less than 20 Hz, with peak response behavior to frequencies of 0.1 to 2 Hz, then decreasing with increasing frequencies up to 20 Hz, at which point no responses were observed (Kempster et al., 2013). As such, responses of resident elasmobranchs to electric fields produced by higher frequency (50/60 Hz) sources like the Project cables cannot be interpreted from research with lower frequency electric fields. These studies, however, do suggest that elasmobranchs are unlikely to easily detect electric fields produced by 50/60-Hz power sources.

In fact, the behavioral response of a small demersal catshark (*Cephaloscyllium isabellum*) to magnetic fields up to 14,300 mG produced by a 50-Hz source was evaluated within a laboratory setting (Orr, 2016). Sharks were exposed for 72 hours, during which they did not exhibit any significant behavioral changes; introduction of an olfactory stimulus resulted in normal foraging behaviors, indicating that the 50-Hz EMF did not interfere with the normal behavioral response to this stimulus (Orr, 2016). As such, installation of AC submarine cables in coastal waters is unlikely to cause changes in shark behavior or distribution, according to the study author (Orr, 2016). Moreover, this study confirms previous studies that found that elasmobranchs detect low frequency EMF, but that EMF produced by 50/60-Hz power sources were unlikely to be detected. More recently, researchers exposed juvenile thornback rays (*Raja clavata*) to a 4,500 mG 50-Hz magnetic field to assess potential behavioral effects; exposure was determined to have no significant effect on ray vertical activity, horizontal activity, or propensity to remain immobile (Albert et al., 2022). Overall, these studies demonstrate that 50/60-Hz EMF are unlikely to be detected by elasmobranchs and thus will not result in behavioral changes.

Field Studies of Elasmobranch Distribution around Submarine Cables

Unlike finfish, there have been relatively few field studies the have been specifically designed to assess the potential effects of 50/60-Hz submarine AC power cables on elasmobranch populations and distributions. This could be a result of lower densities and broad ranges of these species versus finfish species, or due to a lesser commercial importance. Love et al. (2016), however, did evaluate elasmobranchs during their multi-year survey at unburied AC submarine cable sites off the coast of California. Based on their research, they concluded that there was no evidence that "energized power cables in this study were either attracting or repelling these fishes [Elasmobranchs]" and that, most likely, "energized cables are either unimportant to these organisms [Elasmobranchs] or that at least other environmental factors take precedence" (Love et al., 2016). These authors also noted that the study area contained a high diversity of elasmobranchs, and thus constituted a rich study opportunity.

Evaluation of EMF Exposure from Project Cables

When exposed to 14 mG, 50-Hz magnetic fields under laboratory conditions, elasmobranchs did not demonstrate altered behaviors, suggesting that this level is not detectable by the sharks (Orr, 2015). Although the maximum field levels calculated at 3.3 feet (1 m) from the buried IACs, RWECs, and RWEC Landfall Cables (24, 58, and 55 mG, respectively, at peak loading) are above this laboratory-tested level, it should be noted that a detectable magnetic field is likely to be much higher than the maximum tested non-detectable magnetic field of 14 mG, especially considering that magnetic fields up to 1,100 mG had no observable impact on elasmobranchs in an ocean environment (Love et al., 2016). Altogether, this research indicates that the magnetic fields associated with the buried Project cables likely would not be detectable by resident elasmobranchs.

Induced electric fields were calculated using a dogfish model; this was generated as an ellipsoid with a length of 3.3 feet (1 m) and a maximum girth of 1.25 feet (0.4 m) (Table 9). Although the scientific literature suggests that elasmobranchs are capable of detecting a 1 mV/m electric field produced by a 10-Hz power source (Andrianov et al., 1984), detection abilities of elasmobranchs were also shown to rapidly decline as the frequency of the source increases. In fact, Kempster et al. (2013) reported that elasmobranchs did not detect electric fields produced at frequencies above 20 Hz. As such, it is not expected that resident elasmobranchs in the Project Area are capable of detecting induced electric fields from the 60-Hz cables, which are far less than 1 mV/m at 3.3 feet (1 m) from the seabed using a dogfish model.

Table 9. Calculated maximum magnetic field and induced electric field (using dogfish model) at 3.3 feet (1 m) above seabed for 3.3-foot (1 m) burial depth and <u>peak loading</u>

		Induced Electric Field (mV/m)	
Cable Type	**Magnetic Field (mG)**	**Seawater**	**Dogfish Model**
IAC	24	1.8	0.2
RWEC	58	3.2	0.4
RWEC Landfall Cable	55	4.0	0.4

Assessment of EMF Exposure to Hardground-Associated Species from the OSSs and WTGs

The presence of vertical and hardground structures, such as offshore platforms, footings, and concrete mattresses, creates new habitat for aquatic life that may attract structure-associated species like reef fish. Artificial structures frequently have been observed to provide habitat for reef and hardground-associated species (Quigel and Thornton, 1989; Petersen and Malm, 2006). This attraction occurs independently of cable-associated EMF.

While the addition of vertical turbine footings can be considered an ancillary ecological benefit of offshore wind development, the exposure of reef-associated species to EMF in the vicinity of the turbine footings is expected to be different than that of species migrating across the transmission cable route. Additionally, for certain areas of the cable route, cable burial is impracticable. At these points, concrete mattresses or other protective coverings will be installed as a shield for the cable; these are expected to provide hardground habitat for marine species.

Description of Reef Communities in the Project Area

Within the Project Area, reef-associated fish include species of commercial and recreational importance like scup, black sea bass, and tautog. At least two species of reef-associated sharks—dusky sharks (*Carcharhinus obscurus*) and sand tiger sharks (*C. taurus*)—are expected to occur in the Project Area. In addition, large crustaceans, like American lobster, utilize crevices in rocky hardground areas as shelter from predators. Because these species are attracted to natural and artificial structures, it is likely that some individuals will inhabit Project platforms and turbine footings. During time spent there, these individuals might be exposed to EMF generated by operational cables. The exposure experienced by reef-associated species at platforms and turbines is expected to be longer than that of individuals that encounter cable routes as part of routine migration or swim patterns.

Studies of Long-Term Exposure to AC EMF on Fish

Based on information presented above, finfish and elasmobranchs are not expected to be sensitive to 60-Hz AC magnetic fields between 500 and 1000 mG. Further, elasmobranch detection of electric fields produced by a 60-Hz AC source is below 1 mV/m. In addition, research has been conducted to determine the potential for physiological effects following longer-term exposure to AC magnetic fields. This includes a series of studies conducted to assess if exposure to AC magnetic fields alters the development of sensitive early fish life stages. Additional research has centered on the examination of physical effects resulting from chronic EMF exposure in adult fish as described below.

The bulk of the evidence from these laboratory studies indicates that developmental endpoints are largely unaffected by exposure to AC EMF. Although exposure to a 1,000 mG magnetic field produced by a 60-Hz power source slowed medaka (*Oryzias latipes*) embryonic development, no significant effects on hatching rate, physical abnormalities, or survival were observed (Cameron et al., 1985). Authors noted that the observed delay in embryonic development was equivalent to 18 hours, and as such is unlikely to result in long-term population-level effects. Zebrafish (*Danio rerio*) embryos exposed to a 10,000 mG magnetic field produced by a 50-Hz power source also experienced some similar developmental delays (Skauli et al., 2000). Rainbow trout (*Oncorhynchus mykiss*) embryos exposed to electric fields between 5 to 5,000 mV/m, however, exhibited no developmental effects (Brouard et al., 1996). Even after a 2-month exposure to these field levels, no changes in the survival or growth of exposed trout fry and fingerling were observed (Brouard et al., 1996). A recent study by Fey et al. (2019) indicated that a 36-day exposure to 50-Hz EMF at a level of 1 mT (10,000 mG) had no significant effects on larval mortality, hatching time, and larval growth, but did increase the rate of yolk sac absorption, which the authors hypothesized could affect future growth rates. Results from these studies are important for two reasons. First, the early life stages of fish are generally considered more sensitive to stressors than adult fish; because of this, results from early life stage studies represent a conservative assessment of cable-associated EMF on fish development and growth. Second, because fish eggs and larvae are largely passively distributed throughout the water column and undergo naturally high mortality, chronic exposures of embryos to EMF would affect only a tiny portion of the population, and thus would not result in a population-level effect.

In terms of potential effects of AC EMF on adult fish, the studies conducted to determine the chronic effects of AC EMF exposures on juvenile and adult fish largely demonstrate that effects are minor or only occur at levels not projected to occur under field conditions. Samiee and Samiee (2017) exposed young carp (*Cyprinus carpio*) to 50-Hz magnetic fields between 1,000 and 70,000 mG and examined resulting brain histopathology. Only exposures greater than 30,000 mG were observed to result in a significant increase in brain lesions and other histopathological changes. The authors did not determine the exact mechanism of this effect. Similarly, Stankevičiūtė et al. (2019) found that early life stage rainbow trout and Baltic clams (*Limecola balthica*) exposed to 1 mT (10,000 mG) EMF from a 50-Hz source for 40 and 12 days, respectively, exhibited evidence of genotoxic and cytotoxic responses. Survival rates for both species, however, were unaffected by exposure (Stankevičiūtė et al., 2019).

Nofuzi et al. (2015) periodically exposed rainbow trout to magnetic fields between 1 and 500 mG produced by a 15-Hz AC source over 60 days. This type of exposure may mimic expected field exposures where fish may move in and out of produced EMF. Exposed trout demonstrated improved condition; 1-hour exposures daily for 3 months resulted in greater growth rates and increased immune system activity in fish (Nofouzi et al., 2015). Improved immune responses in fish also were reported by Cuppen et al. (2007); exposures between 1.5 to 500 mG from a 200- to 5,000-Hz source resulted in an increased survival of diseased goldfish. Conversely, juvenile tilapia (*Oreochromis niloticus*) exposed for 1 month to magnetic fields between 300 mG to 2,000 mG produced by a 50-Hz source demonstrated reduced growth and lowered digestive enzyme activity. There was no notable trend of increased growth, however, with increased magnetic-field strength, and authors reported that recovery of digestive function improved following removal of fish from magnetic fields (Li et al., 2015).

Evaluation of EMF Levels at Mattress-Covered Project Cables

The maximum magnetic-field levels calculated at 3.3 feet (1 m) above the unburied areas along the cable route were 50 mG and 131 mG for the IACs and RWECs, respectively, at peak loading. Based on information from the available scientific literature, these values are below magnetic-field levels expected to cause physiological effects (i.e., from approximately 500 mG to greater than 10,000 mG). Chronic exposures to low-level magnetic fields produced by 50- and 60-Hz AC power sources did not impact growth or produce health effects in exposed fish. Hence, it can be reasonably concluded that those marine fish species inhabiting these areas along the cable route will not be harmed by magnetic fields.

Evaluation of EMF Exposure from OSSs and WTGs

Based on modeling results, the volume-average magnetic field within the skirt region below the j-tubes is expected to be approximately 245 mG or less. This represents the maximum realistic exposure of mobile hardground species identified as likely to inhabit the Project Area.

Chronic exposures to 1,000 to 10,000 mG magnetic fields were associated with small changes in developmental rates of embryonic fish. Chronic exposures to fish embryos, however, are not projected to occur in the Project Area, as fish embryos are passively dispersed through the water column. This passive distribution means that exposure time at the OSS and WTG areas will be very short. When compared to the observed sensitivity of embryonic fish, juvenile and adult fish physiologies appear to be less sensitive to magnetic fields produced by 50-Hz and 60-Hz power sources. Lesions occurred after exposure to field levels over four times higher than the maximum calculated 245 mG field at the OSSs and turbine footings.

In conclusion, the magnetic-field levels expected to occur within the OSS and WTG areas are significantly lower than those observed to cause developmental delays in sensitive embryonic life stages or effects in adult fish and bivalves.

Conclusions

The calculated magnetic-field levels generated by the Project's cables are well below limits established by ICES and ICNIRP to protect the health and safety of the general public. Moreover, these calculated magnetic-field and induced electric-field levels for Project cables are not expected to affect populations of marine organisms residing in the area.

Many marine species, including certain fish, invertebrates, and elasmobranchs, can detect and respond to the static geomagnetic field and in a few cases, low-frequency electric fields (~0 to 10 Hz). EMF generated by 50/60-Hz AC cables, however, are not readily perceived as are DC fields in the natural environment. Hence, this assessment reviewed data and information generated from laboratory and field experiments with 50/60-Hz fields, since studies of static magnetic fields cannot be used to predict the likelihood of effects from exposure to submarine cables.

As part of the evaluation process, Exponent conducted modeling of the magnetic-field levels and induced electric-field levels associated with the Project cables. Results from these calculations indicate that the magnetic field at 3.3 feet (1 m) above the seabed will be 58 mG or lower for the IACs, RWECs, and RWEC Landfall Cables for a 3.3-foot burial depth and peak loading. These maximum calculated field levels were then compared to magnetic-field levels reported in the scientific literature as causing behavioral responses in species groups expected to inhabit the Project Area, including fish, elasmobranchs, and marine invertebrates. This conservative evaluation resulted in the following conclusions, which are consistent with those of a 2019 BOEM report (Snyder et al., 2019):

- Data from field surveys conducted at 60-Hz AC submarine cable sites demonstrate that the behaviors and distributions of large crustaceans are unaffected by these magnetic fields.
- Observations of cephalopod distributions at the same 60-Hz AC cable sites also indicated that these species are not affected by the presence of AC EMF.
- Magnetic-field levels calculated for all cables are below thresholds at which laboratory and field studies reported behavioral changes in magnetosensitive fish species.

- Elasmobranchs are not expected to detect the magnetic fields generated by the 60-Hz AC submarine cables.
- Calculated electric fields associated with Project cables are below the published detection thresholds of electrosensitive fish and elasmobranchs.
- For those areas expected to attract certain marine species (OSS and WTG structures and mattress-covered cables areas), calculated magnetic-field levels are below levels reported to cause physiological effects following chronic exposures.

In conclusion, conservative calculations of magnetic-field and induced electric-field levels based on the Project's cable specifications and peak and average load levels indicate that EMF produced by the proposed Project cables will be below the detection thresholds for magnetosensitive and electrosensitive marine organisms. Because of this, marine species' behaviors and populations are not expected to be impacted by operating the RWECs and IACs. This conclusion is supported by years of biological surveys conducted at existing windfarm sites that also indicate no long-term or large-scale changes to populations of marine organisms residing at these sites.[20] Moreover, these findings are also corroborated by reviews of the ecological effects of Marine Renewable Energy projects; the authors reported 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" and that "EMFs associated with subsea cables are not harmful and do not pose a risk to biota . . . because their EMF signatures are low." (Copping et al., 2016; 2020). Furthermore, a 2019 BOEM report that assessed the potential for AC EMF from offshore wind facilities to affect marine populations concluded that for the southern New England area, no negative effects are expected for populations of key commercial and recreational fish species (Snyder et al., 2019). As such, the conclusions of this evaluation for the Project cables agree with the general scientific and regulatory understanding of AC EMF and responses of marine species.

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

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Attachment A

Cable Configurations and Burial Depths

Magnetic-field and induced electric-field levels for the Project were calculated for five configurations as summarized in Table A-1. The IACs and RWECs[21] were each modeled at two burial depths while the RWEC Landfall Cables were modeled at one burial depth. All three cable types are three-core cables, with all three phase conductors contained within a single large cable. Cross-sectional drawings indicating the various components and dimensions of the RWECs and IACs are shown in Figure A-1.[22]

The target burial depth of all cables is 3.3 to 6.6 feet (1 to 2 m) beneath the seabed and was conservatively modeled at the 3.3-foot (1 m) burial depth closer to the seabed. Where it is impracticable to bury the cables (such as cable or pipeline crossings or where bedrock is encountered), the cable will lie upon the surface of the seabed for short areas. In these cases, the cables may self-bury in fine sediments to some extent; however, it is anticipated that these portions of the cable where burial depth is not achieved will be covered with protective concrete mattresses or rock berms. For the purposes of this study, a minimum thickness of 1 foot (0.3 m) was assumed for modeling. The potential ability of these mattresses or other covering to attenuate magnetic-field levels was not considered; their primary effect to calculations was in effectively changing the cable burial depth to 1 foot (0.3 m).

At landfall, the RWEC Landfall Cable will be used and installed via HDD. The burial depth over most of this portion of the route is expected to be significantly greater than in other portions of the route, with most of the HDD at least 15 feet (4.6 m) beneath the seabed and beach, and at a maximum of more than 100 feet (30 m). The magnetic-field level from the cable at ground level will be much lower over this portion of the cable due to the greater burial depth. Nevertheless the RWEC Landfall Cable was modeled at a burial depth of 3.3 ft (1 m) as a conservative approach to account for potentially small areas where the cable enters the seabed in HDD conduit or connects to the TJB where burial depth may not be as deep as the rest of the HDD.

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[21] OSS-Link Cables also may be installed in the OSS-Link Cable Corridor approximately 9 mi (14.5 km) if two offshore substations are constructed. The OSS-Link Cables are proposed to be the same as the RWECs and so are not discussed separately.

[22] The RWEC Landfall Cable is similar to the RWEC, but slightly larger.

Table A-1. Summary of offshore modeling configurations

Configuration	1a	1b	2	3a	3b
Description	RWEC & OSS-Link Cable		RWEC Landfall Cable	IAC	
Voltage	275 kV		275 kV	66 kV*	
Average Loading	690 A		690 A	480 A	
Peak Loading	985 A		985 A	685 A	
Ampacity Rating	1010 A		1010 A	700 A	
Cable Cross Section	1200 mm^2		1400 mm^2	630 mm^2	
Cable Type, Nominal Outer Diameter (OD)	3-core XLPE, 10.1-inch OD (256 millimeter [mm])		3-core XLPE, 10.4-inch OD (265 mm)	3-core XLPE, 6.1-inch OD (155 mm)	
Distance Between Conductor Centers within Cable	4.3-inches (110 mm)		4.5-inches (113.3 mm)	2.5-inches (63 mm)	
Minimum Horizontal Distance between Cables[†]	160 feet (50 m)		16 feet (5 m)	9.2 feet (2.8 m)	
Installation Type	Buried	Surface-Laid‡	Buried	Buried	Surface-Laid‡
Minimum Target Burial Depth to Top of Cable	3.3 feet (1 m)	1 foot (0.3 m)	3.3 feet (1 m)	3.3 feet (1 m)	1 foot (0.3 m)
Evaluation Heights	At seabed and 3.3 feet (1 m) above seabed§				

* For the same total power, cable current-levels would be expected to be lower for higher voltage cables (e.g., 72 kV). Magnetic- and induced electric-field levels would also be expected to be lower.

† RWEC Landfall Cables and IACs are conservatively modeled at locations where the distance between two respective cables is at a minimum. Over the majority of the route, the distance between these cables is much greater.

‡ Surface-laid cables will be covered with a rock berm or a concrete mattress that is 1-foot (0.3-m) thick.

§ 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 feet (1 m) above the protective cover.

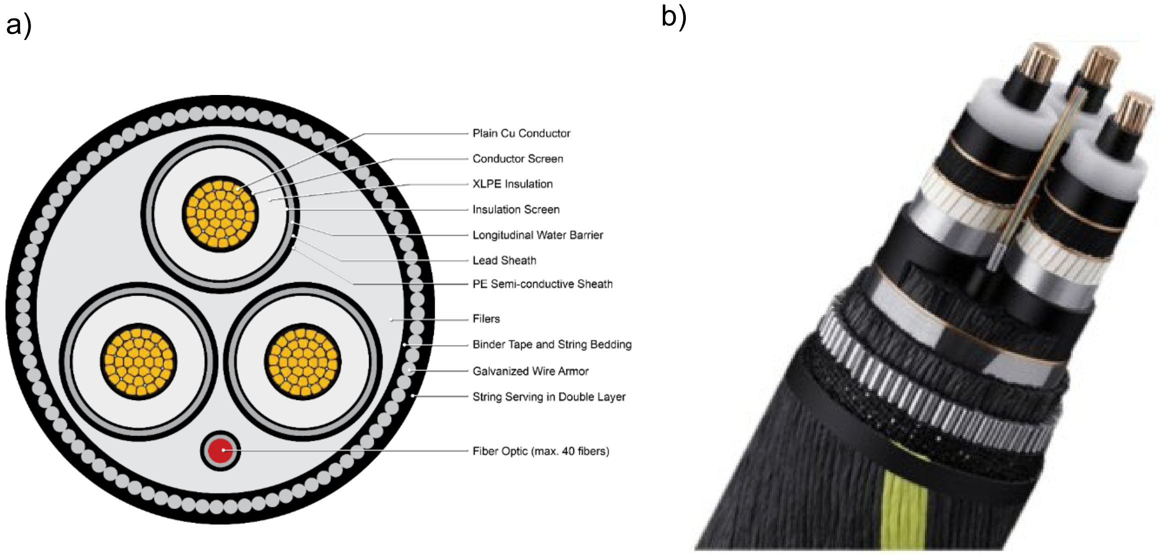

Figure A-1. a) Illustrative cross-section of an example three-core submarine cable, b) photograph showing the various layers of a submarine cable

Attachment B

Calculation Methods and Assumptions

VHB and Revolution Wind provided data to Exponent regarding the preliminary cable design, as well as the loading for each proposed cable configuration. These input data were discussed in Attachment A, Table A-1, and related text. From these data, Exponent developed models of the five offshore configurations of the cables for computation of the magnetic and induced electric fields.

Magnetic Fields and Induced Electric Fields in Seawater

Magnetic-field calculations were performed using data including current, burial depth, and conductor configurations. As noted in the body of this report, the electric field associated with voltage applied to the conductors within the cables are entirely shielded by 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.

Magnetic- and induced electric-field levels in seawater were calculated with finite element analysis simulations in COMSOL Multiphysics 5.4 using assumptions on conductivity, relative permittivity, and relative permeability, as noted in Table B-1. Calculations were performed at the seabed surface and at a height of 3.3 feet (1 m) above the seabed in accordance with IEEE Std. 0644-2019 and IEEE Std. C95.3.1-2010 (IEEE, 2010, 2019). Certain simplifying assumptions were made to perform calculations: 1) the conductors of each cable were parallel to one another and infinite in extent; 2) there was no attenuation of magnetic fields from any surrounding material such as the seabed, the earth, grout, mattresses, rock berms, or other materials; and 3) the reduction in the magnetic field outside the cable by the cable armoring (ferromagnetic shielding and induced eddy currents) was not included. These modeling assumptions were made to ensure that the calculated field levels would overestimate the actual field level at any specified loading and burial depth. In addition, the modeling assumes that there were no unbalanced currents flowing along the outer sheaths of the cables.

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

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

Ferromagnetic shielding (i.e., flux shunting) created by the cable armoring, as well as eddy currents induced, will attenuate (i.e., reduce) the field levels outside the cable. The specific design of the cable and its magnetic permeability will determine the magnitude of the attenuation (i.e., higher permeability will attenuate the magnetic field by shunting). In addition, eddy currents induced in conductive sheathing materials will create a magnetic field that partially cancels the magnetic field from the conductors within the cable thereby reducing field levels. A study by Silva (2006) has shown that flux shunting accounts for an almost 2-fold reduction in the magnetic field, with a much smaller reduction attributable to eddy currents. Additionally, the three conductors of the offshore three-core cables are helically twisted inside the cable during manufacturing, which further increases the mutual cancellation of the magnetic fields from each of the three conductors, and thus field levels decrease more rapidly with distance (Pettersson and Schönborg, 1997). Finally, a recent study performed post-construction measurements over similar AC three-core XLPE submarine cables, which found 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).[23]

Electric Fields Induced in Marine Organisms

The oscillating magnetic fields from the submarine cables in the seawater above the cables will induce a weak electric field within the body of marine organisms, which may be detectable by certain electrosensitive marine organisms. As such, the magnitude of the electric field induced in marine organisms swimming over the offshore cable segments can be calculated by modeling representative species as homogeneous ellipsoids. In general, while a larger electric field will be

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

induced in a larger animal, the specific detection thresholds for electrosensitive species are also important in determining the likelihood that a specific species will be capable of detecting and responding to the 60-Hz cable.

Assessment Approach

Exponent used two separate assessment approaches for evaluating the different Project elements with respect to EMF.

Buried Cables: Generally, the IACs, the RWECs, and the RWEC Landfall Cables will be buried. After construction, the interaction of interest will be detection of EMF by marine species in the offshore environment; there is concern that detection of EMF might affect migration, location preferences, or social behavior. If EMF can be detected by some species, the follow-on question is whether this EMF detection can affect or alter the behavior of these species resulting in potential deleterious population-level effects.

For this reason, the magnetic-field and induced electric-field levels associated with the submarine cables are assessed by calculating them along a transect perpendicular to the cables at a height of 3.3 feet (1 m) above the seabed as relevant reference locations for species on the seabed and most mobile marine species above.[24] The calculated field levels are then compared to the detection thresholds of various marine species expected to be in the Project Area (e.g., sharks, fish including key groundfish species, and larger crustaceans such as crabs and lobsters) to assess the likelihood of detection that could lead to alterations of animal behavior.

Protective Mattresses: In contrast to the buried cables, the small portion of the cables to be covered with protective mattresses are expected to generate a reef effect, which has been observed at other established wind farm sites (Petersen and Malm, 2006).

Since the physical structure of the protective mattresses covering small portions of the cables is likely to attract certain species to these new habitat features, regardless of the presence of EMF, the question of detection important for the assessment of the buried cables is not as important

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[24] 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.

for the surface-laid cables with protective covering. Rather, since the new habitat will encourage certain marine species to spend a greater fraction of time relatively close to the sources of EMF, the question of assessment becomes whether long-term exposure to EMF, which is more likely to occur near these structures, is likely to have biological effects on those species.

To answer this question, magnetic-field and induced electric-field levels at surface-laid portions with protective covering are assessed by calculating field levels along a transect perpendicular to the cables at the seabed (or top of the protective covering) as a conservative reference location. These field levels were compared to those reported in the scientific literature where physiologic responses were measured over longer periods than are typically used for acute behavioral studies.

WTGs and OSSs

All calculations for the WTGs and OSSs were performed using finite element analysis (FEA) in COMSOL Multiphysics (software version 5.5), with the same methods applied to the modeling of the IACs, RWECs, and RWEC Landfall Cables. In contrast to the relatively simple modeling geometry, however, the models of the WTGs and particularly the OSS are substantially more complex. As shown in Figure 2 in the body of the report, the separation of the cables away from the OSS monopile and their radial divergence requires a significantly larger modeling domain. The calculation physics and approach used in COMSOL, however, is the same as for the IACs, RWECs, and RWEC Landfall Cables, and also solves the time-harmonic Maxwell-Ampere's law for the magnetic fields generated by modeled cables. The same conservative assumptions (neglecting shielding effects) used for the modeling of individual cables were also used for the individual cables in the WTG and OSS models. In addition, the j-tubes that contain the individual cables, and run vertically down the WTG and OSS foundations, are made of black steel. Black steel has high magnetic permeability and therefore will reduce magnetic-field and induced electric-field levels substantially compared to those calculated here.

Other Modeling Considerations

Cable Effects

As discussed above, the modeling approach is designed to produce conservative results for the maximum magnetic-field and induced electric-field levels. The models do not account for the attenuation of magnetic fields from conductor sheaths and outer steel armoring of the cables, nor do they include the significant shielding likely to occur due to the black steel j-tubes at the WTG or OSS foundations and their placement within these WTG structures.

A previous study shows that flux shunting accounted for an almost 2-fold reduction in the magnetic field, with a much smaller reduction attributable to eddy currents (Silva et al., 2006). In addition, a recent study, submitted to the U.S. Department of Interior, BOEM, performed post-construction measurements over similar AC three-core XLPE submarine cables. One finding from that report was 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).[25] The modeling method applied here is more sophisticated than the method used in previous modeling of offshore submarine cables (Hutchison et al., 2018), because it accounts for the helical twisting of the conductors, which results in lower calculated magnetic-field levels.

Unbalanced Currents and Ground Currents

Another factor not accounted for in these models is the magnetic field resulting from unbalanced currents flowing along the sheaths or armoring of the cables. These currents can occur due to unequal current flows among the three phases of an AC transmission line or can also occur when the ground at one end of the cable is at a different electric potential than the other end of the cable. In this case, ground currents can flow along armoring or sheaths. While the degree of imbalance of the currents flowing on each of the phase conductors can be controlled to some extent by system design and operation, ground currents may be completely unrelated to the generation or transmission of electricity by the Project and therefore are more difficult to control or predict. The combination of unbalanced phase currents and grounding-

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[25] As noted above, while the Hutchison et al. (2018) report focused on DC submarine transmission lines, a portion of the report also reported measurements around an AC transmission cable, which is referenced here.

related currents can be thought of as a single-phase effective net current flowing straight along the cable. Hutchison et al. (2018) reported measurement data for an AC submarine cable that indicate the highest measured AC field (near to the cable itself) is produced by the phase currents, but at some distance away, unbalanced AC currents on the cable can have a much weaker but noticeable contribution to the AC magnetic field.

Attachment C

Calculated Magnetic and Electric Field Levels for Modeled Cable Configurations

Calculated magnetic- and electric-field levels in seawater are provided below for each of the five cable configurations summarized in Attachment A, Table A-1. Figures are shown for each of the three primary configurations at a 3.3-foot (1 m) burial depth and average loading, and summary tables are shown for all modeled configurations for both average and peak loading. In the tables and figures below, field levels are presented as a function of horizontal distance from the circuit centerline.

Calculated magnetic-field levels in seawater are summarized in Table C-1 and Table C-2 for all modeled cable configurations for transects at the seabed and at a height of 3.3 feet (1 m) above the seabed, and for average and peak loading.

Calculated electric-field levels induced in seawater are summarized in Table C-3 and Table C-4 for all modeled cable configurations for transects at the seabed and at a height of 3.3 feet (1 m) above the seabed for both average and peak loading.

The calculated electric-field levels induced in representative marine species are summarized in Table C-5 and Table C-6.

In each table, calculated field levels are summarized for the IACs, RWECs, and RWEC Landfall Cables, at the seabed and at 3.3 feet (1 m) above the seabed. Where covered by protective concrete mattresses or rock berms, field levels are reported at the top of the protective cover and at 3.3 feet (1 m) above the protective cover.

As shown in Attachment A, Table A-1 the IACs, RWECs, and RWEC Landfall Cables are modeled at locations where the distance between any two respective cables is at a minimum. The distance between the two RWECs (164 feet [50 m]) is great enough that only one RWEC was modeled to characterize field levels. In contrast, the minimum modeled distance between the two RWEC Landfall Cables (16 feet [4.9 m]) and any two IACs (9.2 feet [2.8 m]) is small enough that both cables were included in the model to capture additive effects. In Tables C-1 through C-4, field levels for the RWEC are reported at a horizontal distance of ±10 feet (± 3 m) and ±30 feet (±9 m) from the cable. For the RWEC Landfall Cables and IACs, field levels are reported at a horizontal distance of ±10 feet (± 3 m) and ±30 feet (±9 m) from the *centerline of the two modeled cables* (as shown in the main body of the report in Figure 4 and Figure 5).

Results are summarized in this way for consistency of presentation. While it appears that field levels from the RWEC Landfall Cables and IACs decrease more slowly with distance than the RWEC, in fact, field levels decrease at a similar rate. It is only the presence of a second cable in relatively close proximity that causes that appearance that field levels decrease more slowly with distance.

Calculated field levels are plotted as a function of horizontal distance from the circuit centerline in Figure C-1 through C-3 (magnetic-field levels) and Figure C-4 to C-6 (induced electric-field levels) for each of the three representative cable configurations. All figures present results for calculations of cables installed at a 3.3-foot (1 m) burial depth and average loading. Results for this installation type are expected to be representative of those encountered along most of the proposed cable route under typical loading.

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

Cable	Installation Type	Location	Horizontal Distance from Cable*		
			Max	±10 feet	±30 feet
IAC	Buried (3.3 feet)	Seabed	57	21	1.8
		3.3 feet Above Seabed	17	12	1.7
	Surface-Laid (1 foot)	Top of Protective Cover	522	28	1.8
		3.3 feet Above Protective Cover	35	18	1.8
RWEC	Buried (3.3 feet)	Seabed	147	17	2.2
		3.3 feet Above Seabed	41	13	2.1
	Surface-Laid (1 foot)	Top of Protective Cover	1071	19	2.2
		3.3 feet Above Protective Cover	91	16	2.2
RWEC Landfall Cable	Buried (3.3 feet)	Seabed	144	120	5.6
		3.3 feet Above Seabed	39	38	5.2

* Two cables are modeled for each cable type. The distance between the two RWECs is >150 feet, while the distance between any two IACs and between the two RWEC Landfall Cables is <20 feet. Horizontal distance is measured from the center of the RWECs or from the centerline of the two modeled IACs and RWEC Landfall Cables.

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

Cable	Installation Type	Location	Horizontal Distance from Cable*		
			Max	±10 feet	±30 feet
IAC	Buried (3.3 feet)	Seabed	82	30	2.6
		3.3 feet Above Seabed	24	17	2.5
	Surface-Laid (1 foot)	Top of Protective Cover	745	40	2.6
		3.3 feet Above Protective Cover	50	26	2.6
RWEC	Buried (3.3 feet)	Seabed	210	25	3.1
		3.3 feet Above Seabed	58	19	3.0
	Surface-Laid (1 foot)	Top of Protective Cover	1529	28	3.1
		3.3 feet Above Protective Cover	130	23	3.1
RWEC Landfall Cable	Buried (3.3 feet)	Seabed	206	171	7.9
		3.3 feet Above Seabed	55	54	7.5

* Two cables are modeled for each cable type. The distance between the two RWECs is >150 feet, while the distance between any two IACs and between the two RWEC Landfall Cables is <20 feet. Horizontal distance is measured from the center of the RWECs or from the centerline of the two modeled IACs and RWEC Landfall Cables.

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

Cable	Installation Type	Location	Horizontal Distance from Cable* Max	±10 feet	±30 feet
IAC	Buried (3.3 feet)	Seabed	2.1	1.4	0.4
		3.3 feet Above Seabed	1.3	1.1	0.4
	Surface-Laid (1 foot)	Top of Protective Cover	5.4	1.6	0.4
		3.3 feet Above Protective Cover	1.7	1.3	0.4
RWEC	Buried (3.3 feet)	Seabed	4.4	1.5	0.5
		3.3 feet Above Seabed	2.3	1.3	0.5
	Surface-Laid (1 foot)	Top of Protective Cover	13	1.6	0.6
		3.3 feet Above Protective Cover	3.5	1.5	0.5
RWEC Landfall Cable	Buried (3.3 feet)	Seabed	4.8	4.5	1.2
		3.3 feet Above Seabed	2.8	2.8	1.1

* Two cables are modeled for each cable type. The distance between the two RWECs is >150 feet, while the distance between any two IACs and between the two RWEC Landfall Cables is <20 feet. Horizontal distance is measured from the center of the RWECs or from the centerline of the two modeled IACs and RWEC Landfall Cables.

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

Cable	Installation Type	Location	Horizontal Distance from Cable* Max	±10 feet	±30 feet
IAC	Buried (3.3 feet)	Seabed	3.0	1.9	0.6
		3.3 feet Above Seabed	1.8	1.5	0.6
	Surface-Laid (1 foot)	Top of Protective Cover	7.7	2.2	0.6
		3.3 feet Above Protective Cover	2.5	1.8	0.6
RWEC	Buried (3.3 feet)	Seabed	6.3	2.2	0.8
		3.3 feet Above Seabed	3.2	1.9	0.8
	Surface-Laid (1 foot)	Top of Protective Cover	18	2.3	0.8
		3.3 feet Above Protective Cover	4.9	2.1	0.8
RWEC Landfall Cable	Buried (3.3 feet)	Seabed	6.8	6.4	1.7
		3.3 feet Above Seabed	4.0	3.9	1.6

* Two cables are modeled for each cable type. The distance between the two RWECs is >150 feet, while the distance between any two IACs and between the two RWEC Landfall Cables is <20 feet. Horizontal distance is measured from the center of the RWECs or from the centerline of the two modeled IACs and RWEC Landfall Cables.

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

Cable	Installation Type	Location	Marine Species	
			Dogfish	Sturgeon
IAC	Buried (3.3 feet)	Seabed	0.4	0.7
		3.3 feet Above Seabed	0.1	0.2
	Surface-Laid (1 foot)	Top of Protective Cover	3.4	6.4
		3.3 feet Above Protective Cover	0.2	0.4
RWEC	Buried (3.3 feet)	Seabed	1.0	1.8
		3.3 feet Above Seabed	0.3	0.5
	Surface-Laid (1 foot)	Top of Protective Cover	7.0	13
		3.3 feet Above Protective Cover	0.6	1.1
RWEC Landfall Cable	Buried (3.3 feet)	Seabed	0.9	1.8
		3.3 feet Above Seabed	0.3	0.5

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

Cable	Installation Type	Location	Marine Species	
			Dogfish	Sturgeon
IAC	Buried (3.3 feet)	Seabed	0.5	1.0
		3.3 feet Above Seabed	0.2	0.3
	Surface-Laid (1 foot)	Top of Protective Cover	4.8	9.1
		3.3 feet Above Protective Cover	0.3	0.6
RWEC	Buried (3.3 feet)	Seabed	1.4	2.6
		3.3 feet Above Seabed	0.4	0.7
	Surface-Laid (1 foot)	Top of Protective Cover	10	19
		3.3 feet Above Protective Cover	0.8	1.6
RWEC Landfall Cable	Buried (3.3 feet)	Seabed	1.3	2.5
		3.3 feet Above Seabed	0.4	0.7

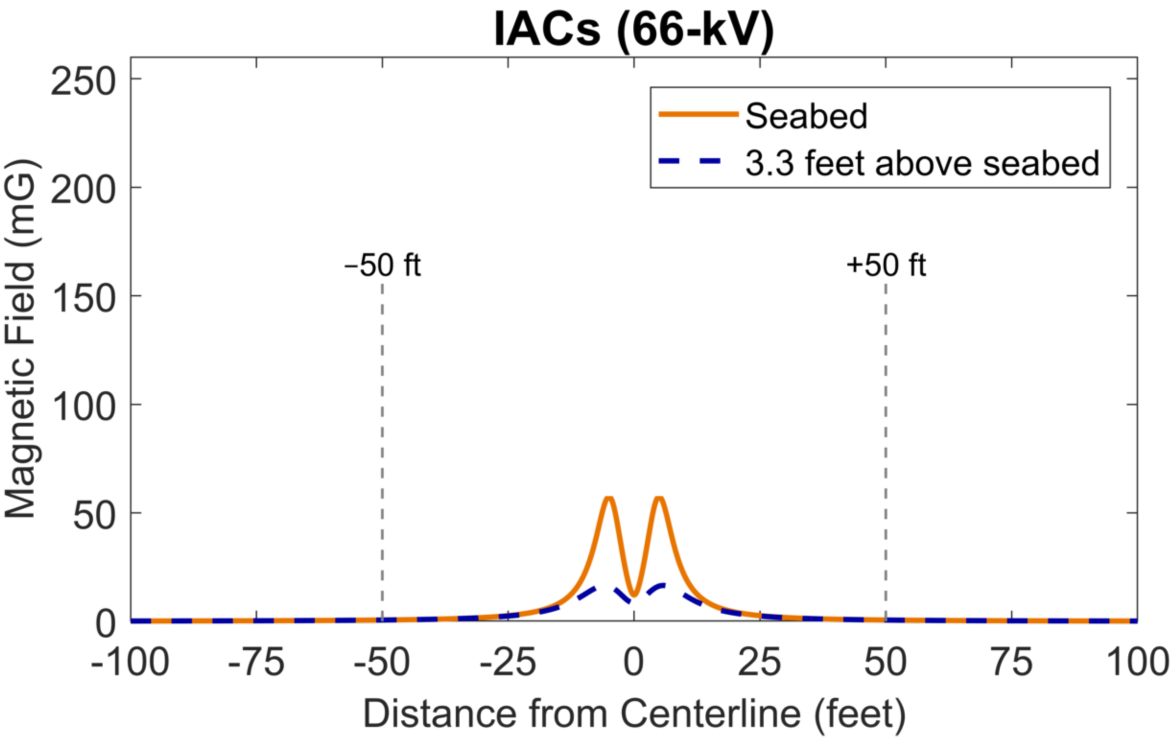

Figure C-1. Calculated magnetic-field levels in seawater above the IACs for a 3.3-foot burial depth and average loading.

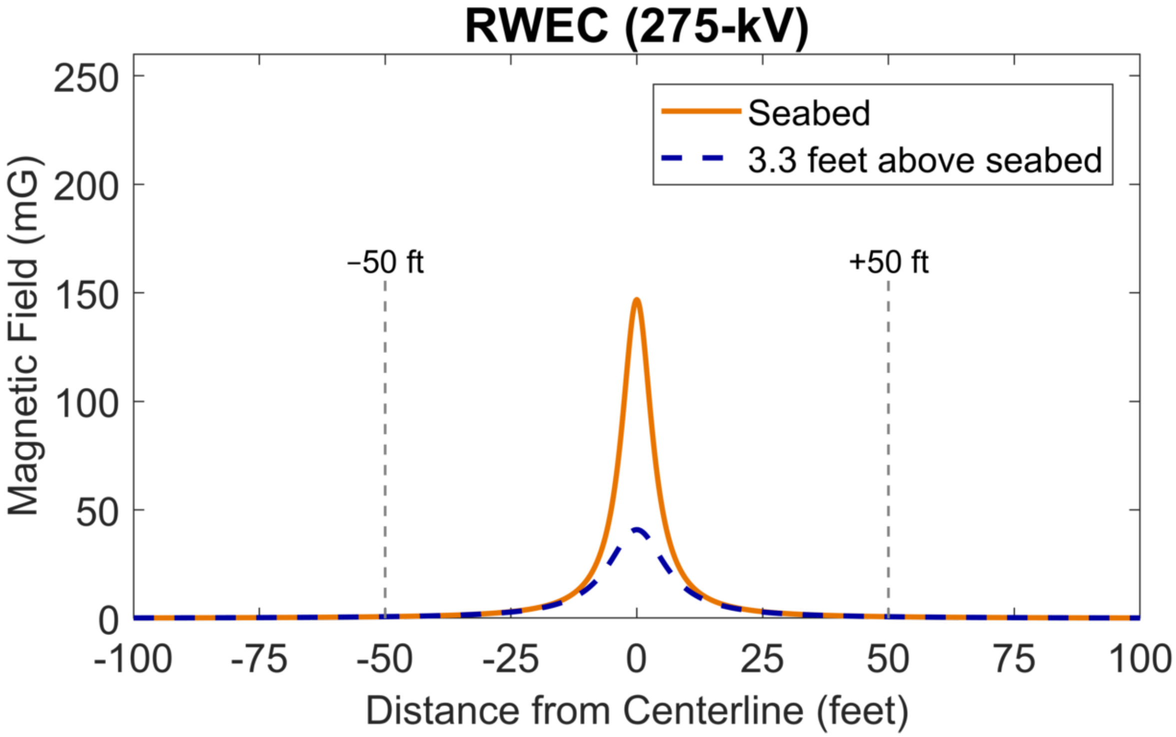

Figure C-2. Calculated magnetic-field levels in seawater above the RWEC for a 3.3-foot burial depth and average loading.

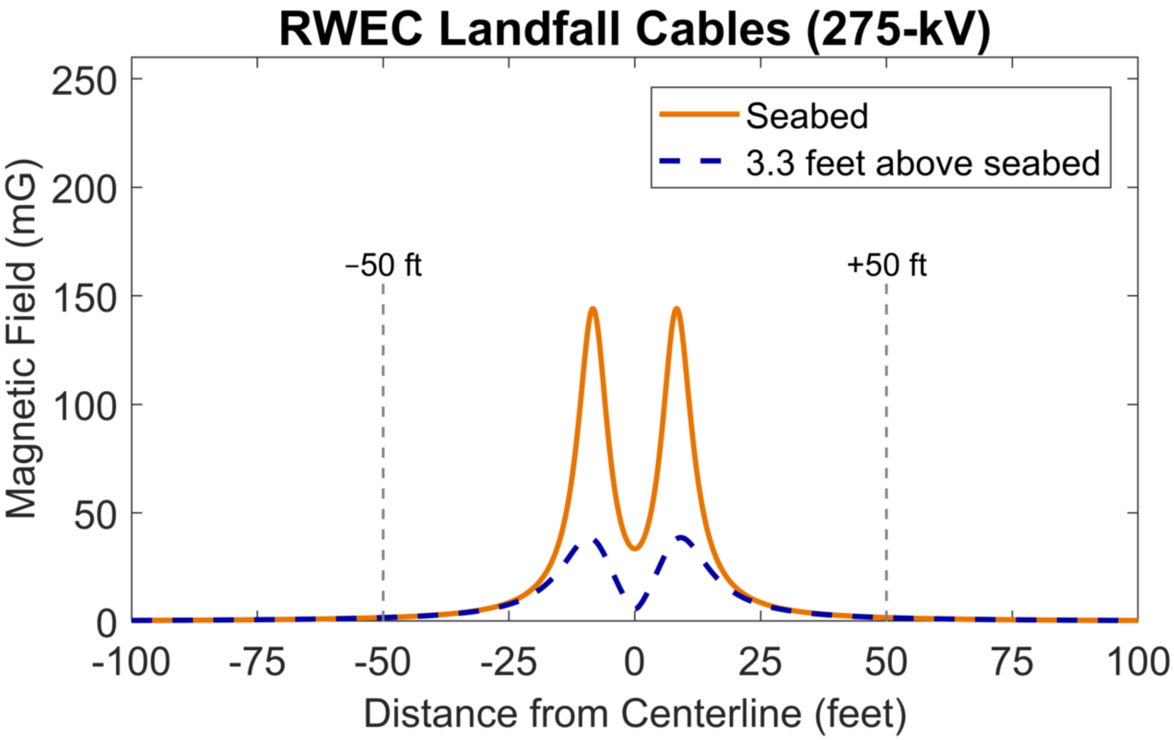

Figure C-3. Calculated magnetic-field levels in seawater above the RWEC Landfall Cables for a 3.3-foot burial depth and average loading.

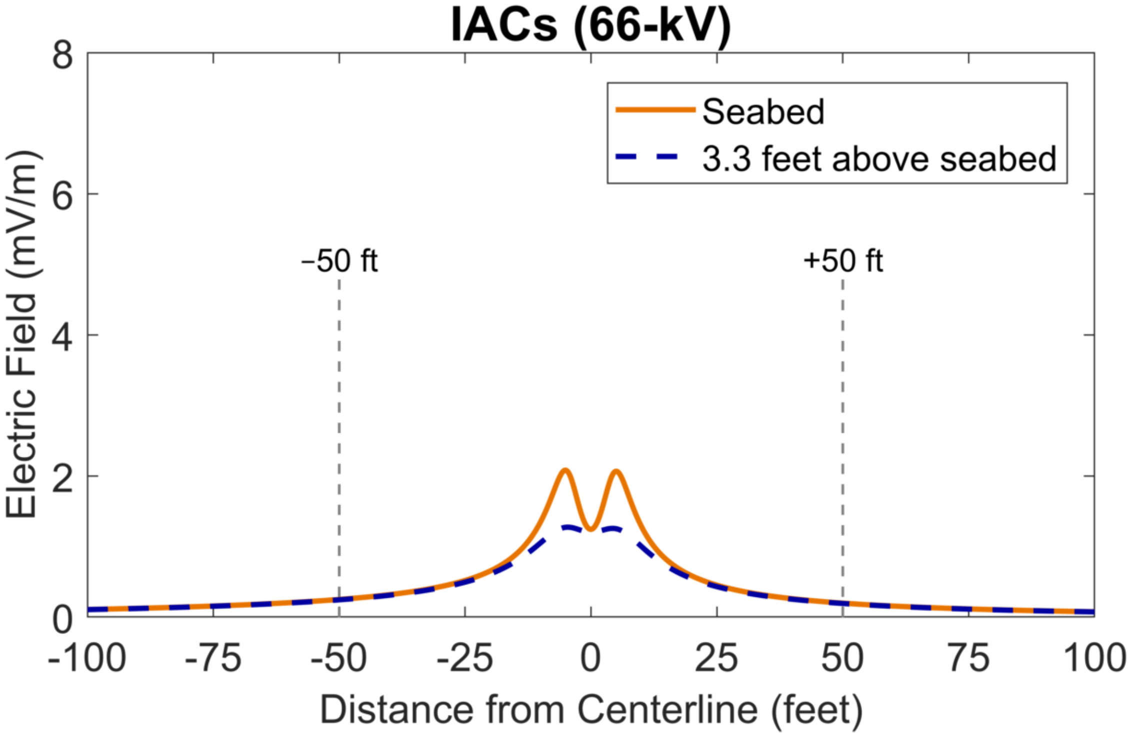

Figure C-4. Calculated induced electric-field levels in seawater above the IACs for a 3.3-foot burial depth and average loading.

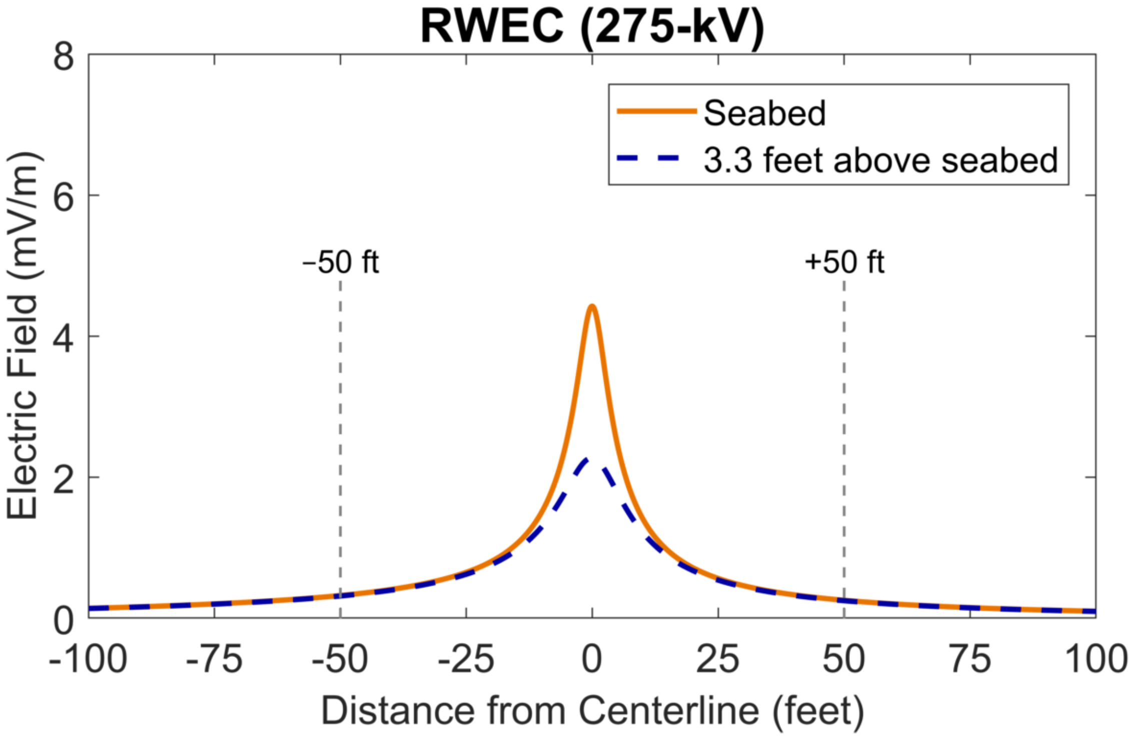

Figure C-5. Calculated induced electric-field levels in seawater above the RWEC for a 3.3-foot burial depth and average loading.

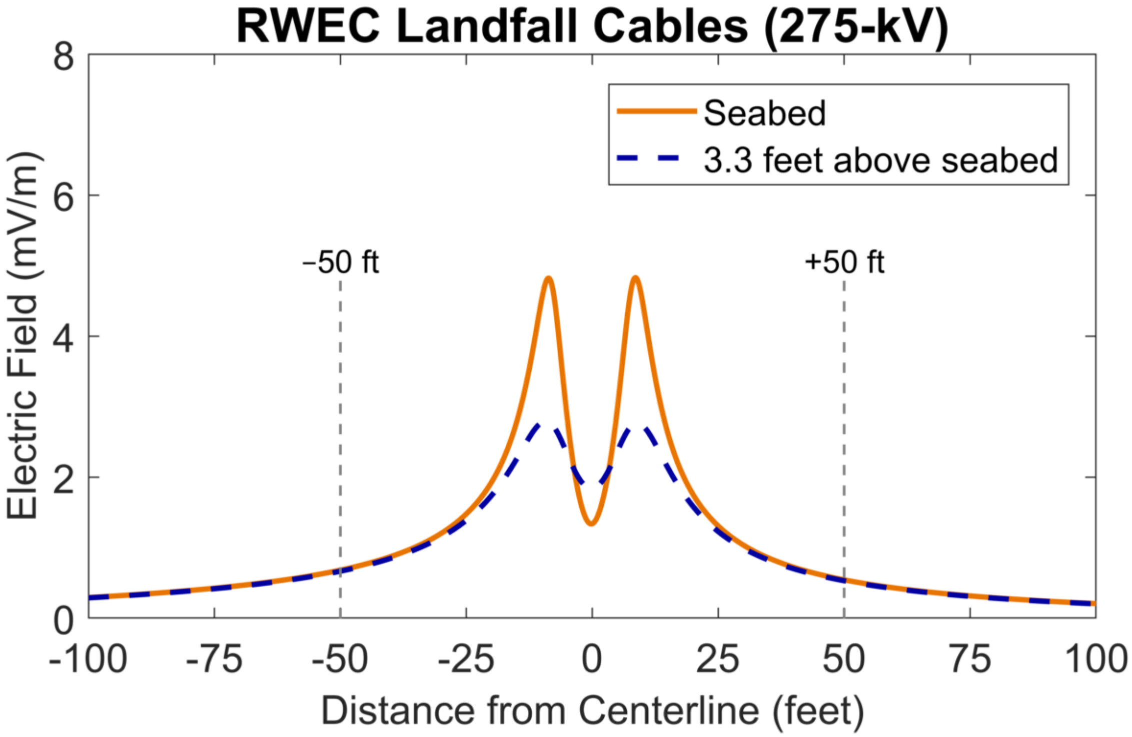

Figure C-6. Calculated induced electric-field levels in seawater above the RWEC Landfall Cables for a 3.3-foot burial depth and average loading.