Appendix P1. Electric and Magnetic Field Assessment for the Proposed Mayflower Wind Project

Document Revision	B
Issue Date	October 2021

GRADIENT

October 26, 2021

Mayflower Wind Energy LLC
101 Federal Street
Boston, MA 02210

Re: Electric and Magnetic Field Assessment Report for Federal Permitting Submittal

Dear Sir or Madam:

Gradient's Electric and Magnetic Field (EMF) Assessment accompanies this cover letter. The EMF Assessment models and predicts reasonable maximum magnetic field (MF) levels for the proposed Mayflower Wind submarine and onshore export cables, and compares the results to health-protective exposure guidelines. In addition, this report assesses whether model-predicted MF levels may impact marine organisms, including commercially and recreationally important fish species and benthic organisms.

The Mayflower Wind Project will generate power from the OCS-A 0521 Lease Area located south of Martha's Vineyard and Nantucket. Within the Falmouth Export Cable Corridor (ECC), up to five submarine offshore export cable(s), including up to four power cables and up to one dedicated communications cable will be installed from one or more OSP(s) within the Lease Area in federal waters, and run through Muskeget Channel into Nantucket Sound in Massachusetts state waters. The offshore export cables will make landfall via horizontal directional drilling (HDD) in Falmouth, Massachusetts.

It is worth noting that only three power cable circuits are modeled in this EMF Assessment study, although the Project Design Envelope includes up to four power cable circuits. For the offshore and landfall areas of the Falmouth ECC, the maximum MF for the addition of a fourth power cable circuit would be very similar to what has already been predicted for three power cables circuits. This is because the large cable separation leads to very little MF interaction among the circuits.

For the onshore areas of the Falmouth onshore export cable route, the modeling shows various installation configurations including three circuit arrangements as well as one circuit and two circuit arrangements, which reflect different areas of the export cable route and also the situation where a circuit is de-energized and out of service. These one- and two-circuit arrangements have higher predicted resultant MFs than the three circuit arrangements.

Therefore, the arrangements studied in this report capture the predicted maximum MFs from the Project for an installation of up to four power cable circuits, where the phase assignment among the twelve conductors for the four-circuit case would be selected to achieve effective MF cancellation where feasible.

Sincerely,

GRADIENT

Christopher M. Long

Christopher M. Long, Sc.D., DABT
Principal
email: clong@gradientcorp.com

Electric and Magnetic Field (EMF) Assessment for the Proposed Mayflower Wind Project

Prepared for

Burns & McDonnell
400 S. Tryon Street, Suite 800
Charlotte, NC 28202

and

Mayflower Wind Energy LLC
2 Drydock Avenue
Boston, MA 02210

October 15, 2021

GRADIENT

www.gradientcorp.com
One Beacon Street, 17th Floor
Boston, MA 02108
617-395-5000

Table of Contents

Page

List of Tables

List of Figures

Abbreviations

µT	Microtesla
A	Ampere
AC	Alternating Current
BOEM	Bureau of Ocean Energy Management
cm	Centimeter
DC	Direct Current
EMF	Electric and Magnetic Field
ft	Foot
G	Gauss
HDD	Horizontal Directional Drilling
ICNIRP	International Commission on Non-Ionizing Radiation Protection
In	Inch
kV/m	Kilovolts Per Meter
Lease Area	Lease Area OCS-A 0521
MA EFSB	Massachusetts Energy Facilities Siting Board
Mayflower Wind	Mayflower Wind Energy LLC
MF	Magnetic Field
mG	Milligauss
MRI	Magnetic Resonance Imaging
MW	Megawatt
NIEHS	National Institute of Environmental Health Sciences
OCS	Outer Continental Shelf
OSP	Offshore Substation Platform
PE	Polyethylene
POI	Point of Interconnection
PP	Polypropylene
PVC	Polyvinyl Chloride
RMS	Root Mean Square
ROW	Right-of-Way
V/m	Volts Per Meter
WHO	World Health Organization
WTG	Wind Turbine Generator
XLPE	Cross-Linked Polyethylene

Executive Summary

Gradient has performed an independent electric and magnetic field (EMF) assessment for the Mayflower Wind Project, which will deliver offshore wind electricity generation to the New England energy grid *via* up to three high voltage three-core submarine export cables and up to nine single-core onshore export cables (up to 362 kV rated voltage). This report summarizes Gradient's EMF Assessment for both the offshore submarine export cables to be used to bring Project electricity from the Lease Area to the landfall site, as well as the onshore transmission system to be used to bring Project electricity from the offshore export cable landfall location to a new onshore substation located in Falmouth, Massachusetts.

The MF modeling analysis is focused on a base case electrical design using a 60-Hz system and 275-kV nominal operating voltage (300-kV maximum operating voltage). The magnetic field (MF) modeling was conservatively performed assuming cable currents based on values higher than those corresponding to maximum wind farm output (100 percent capacity) at nominal voltage and operating mode. The wind farm is expected to operate at an annual-average capacity factor of around 50 percent; thus, much of the time, the actual output and MF attributable to Project export cables will be correspondingly lower than predicted herein for maximum output. Although EMF Assessments typically include modeling analyses of both magnetic and electric fields, no electric field levels are included in this report, due to several reasons. First, there will be no direct electric field effects from the Project submarine export cables, because the electric fields of each of the power cores within the cables are to be contained by metallic sheaths earthed at both ends. This metallic layer will serve to shield the electric fields produced by the voltage on the phase conductors. It is also the case for the onshore underground export cables that the power cores within the cables will be contained by metallic sheaths, thus shielding the electric fields produced by the voltage on the phase conductors. Regardless, underground cables do not produce aboveground electric fields due to shielding by the earth.

The analysis examines submarine export cables that will carry electricity from the offshore substation platform(s) (OSP[s]) to the landfall site. Modeling was performed for six scenarios, including two representative seabed installation scenarios (a likely installation case and a conservative installation case) and four landfall site installation scenarios (landside beach installation scenarios at two locations [Shore St. and Worcester Ave.], and transition joint bay locations at the same landfall locations). Modeling for the two representative seabed installation scenarios was conducted at the sea floor, while modeling for the four landfall site installation scenarios was conservatively conducted at the ground surface. While it is standard practice to model EMF at a height of 1 meter above the ground surface, we assumed that a person could be lying flat on the beach or ground surface at the landfall locations and we thus conservatively conducted modeling for each of the landfall site installation scenarios at the ground surface. Table ES.1 summarizes the burial depth and cable spacing information for each of the modeled scenarios, as well as the modeling results.

These modeling calculations show that the highest modeled MF levels for these submarine cable installation scenarios would occur directly above the submarine export cables, with a rapid reduction in MF levels with increasing lateral and vertical distance from the cables, *i.e.*, decreasing proportional to the square of the distance from the cables. For the landside beach and transition joint bay installation scenarios, the modeled MFs at the ground surface are well below EMF exposure guidelines or limits designed to be protective against any adverse health effects in humans, including the International Commission on Non-Ionizing Radiation Protection (ICNIRP) guideline of 2,000 mG for allowable public exposure to 60-Hz MF. As discussed in more detail in Section 2 of this report, a number of national and world health organizations have developed EMF exposure guidelines or limits. The limit values should not be viewed as demarcation lines between "safe" and "dangerous" levels of EMFs, but rather, levels that assure safety with adequate margins to allow for uncertainties in the science. For MFs, these health-based guidelines range from 1,000 to 10,000 milligauss (mG).

Table ES.1. Summary of Modeling Parameters and Results for Submarine Export Cable Installation Scenarios

Installation Scenario[a]	Burial Depth	No. of Cables	Cable Separation	Predicted Resultant Magnetic Field (mG)		
				Max. Directly Above Cable Centerline[b]	±10 ft (±3 m) from Outer Cables[c]	±25 ft (±7.6 m) from Outer Cables[c]
Seabed – Likely case	6.6 ft (2 m)	3	164 ft (50 m)	85.5	28.8 / 28.8	6.5 / 6.5
Seabed – Conservative case	On surface	3	164 ft (50 m)	1,859	41.9 / 41.9	6.9 / 6.9
Landside Beach – Worcester Ave.	52.8 ft (16.1 m)	3	16.4 ft (5 m)	3.8	3.4 / 3.4	2.8 / 2.8
Landside Beach – Shore St.	9.8 ft (3 m)	3	90 ft (27.4 m)	39.3	20.5 / 20.5	6.2 / 6.2
Transition Joint Bay – Worcester Ave.	6.6 ft (2 m)	3	16.4 ft (5 m)	77.2	36.8 / 36.8	10.3 / 10.3
Transition Joint Bay – Shore St.	6.6 ft (2 m)	3	90 ft (27.4 m)	86.0	28.8 / 28.8	6.8 / 6.8

Notes:
ft = Foot; m = Meter; mG = Milligauss.
[a] All installation scenarios are based on a design study case of 275 kV nominal operating voltage, with each cable carrying a current of 1,200 amperes root mean square (A RMS).
[b] The maximum magnetic field is the field projected to occur at the location of closest approach to the cable. For buried cables, this corresponds to the seafloor or ground surface. For the cable laid on the seafloor, magnetic fields were modeled at 1 ft (0.3 m) above the cable under the assumption that the cable will be covered with a 1-ft thick (0.3-m thick) mattress.
[c] The values provided at lateral distances of 10 and 25 ft are for 10 and 25 ft from the outer cables.

For the onshore transmission route, MF levels were modeled for six representative underground installation scenarios of the onshore export cables. Cross-sections of the installation scenarios are provided in Section 4.3. In all cases, the duct bank (or direct-buried cables) will be buried at a minimum target depth of 3 ft (0.91 m) below ground surface.

- One installation case of three circuits arranged in a 2D×5W underground duct bank;
- One installation case of two circuits arranged in a 3D×2W underground duct bank;
- A single-circuit installation case in a 2D×2W duct bank;
- A single-circuit installation case in a 1D×4W duct bank;
- A single-circuit installation case in a splice vault; and finally,
- A three-circuit installation case where the ducts are installed in a trefoil configuration.

Table ES.2 presents the burial depth and cable spacing information for each of the modeled scenarios for the onshore underground export cables, as well as the modeling results. These modeling calculations show that the highest MF levels for the onshore underground duct bank cross sections would occur directly above the duct banks, with rapid reductions in MF levels with lateral and vertical distance from the duct banks. The peak modeled MF levels for the duct bank installation cases range from 187 mG (three cables in a 2D×5W duct bank) to 403 mG (single cable in a 1D×4W duct bank), and are all less than the ICNIRP health-based guideline of 2,000 mG for allowable public exposure to 60-Hz MFs.

Table ES.2. Summary of Modeling Parameters for Onshore Export Cable Installation Scenarios

Installation Scenario[(a)]	Burial Depth[(b)]	No. of Cable Circuits	Predicted Resultant Magnetic Field (mG)		
			Maximum Above Duct Bank[(c)]	±10 ft (±3 m) from Duct Bank Centerline[(d)]	±25 ft (±7.6 m) from Duct Bank Centerline[(d)]
2D×5W Duct Bank	3 ft (0.9 m)	3	187.1	84.0 / 86.9	18.3 / 18.6
3D×2W Duct Bank	3 ft (0.9 m)	2	223.4	93.0 / 91.1	21.6 / 21.5
2D×2W Duct Bank	3 ft (0.9 m)	1	220.0	80.8 / 78.4	18.0 / 17.7
1D×4W Duct Bank	3 ft (0.9 m)	1	403.3	156.7 / 128.1	32.4 / 29.0
Splice Vault	3 ft (0.9 m)	1	292.7	132.0 / 110.6	31.0 / 27.9
Trefoil Duct Arrangement	3 ft (0.9 m)	3	321.5	145.0 / 145.0	31.7 / 31.7

Notes:

ft = Foot; m = Meter; mG = Milligauss.

(a) All installation scenarios are based on a design study case of 275 kV nominal operating voltage, with currents of 1,200 amperes root mean square (A RMS).

(b) Burial depth to top of duct bank.

(c) The maximum magnetic field is the field projected to occur at the location of closest approach to the cable at 3.28 ft (1 m) above the ground surface.

(d) The values presented are the modeled fields at the given lateral distances from the duct bank centerline. The two values presented correspond to the fields to the left and right of the centerline, respectively.

1 Introduction

Mayflower Wind Energy LLC (Mayflower Wind) is proposing an offshore wind renewable energy generation project (the Project) located in federal waters off the southern coast of Massachusetts in the Outer Continental Shelf (OCS) Lease Area OCS-A 0521 (Lease Area) that will deliver electricity to the regionally administered transmission system via submarine offshore export cables with a sea-to-shore transition in Falmouth, Massachusetts, and an onshore transmission system extending to the point of interconnection (POI) in Falmouth, Massachusetts.

1.1 Goals and Objectives

The purpose of this Electric and Magnetic Field (EMF) Assessment for the proposed Mayflower Wind submarine and onshore export cables is to model magnetic field (MF) levels for likely and conservative Project submarine cable installation conditions and reasonable maximum MF level onshore cable installation conditions that are representative of the preferred route for the Project. We also compared model-predicted MF levels to health-protective exposure guidelines. In addition, this report assesses whether model-predicted MF levels may impact marine organisms, including commercially and recreationally important fish species and benthic organisms.

Although EMF Assessments typically include modeling analyses of both magnetic and electric fields, no electric field levels are included in this report, due to several reasons. First, there will be no direct electric field effects from the Project submarine export cables, because the electric fields of each of the power cores within the cables are to be contained by metallic sheaths earthed at both ends. This metallic layer will serve to shield the electric fields produced by the voltage on the phase conductors. It is also the case for the onshore underground export cables that the power cores within the cables will be contained by metallic sheaths, thus shielding the electric fields produced by the voltage on the phase conductors. Regardless, underground cables do not produce aboveground electric fields due to shielding by the earth.

1.2 Project Description

The Mayflower Wind Project includes a Lease Area located south of Martha's Vineyard and Nantucket. Wind turbine generators (WTGs) to be constructed within the Lease Area will deliver power via inter-array cables to the OSP(s). Up to four submarine offshore export cable(s), including up to three power cables and up to one dedicated communications cable, will be installed from one or more OSP(s) within the Lease Area in federal waters, and run through Muskeget Channel into Nantucket Sound in Massachusetts state waters. The offshore export cables will make landfall *via* horizontal directional drilling (HDD) at three potential landing location(s) at the end of Worcester Avenue, Shore Street, or Central Park in Falmouth, Massachusetts.

The underground onshore export cables extending from the HDD landing(s) to an onshore substation to be built in Falmouth will be installed within and beneath existing public roadways, shoulders, or median (Figure 1.1). The new onshore substation will provide an interface and enable connection to the administered electrical transmission system (Figure 1.1). The preferred substation location is the Lawrence-Lynch site off of Gifford Street in Falmouth.

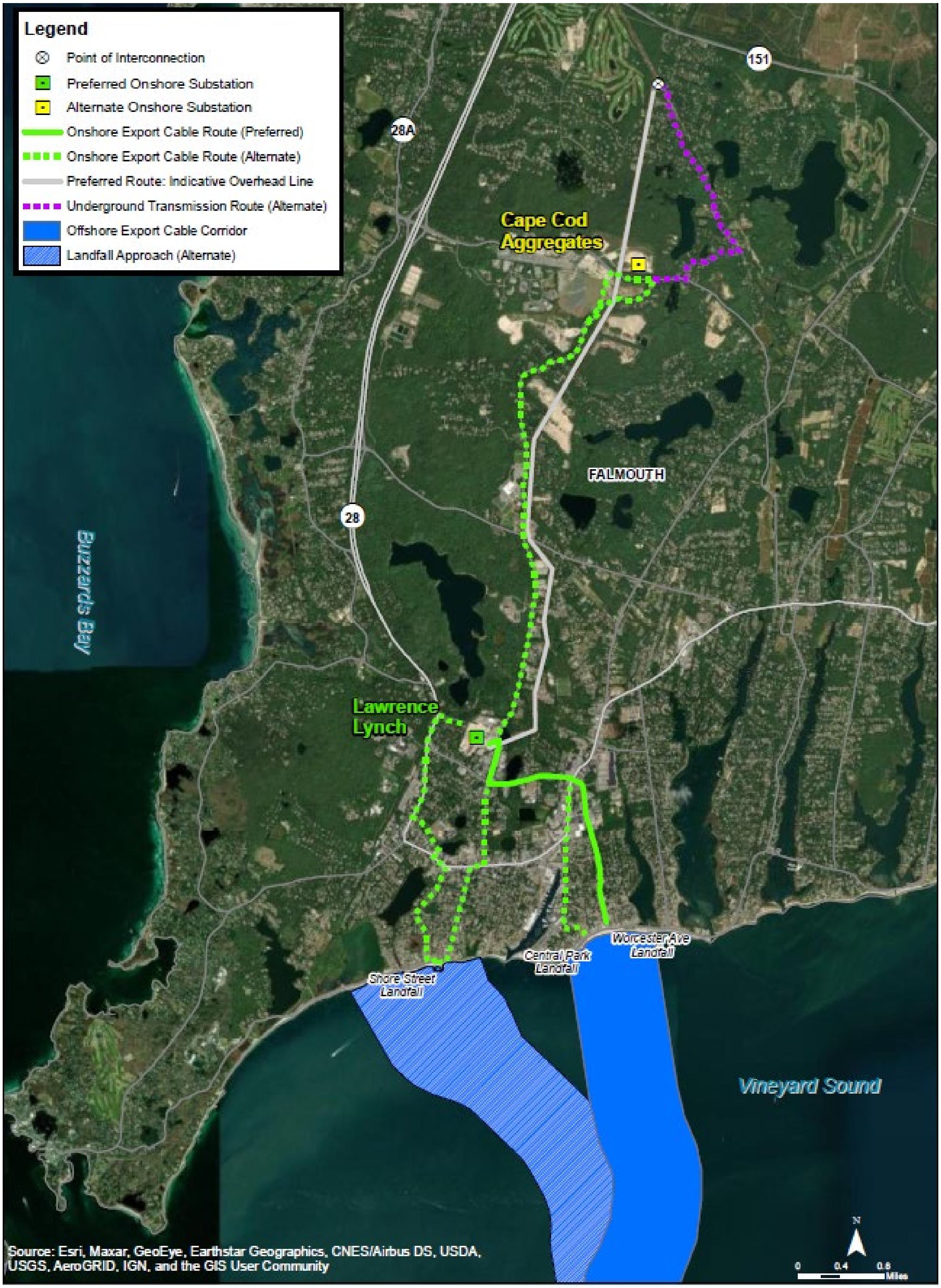


Figure 1.1 Location of Preferred and Alternate Onshore Project Components.

2 Nature of Electric and Magnetic Fields

2.1 Units for EMFs Are Volts Per Meter (V/m) and Milligauss (mG)

The electrical tension on utility power lines is expressed in volts or kilovolts (1 kV = 1,000 V). Voltage is the "pressure" of the electricity and can be envisioned as analogous to the pressure of water in a plumbing system. The existence of a voltage difference between power lines and the ground results in an "electric field," usually expressed in units of volts per meter (V/m) or kilovolts per meter (kV/m). The size of the electric field depends on the voltage, the separation between lines and the ground, and other factors.

Power lines also carry an electric current that creates a "magnetic field" (MF). The units for electric current are amperes (A), which measure the "flow" of electricity. Electric current is analogous to the flow of water in a plumbing system. The magnitude of the MF produced by an electric current is usually expressed as magnetic flux density (widely referred to as the "magnetic field") in units of gauss (G) or milligauss (mG) (1 G = 1,000 mG).[1] The size of the MF depends on the electric current, the distance to the current-carrying conductor, and other factors.

2.2 There Are Many Natural and Manmade Sources of EMFs

People experience a variety of natural and manmade EMFs. EMFs can be steady or slowly varying (often called "direct current fields" or "DC fields") or can vary with regular intervals over time (often called "alternating current fields" or "AC fields"). When the time variation corresponds to that of standard North American power line currents (*i.e.*, 60 cycles per second), the fields are called "60-Hz" EMFs.

On a larger scale, Earth's core creates a steady DC MF that can be easily demonstrated with a compass needle. The size of Earth's MF along the southern New England coast is about 516 mG (CSA Ocean Sciences Inc. and Exponent, 2019). Manmade MFs are also common in everyday life, such as the strong, steady (DC) MFs generated by permanent magnets. Typical toy magnets (e.g., "refrigerator door" magnets) have fields of 100,000 to 500,000 mG.

Naturally occurring EMFs are ubiquitous in the oceans. Additional natural sources of EMFs besides the Earth's MF include those associated with the movement of ocean currents and marine organisms through the Earth's MF and those directly produced by marine organisms. The movement of ocean currents and marine organisms through the Earth's MF produces weak DC electric fields (CSA Ocean Sciences Inc. and Exponent, 2019). Marine organisms produce bioelectric fields, such as from heartbeats and gill movement, close to their body surfaces; in addition, electric fish species such as the electric eel can generate strong electric fields for defense purposes. These bioelectric fields, which include both AC and DC electric fields, can be as high as 0.5 V/m, but typically diminish to negligible levels within 4 to 8 inches (in), or 10 to 20 centimeters (cm), from the source organism (CSA Ocean Sciences Inc. and Exponent, 2019). While these bioelectric fields can include AC fields that change direction several times per second, they are generally for frequencies of less than 10 Hz (e.g., electric fields from a heartbeat of 120 beats per minute would have a frequency of 2 Hz) and thus are considerably below the frequencies of the 60-Hz AC electric fields that are characteristic of US power generation and transmission (CSA Ocean Sciences Inc. and Exponent, 2019).

[1] Another unit for MF levels is the microtesla (μT) (1 μT = 10 mG).

2.3 Key Determining Factors for EMFs from Submarine Cables

As discussed above, the strength of EMFs from transmission lines is directly proportional to voltage and current. In addition, for submarine cables, other key determining factors of EMF levels include cable design and burial depth. Submarine cables typically consist of three-core armored cables, where three insulated and sheathed power cores of copper or aluminum conductors are bundled and twisted together in a triangular configuration and surrounded by outer layers of additional insulation and steel wire armoring. Importantly, power cores with metal sheaths surrounding the conductor bundles have no direct electric field effects outside the cables, because the grounded metallic sheaths serve to shield the electric fields produced by the voltage on the phase conductors.

In contrast to the electric fields from the conductors, MFs are not contained if the armoring of the cables is non-magnetic (or if there is a break in magnetic steel armor), and 60-Hz AC MFs will thus surround submarine cables. MFs surrounding submarine cables will depend on such factors as the current flow, conductor separation distances and other cable design specifications, and burial depth. Because the conductor bundles within a submarine cable are located very close to each other with a triangular geometry, and because the currents in all three phase conductors add to zero for a balanced load, the MFs that they each create will partially cancel with each other, lowering the overall MF from the submarine cables. Due also to the close proximity of the conductor bundles to each other, MFs from submarine cables drop off rapidly with both lateral and vertical distance from the cables, *i.e.*, decreasing proportional to the square of the distance. Burial depth is thus a key factor affecting MF levels at the seafloor (and higher up in the water column), with an approximate 4-fold reduction in seafloor MF levels resulting from a doubling in burial depth from 3.3 to 6.6 feet (ft) (1 to 2 m) (CSA Ocean Sciences Inc. and Exponent, 2019). Given the rapid drop-off of MF levels with lateral and vertical distance from the cables, exposures of marine organisms to submarine cable MFs are localized and highly dependent on the distance of the organisms from the cables, with exposures to only low to negligible MF levels occurring beyond about 10 to 25 ft (3 to 7.6 m) from submarine cables.[2] For example, pelagic fish species that typically spend their time in the water column well above the seafloor would only rarely come into contact with MFs from submarine cables (CSA Ocean Sciences Inc. and Exponent, 2019).

2.4 Power-Frequency EMFs Are Found Near Electric Lines and Appliances

In North America, electric power transmission lines, distribution lines, and electric wiring in buildings carry AC currents and voltages that change size and direction at a frequency of 60 Hz. These 60-Hz currents and voltages create 60-Hz EMFs nearby. The size of the MF is proportional to the line current, and the size of the electric field is proportional to the line voltage. The EMFs associated with electrical wires and electrical equipment decrease rapidly with increasing distance away from the electrical wires.

When EMFs derive from different wires or conductors that are in close proximity or adjacent to one another, they may partially add or partially cancel, and the size of the net EMF produced at a location of interest will be somewhere in the range between the vector sum of EMF from the individual sources and the vector difference between the EMF from the individual sources. For example, because adjacent wires in a three-phase system are normally carrying current with phase angles offset 120° from one another, the MFs of each conductor partially cancel each other, which reduces the strength of the net MF from the three conductors.

[2] For a typical submarine cable burial scenario, CSA Ocean Sciences Inc. and Exponent (2019) demonstrated that MF levels directly above a submarine cable are 50 to 75 percent reduced 3.3 ft (1 m) above the seafloor as compared to at the seafloor, while MF levels at the seafloor are 90 to 95 percent reduced at lateral distances of 10 to 25 ft (3 to 7.6 m) versus directly at the cable centerline.

EMFs in the home arise from electric appliances, indoor wiring, grounding currents on pipes and ground wires, and outdoor distribution or transmission circuits. Inside residences, typical baseline 60-Hz MF (away from appliances) range from 0.5 to 5.0 mG.

Higher 60-Hz MF levels are found near operating appliances. For example, can openers, mixers, blenders, refrigerators, fluorescent lamps, electric ranges, clothes washers, toasters, portable heaters, vacuum cleaners, electric tools, and many other appliances generate MF in the range of 40-300 mG at distances up to 1 ft (0.3 m) (National Institute of Environmental Health Sciences [NIEHS], 2002). MF from personal care appliances held within half a foot (ft) (0.15 m) (e.g., shavers, hair dryers, massagers) can produce average fields of 600-700 mG. At school and in the workplace, lights, motors, copy machines, vending machines, video-display terminals, pencil sharpeners, electric tools, electric heaters, and building wiring are sources of 60-Hz MF. As previously noted, the Earth's MF along the southern New England coast is about 516 mG. Recognizing that it is a source of DC fields rather than 60-Hz fields, magnetic resonance imaging (MRI) is a diagnostic procedure that puts humans in much larger, but steady, MFs (e.g., 20,000,000 mG). Superimposed on this very large, static MF is an additional scanning MF, which is the source of the characteristic auditory noise that accompanies MRI scans, and this time-varying scanning MF exposes the body to MFs changing in time, similar to power-line MFs.

2.5 State, National, and International Guidelines for EMFs

The United States has no federal standards limiting general public or residential exposure to 60-Hz EMF. Table 2.1 shows guidelines established by national and world health organizations that are designed to be protective against adverse health effects. The limit values should not be viewed as demarcation lines between safe and dangerous levels of EMFs, but rather, levels that assure safety with an adequate margin to allow for uncertainties in the science. As part of its International EMF Project, the World Health Organization (WHO) has conducted comprehensive reviews of EMF health effects research and existing standards and guidelines. The WHO website for the International EMF Project (WHO, 2020) notes that, *"[t]he main conclusion from the WHO reviews is that EMF exposures below the limits recommended in the ICNIRP international guidelines do not appear to have any known consequence on health."*

Table 2.2 lists MF guidelines that have been adopted by various states in the United States, including by the Massachusetts Energy Facilities Siting Board (MA EFSB). The MA EFSB has adopted, and long used, edge-of ROW guideline levels of 85 mG for MFs. State guidelines such as those of the MA EFSB are not health-effect based and have typically been adopted to maintain the status quo for EMFs on and near a transmission line right-of-way (ROW).

Table 2.1. 60-Hz MF Guidelines Established by Health and Safety Organizations

Organization	Magnetic Field
American Conference of Governmental and Industrial Hygienists (ACGIH) (occupational)	10,000 mG[(a)] 1,000 mG[(b)]
International Commission on Non-Ionizing Radiation Protection (ICNIRP) (general public, continuous exposure)	**2,000 mG**
Non-Ionizing Radiation (NIR) Committee of the American Industrial Hygiene Association (AIHA) endorsed (in 2003) ICNIRP's occupational EMF levels for workers (occupational)	4,170 mG
Institute of Electrical and Electronics Engineers (IEEE) Standard C95.6 (general public, continuous exposure)	9,040 mG
United Kingdom (UK), National Radiological Protection Board (NRPB) (which was formerly part of the Health Protection Agency [HPA], but is now part of Public Health England [PHE])	2,000 mG
Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) (Draft Standard, December 2006[(c)])	3,000 mG

Notes:
MF = Magnetic Field; mG = Milligauss.
(a) The ACGIH guidelines for whole-body exposure for the general worker (ACGIH, 2020).
(b) The ACGIH guidelines for workers with cardiac pacemakers (ACGIH, 2020).
(c) ARPANSA (2006, 2008).

Table 2.2. State MF Standards and Guidelines for Transmission Lines

State	Line Voltage (kV)	Magnetic Field (mG)
		Edge of ROW
Florida[(a)]	69-230	150[(b)]
	>230-500	200[(b)]
	>500	250[(b,c)]
Massachusetts		**85**
New York[(a)]		200

Notes:
Blank = Not Applicable/Not Available; FLDEP = Florida Dept. of Environmental Protection; kV = Kilovolt; MA EFSB = Massachusetts Energy Facilities Siting Board; MF = Magnetic Field; mG = Milligauss; NIEHS = National Institute of Environmental Health Sciences; ROW = Right-of-Way.
Sources: NIEHS (2002); FLDEP (2008); MA EFSB (2009).
(a) Magnetic fields for winter-normal loading (*i.e.*, at maximum current-carrying capability of the conductors).
(b) Includes the property boundary of a substation.
(c) Also applies to 500-kV double-circuit lines built on existing ROWs.

3 MF Modeling for Offshore Transmission Route

3.1 Software Program Used for Modeling MF Levels for Submarine Cable Installation Scenarios

The FIELDS computer program, designed by Southern California Edison, was utilized to calculate MF strengths from the submarine export cables. This program operates using Maxwell's equations, which accurately apply the laws of physics as related to electricity and magnetism (EPRI, 1982, 1993). Modeled fields using this program are both precise and accurate for the input data utilized. Results of the model have been checked extensively against each other and against other software (*e.g.*, CORONA, from the Bonneville Power Administration, United States Department of Energy) to ensure that the implementation of the laws of physics are consistent. In these validation tests, program results for MF levels were found to be in very good agreement with each other (Mamishev and Russell, 1995).

No electric field levels are included in this report because there will be no direct electric field effects from the Project submarine cables. This is the case because the electric fields of each of the power cores within the cables are to be contained by metallic sheaths earthed at both ends. This metallic layer will serve to shield the electric fields produced by the voltage on the phase conductors. The 60-Hz AC MFs produced by submarine cables will induce a weak electric field in the immediately surrounding marine environment near the buried cables.[3] These induced electric fields differ from direct electric fields produced by transmission lines, as they are very low in strength and are unrelated to the voltage of the cable conductors (CSA Ocean Sciences Inc. and Exponent, 2019). Because they are induced by the 60-Hz MFs surrounding a submarine cable, they are instead proportional to the current flow of the submarine cable conductors. These induced electric fields are not modeled by EMF modeling programs such as the FIELDS computer program; however, CSA Ocean Sciences Inc. and Exponent (2019) provided information on the typical strengths of these induced electric field levels for AC submarine export cables from offshore wind energy projects, which ranged from 0.0019 to 0.0037 V/m (1.9-3.7 mV/m) at the seafloor directly above a cable to 0.0004 to 0.00013 V/m (0.4-0.13 mV/m) at the seafloor 10 to 25 ft (3 to 7.6 m) laterally away from a cable.

In this report, the MF modeling analysis is focused on a base case electrical design using a 60-Hz system and 275-kV nominal operating voltage (300-kV maximum operating voltage). The analysis examines the submarine export cables that will carry electricity from the OSP(s) to the landfall site, given that they are expected to be the largest MF source to the marine environment. The WTGs, as well as the transformers and other power equipment on the OSP(s), are not considered to be significant sources of potential EMF exposure to marine organisms, given their locations far above the ocean surface (CSA Ocean Sciences Inc. and Exponent, 2019). Both direct MF levels and induced electric field levels for the up to 72.5 kV inter-array cables that will carry electricity generated by WTGs to the OSP(s) are expected to be lower than those associated with the high voltage export cables, due to both lesser current flows and smaller diameter cables, consequently leading to greater MF cancellation due to the close spacing of the phase conductors.

[3] By Faraday's Law of Induction, a time-varying MF (*i.e.*, changing magnetic flux) will induce a time-varying electric field in a conducting medium, such as seawater. This is the same principle by which coils rotating in MFs generate electricity.

3.2 Submarine Cable Specifications

Table 3.1 provides a summary of the submarine export cable specifications used in the MF modeling analysis, and Figure 3.1 provides an example schematic of the type of submarine cable proposed for Project usage. Each cable is a three-core armored submarine cable. The power cores are composed of aluminum or copper stranded conductors, cross-linked polyethylene (XLPE) insulation, lead sheaths, and a polyethylene (PE) oversheath. Each cable contains a fiber optic tube made of stainless steel with a PE jacket. The fiber optic tube may have a layer of galvanized steel or stainless-steel armor. The cable assembly includes filler material which may be extruded PE or polypropylene (PP) yarns. A layer of armor bedding will be nylon tapes or PP yarns soaked in bitumen, and the armor will be stainless steel or galvanized steel. A PE coating may be used on the armor wires. The outer jacket will be PP yarns soaked in bitumen.

The cable studied is from the 300-kV rated voltage class. The high voltage cable system may be up to 362 kV in rating. Such cables from the 245-kV and 362-kV voltage class very closely resemble the cable from the 300-kV rated cable, the main difference being the thickness of insulation.

Table 3.1. Indicative Submarine Cable Specifications for a Maximum Conductor Size Used for EMF Modeling[a]

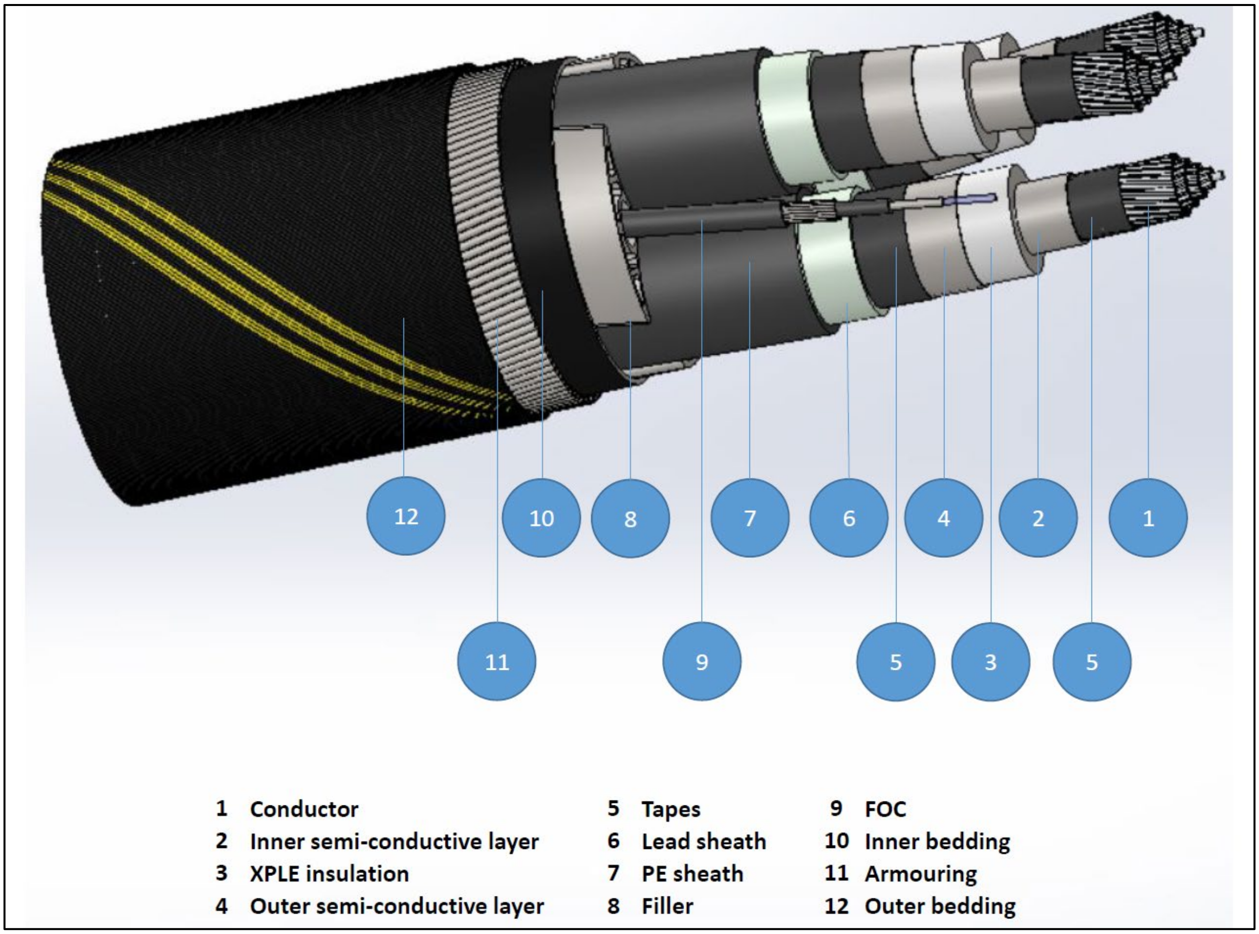
Cable Parameter or Component	Specification Value[b]
Power Core Details	
Conductor type	Copper or aluminum; up to 2,500 mm^2
Conductor diameter	65.0 mm
Power core spacing (center to center)	134.8 mm
Metal sheath type	Lead
Metal sheath thickness	3.0 mm
Outer diameter of metal sheath	128.6 mm
Cable Assembly Details	
Armor type	Stainless steel wires
Armor thickness	6.0 mm
Outer diameter of armor	308.1 mm
Outer diameter of cable	316.1 mm
Electrical Parameters	
Current type and frequency	Alternating current 60 Hz
Rated voltage	300 kV
Conductor current (RMS)	1,200 A
Metal sheath circulating current	250 A

Notes:

A = Ampere; Hz = Hertz; kV = Kilovolt; mm = Millimeter; RMS = Root Mean Square.

[a] Values in the table reflect indicative properties of the type of submarine export cables to be used; they may differ from the actual properties of the actual submarine cables used in the final Project design.

[b] Data are for steady-state conditions only- not fault conditions.



Notes:
FOC = Fiber-Optic Cable; PE = Polyethylene; XLPE = Cross-Linked Polyethylene.
Source: Hellenic Cables.

Figure 3.1. Example Submarine Export Cable Cross Section Illustration.

While not shown in Figure 3.1, the cores within the cable are to be helically wound, meaning that the phase conductors will have a "twisted" design rather than the phase conductors being straight and parallel over long distances. This twisting of the conductors is expected to contribute to substantially greater self-cancellation of MF than predicted from the modeling analysis, which assumes that the conductors do not have a "twisted" design and instead have a continuously straight trefoil configuration.

3.3 Modeled Submarine Cable Installation Scenarios

Modeling was performed for two representative seabed submarine cable installation scenarios and four landfall site installation scenarios consisting of up to 3 three-core submarine export cables, each with capacity to deliver a minimum of 400 megawatts (MW) to the project's POI, and each running at a maximum Root Mean Square (RMS) current of 1,200 A:

- Likely case for installation in the seabed, where the submarine cables have a 6.6-ft (2-m) burial depth and are spaced 164-ft (50-m) apart.

- Conservative case for installation on the seabed, where the submarine cables are laid on the seafloor surface and covered with a 1-ft (0.3-m) thick concrete mattress, and spaced 164-ft (50-m) apart.
- Landside beach case at Worcester Avenue; for this case, a 52.8-ft (16.1-m) burial depth and 16.4-ft (5-m) cable separation is assumed.
- Landside beach case at Shore Street; for this case, a 9.8-ft (3-m) burial depth and 90-ft (27.4-m) cable separation is assumed.
- Landfall site transition joint bay case at Worcester Avenue; for this case, the cables are assumed to have 6.6-ft (2-m) burial depth and are spaced 16.4-ft (5-m) apart.
- Landfall site transition joint bay case at Shore Street; for this case, the cables are assumed to have 6.6-ft (2-m) burial depth and are spaced 90-ft (27.4-m) apart.

Table 3.2 summarizes the modeling parameters provided by Mayflower Wind for these submarine export cable MF modeling cases. The RMS cable currents in Table 3.2 are for the maximum loadings for the three cables that are conservative values derived from a power simulation assuming maximum wind turbine output (100 percent capacity). While the cable and loading are based on a 275-kV nominal operating voltage, Mayflower Wind does not expect the RMS cable currents to exceed these values even for other operating voltages, due to thermal constraints on the cable system. Balanced phase currents were assumed for the cables. As indicated in the Table 3.2 notes (Note a), the modeled cable currents include the effects of charging currents for the Project offshore export system.

Table 3.2. Summary of Modeling Parameters for Submarine Export Cable Installation Scenarios[(a)]

Installation Scenario	Burial Depth	No. Cables	Cable Separation	Max. Cable Current[(a)] (A RMS)
Seabed – Likely case	6.6 ft (2 m)	3	164 ft (50 m)	1,200
Seabed – Conservative case	On surface	3	164 ft (50 m)	1,200
Landside Beach – Worcester Ave.	52.8 ft (16.1 m)	3	16.4 ft (5 m)	1,200
Landside Beach – Shore St.	9.8 ft (3 m)	3	90 ft (27.4 m)	1,200
Transition Joint Bay – Worcester Ave.	6.6 ft (2 m)	3	16.4 ft (5 m)	1,200
Transition Joint Bay – Shore St.	6.6 ft (2 m)	3	90 ft (27.4 m)	1,200

Notes:
A RMS= Amperes Root Mean Square; ft = Foot; m = Meter.
(a) The currents include the effects of charging currents – *i.e.*, the additional electric current that occurs as the line proceeds from the offshore substation toward the onshore substation, because the cable system power cores act to some degree like a capacitor that needs to be charged and discharged in addition to delivering actual electrical power to the onshore substation.

The MF analyses thus encompassed several different burial depths and cable spacings in order to represent both likely submarine cable installation conditions as well as conservative installation conditions. As indicated in Table 3.2, the anticipated burial depth for the export cable route is to be 6.6 ft (2 m), with the modeling assuming a 6.6-ft (2-m) distance from the seafloor to the tops of the cables. Given the potential that hard bottom seafloor conditions or existing infrastructure may be encountered, a second conservative seabed case was modeled in which the submarine cables were laid directly on the seafloor and covered with a 1-ft (0.3-m) thick concrete mattress. For both of these scenarios, MFs were predicted at the seafloor surface for profiles perpendicular to the cables, consistent with other submarine cable MF modeling analyses (Normandeau Associates, Inc., *et al*., 2011).[4] As discussed previously, MF levels in the water column above the seafloor will be substantially less than the modeled MF levels at the seafloor surface. The rate of MF level decrease as a function of height above the cable will be the same as the rate of fall-off as a function of distance laterally from the cable, *i.e*., decreasing proportional to the square of the distance from the cable.

There are several reasons why the modeling for each of the six submarine cable installation scenarios is expected to substantially overpredict MF levels associated with the installed submarine cables. Given the complexity of quantitatively modeling these field reductions, the MF modeling conservatively assumed no shielding of MF from the cable armoring and no MF self-cancellation associated with the twisting of the conductor bundles. Although it is more likely that stainless steel armor will be used in the cables, the usage of ferromagnetic metal armoring such as galvanized steel armoring would also serve to partially attenuate the MFs reaching the outside environment as a result of both ferromagnetic shielding and opposing eddy currents that are induced in the armor (CSA Ocean Sciences Inc. and Exponent, 2019). This shielding factor is difficult to calculate due to the discontinuous nature of the wire armoring, although it will provide less shielding than a solid ferromagnetic pipe covering (for which a shielding factor of 10 is generally assumed; EPRI, 1993; EPRI and HVTRC, 1994). Studies provide support for a shielding factor of approximately two from ferromagnetic metal armoring of submarine cables (Lucca, 2013; CSA Ocean Sciences Inc. and Exponent, 2019). The additional self-cancellation from the twisting of the conductors is less than the cancellation associated with the triangular geometry of the conductors; however, it is not typically reflected in MF modeling analyses of submarine cables due to the complexity of modeling it. It is estimated that the twisting of the conductor bundles will contribute to an approximate 10-fold reduction in MFs for the submarine cables in practice versus the model predictions that do not account for the twisting (CSA Ocean Sciences Inc. and Exponent, 2019; Hutchison et al., 2018).[5]

In addition, the MF modeling analysis did not account for induced currents on the conductor sheathing and ground conductors, which arise due to the both ends bonding arrangement of the submarine cables. Similar to the induced current on passive loops sometimes used as a mitigation measure for underground transmission lines, any sheath current induced by the MFs from the phase conductors' main currents is expected to produce an MF that will tend to oppose (partially cancel) the MF causing the induced current (Istenic *et al*., 2001). The FIELDS computer program does not calculate either the magnitude or phase angle of induced sheath currents, so the modeling was only conducted with the phase conductors' main currents. Given that several cable design features that serve to reduce MF levels outside the cables were not included in the modeling analysis, the modeling should be viewed as providing "conservative upper-bound (highest) calculated EMF levels" (CSA Ocean Sciences Inc. and Exponent, 2019).

---

[4] At the onshore landfall sites, MF levels were conservatively modeled at the ground surface, assuming that the modeled locations are publicly accessible sites (e.g., a beach or an open green space) where people may sit or lie down on the ground surface.

[5] As sponsored by the Bureau of Ocean Energy Management (BOEM), the Hutchison et al. (2018) research study compared modeled MF levels with field measurements of actual MF levels in the proximity of the 30-MW 60-Hz "sea2shore" cable, which was commissioned in 2016 to connect the Block Island wind energy project with the Rhode Island mainland grid. The authors found measured MF levels to be substantially lower than the modeled values, which did not take into account the three-conductor twisted design: "The magnetic field produced by the AC sea2shore cable (range of 0.05-0.3 μT) was ~10 times lower than modeled values commissioned by the grid operator, indicating that the three-conductor twisted design achieves significant self-cancellation" (Hutchison et al., 2018).

3.4 MF Modeling Results for Submarine Cable Installation Scenarios

The results of the MF modeling for the representative seabed and landfall site submarine cable installation scenarios are summarized in Table 3.3 and Figures 3.2 through 3.7. As shown in the table and each of the figures, the highest modeled MF levels for these submarine cable installation scenarios occur directly above the submarine cables. Consistent with the compact bundling of the conductors within the three-core submarine export cables, these plots show rapid reductions in MF with increasing distance from the conductor centerlines. Due to the rapid reductions in MF levels with distance away from the cables, there is minimal interaction of MF from adjacent cables for both the 164-ft (50-m; seabed case) and 90-ft (27.4-m; Shore St. beach and transition joint bay) spacing intervals modeled for the cable installation cases.

Importantly, the lack of interaction of MFs from adjacent Mayflower Wind submarine cables supports the lack of any significant interaction between the Mayflower Wind submarine cables and the Vineyard Wind submarine cables along segments of the offshore export cable routes where they will come into proximity of each other, except where cable crossings may be required. Specific details of cable proximity and crossing will be determined as further details of planned cables are available.

Table 3.3. Modeled Magnetic Fields at the Seafloor/Ground Surface for Project Submarine Export Cables

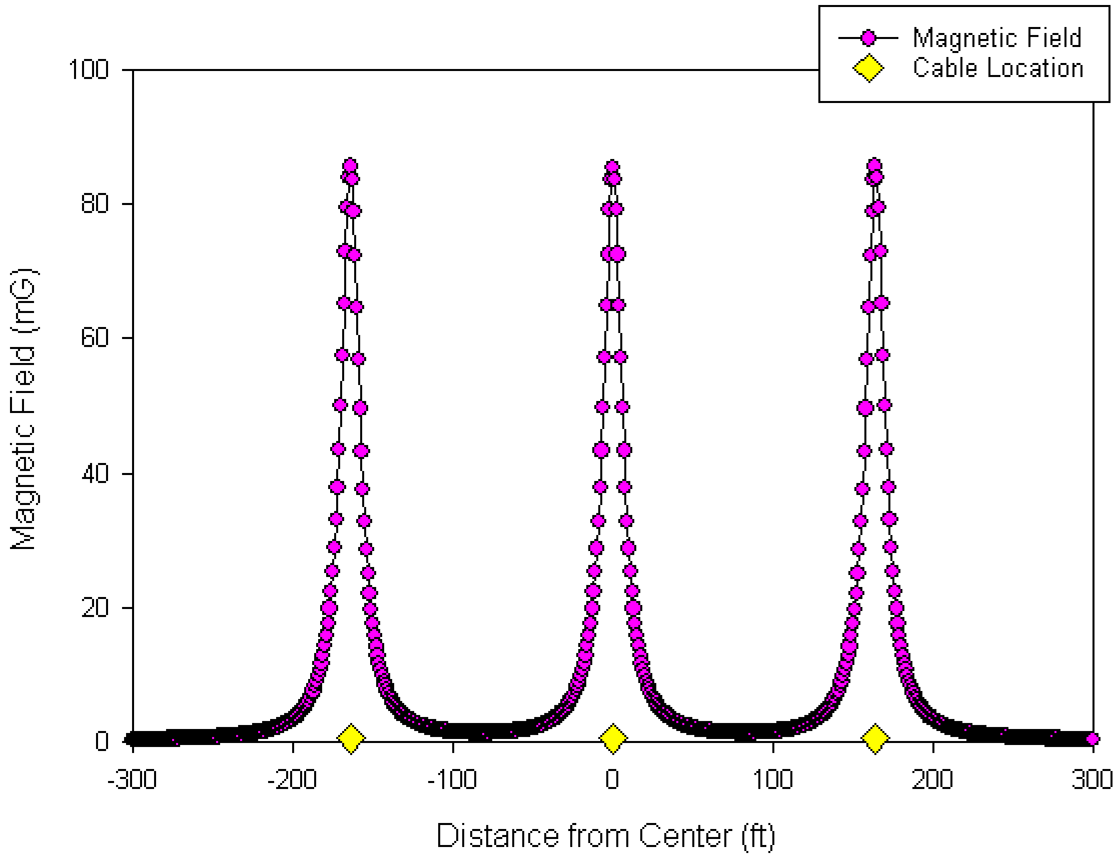
Installation Scenario	Predicted Resultant Magnetic Field (mG)		
	Maximum Directly Above Cable Centerline[a]	±10 ft (± 3 m) from Outer Cables[b]	±25 ft (± 7.6 m) from Outer Cables[b]
Seabed – Likely case	85.5	28.8	6.5
Seabed – Conservative case	1,859	41.9	6.9
Landside Beach – Worcester Ave.	3.8	3.4	2.8
Landside Beach – Shore St.	39.3	20.5	6.2
Transition Joint Bay – Worcester Ave.	77.2	36.8	10.3
Transition Joint Bay – Shore St.	86.0	28.8	6.8

Notes:

ft = Foot; m = Meter; mG = Milligauss.

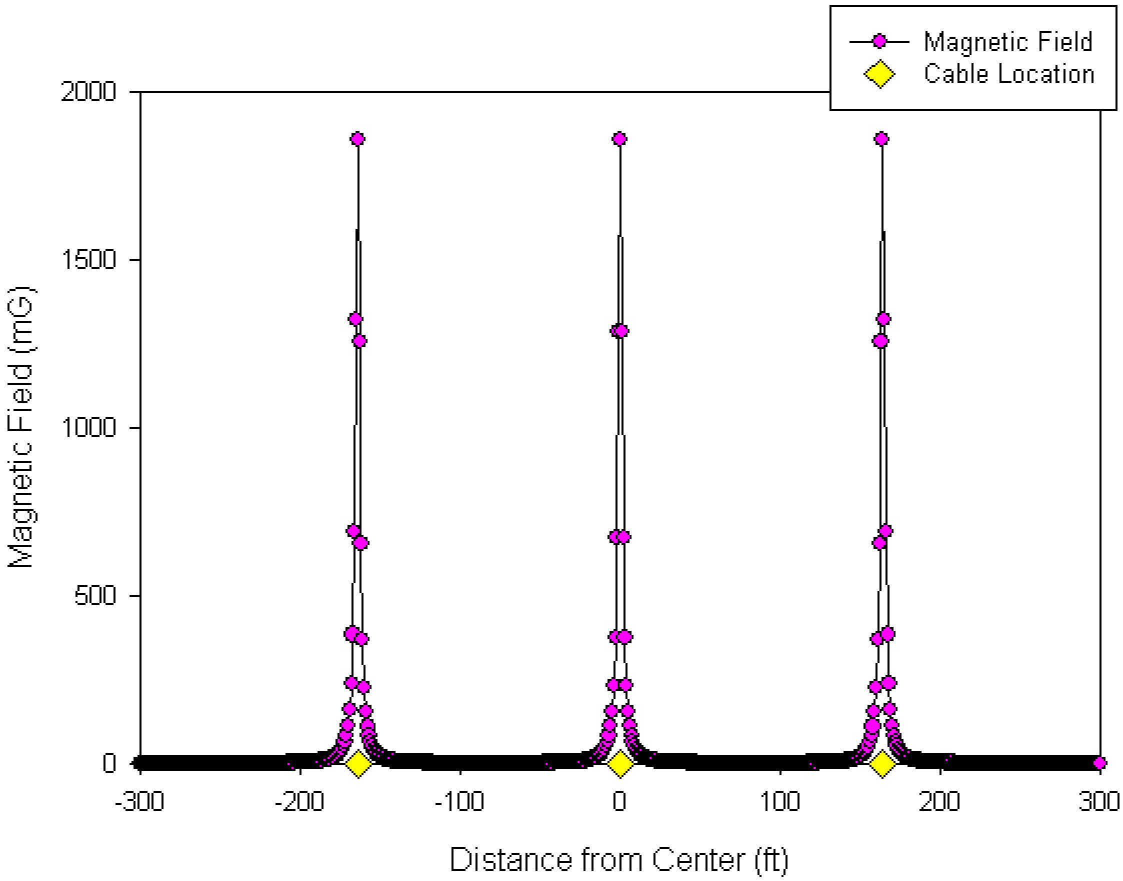
(a) The maximum magnetic field is the field projected to occur at the location of closest approach to the cable. For buried cables, this corresponds to the seafloor or ground surface. For the cable laid on the seafloor, magnetic fields were modeled at 1 ft (0.3 m) above the cable under the assumption that the cable will be covered with a 1-ft thick (0.3-m thick) mattress.

(b) The values provided at lateral distances of 10 and 25 ft are for 10 and 25 ft from the outer cables. Only one value is presented for each lateral distance because the predicted results for the left and right of the cables are identical.



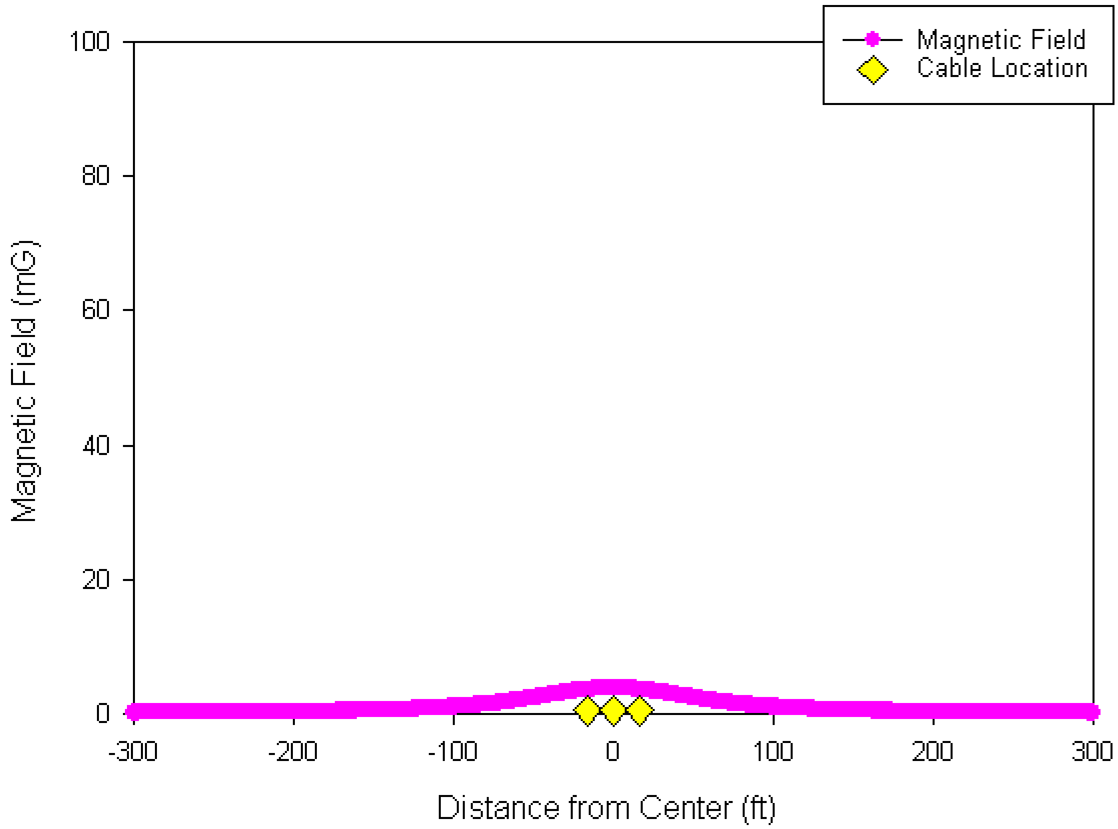
Notes:
A RMS = Amperes Root Mean Square; ft = foot; m = Meter; mG = Milligauss.
Modeling results are based on three submarine export cables each carrying 1,200 A RMS, 164-ft (50-m) cable spacing, and a cable burial depth of 6.6 ft (2 m).
The conductor locations on the graphs are not to scale and are provided to show relative locations.

Figure 3.2. Magnetic Field Modeling Results at the Seafloor for the "Likely" Case of Buried Project Submarine Export Cables.



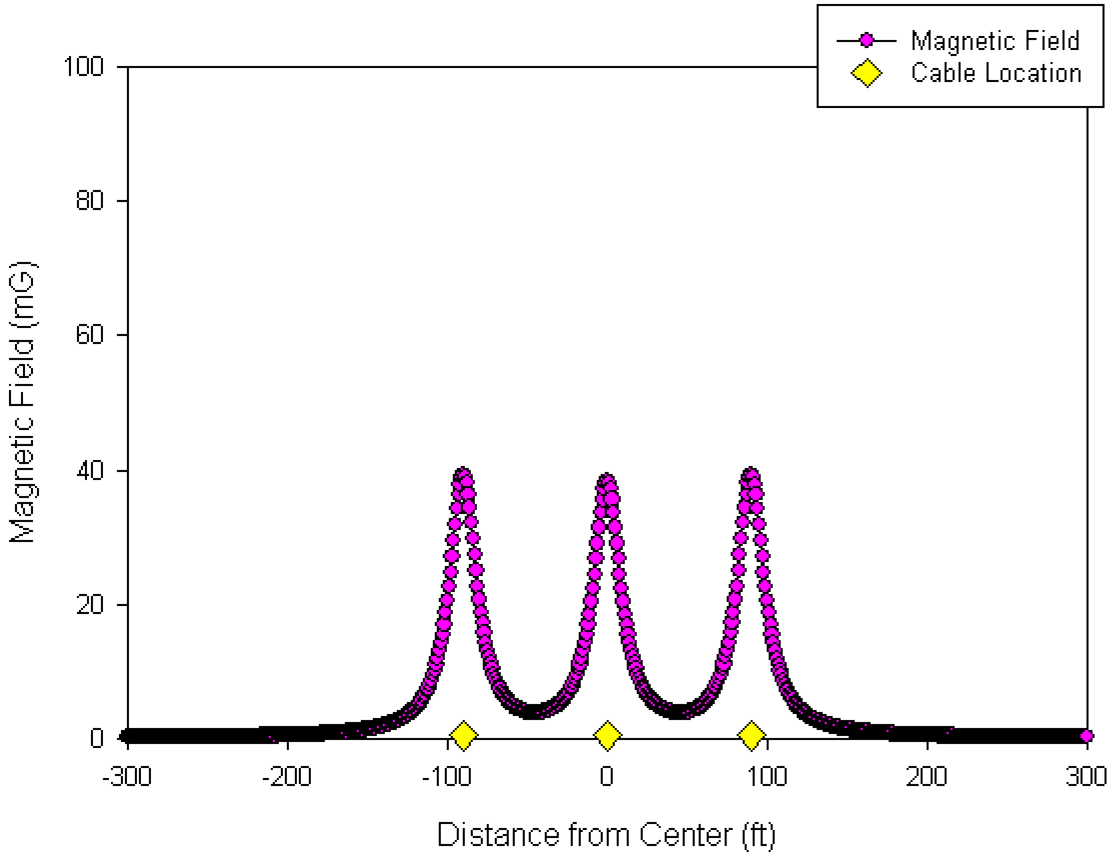
Notes:
A RMS = Amperes Root Mean Square; ft = foot; m = Meter; mG = Milligauss.
Modeling results are based on three submarine export cables each carrying 1,200 A RMS, 164-ft (50-m) cable spacing, and mattress-covered cables installed directly on the seafloor surface.
A 1-ft thick (0.3-m thick) concrete mattress is assumed to cover each submarine cable, extending out to a distance of 4 ft (1.2 m) from the cable centerlines.
The conductor locations on the graphs are not to scale and are provided to show relative locations.

Figure 3.3. Magnetic Field Modeling Results at the Seafloor for the Conservative Installation Case of Unburied Project Submarine Export Cables.



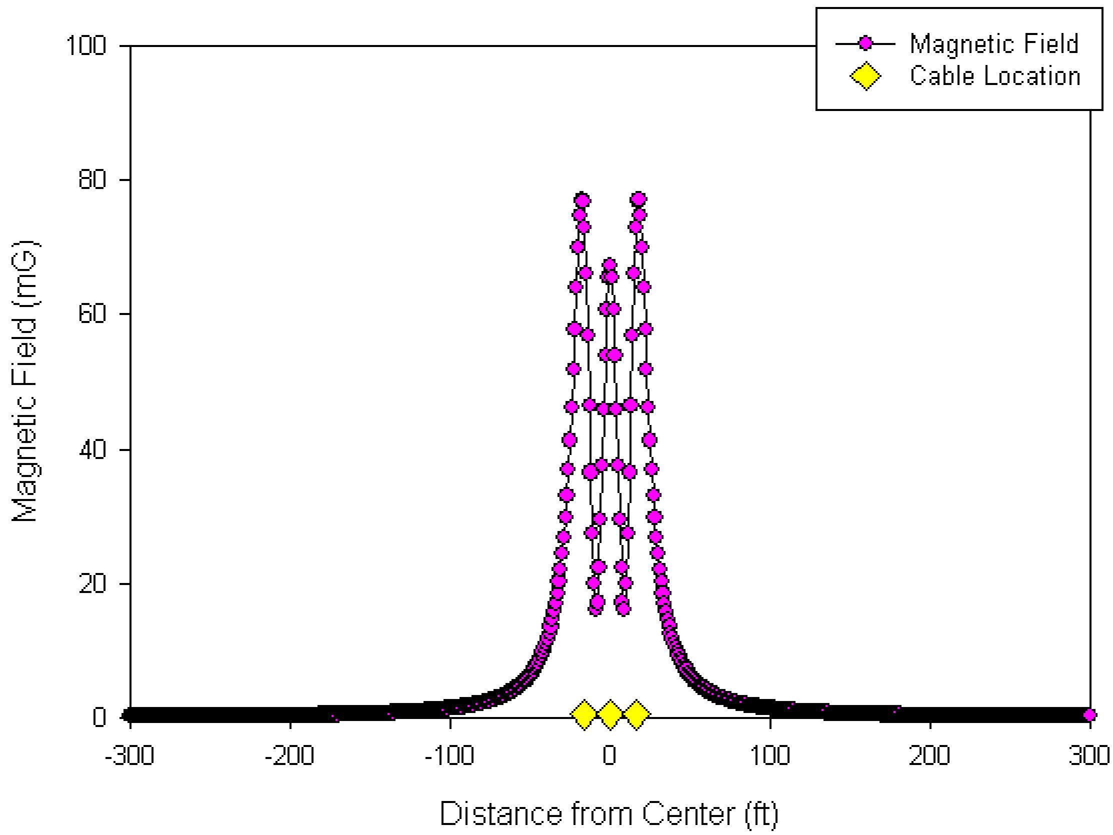
Notes:
A RMS = Amperes Root Mean Square; EMF = Electric and Magnetic Field; ft = foot; = Meter; mG = Milligauss.
Modeling results are based on three submarine export cables each carrying 1,200 A RMS, cable burial depth of 52.8 ft (16.1 m), and cable separation of 16.4 ft (5 m). The conductor locations on the graphs are not to scale and are provided to show relative locations. Notably, the results project magnetic fields at the ground (beach) surface, rather than the 3.3 ft (1 m) above grade height typically used for onshore EMF analyses.

Figure 3.4. Magnetic Field Modeling Results at the Ground Surface of the Landside Beach Installation Case at Worcester Ave. for the Project Submarine Export Cables.



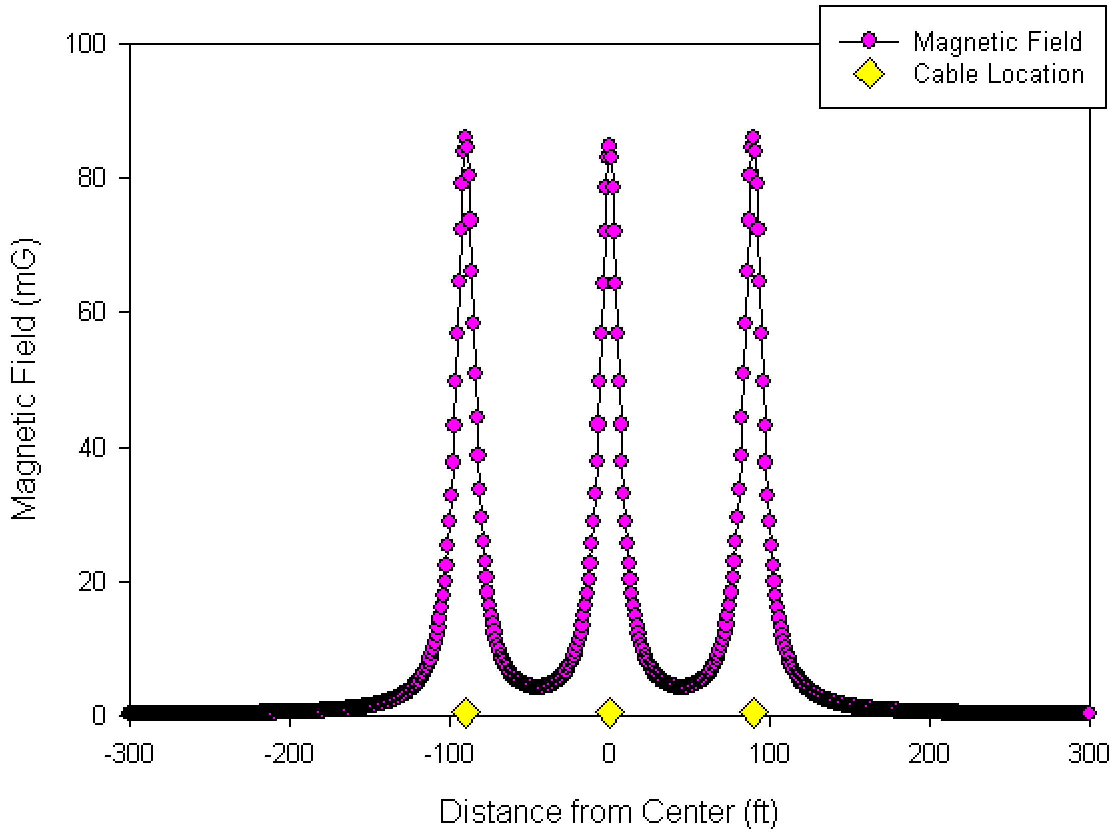
Notes:
A RMS = Amperes Root Mean Square; EMF = Electric and Magnetic Field; ft = foot; m = Meter; mG = Milligauss.
Modeling results are based on three submarine export cable carrying 1,200 A RMS, and, cable burial depth of 9.8 ft (3 m), and cable separation of 90 ft (27.4 m). The conductor locations on the graphs are not to scale and are provided to show relative locations. Notably, the results project magnetic fields at the ground surface, rather than the 3.3 ft (1 m) above grade height typically used for onshore EMF analyses.

Figure 3.5. Magnetic Field Modeling Results at the Ground Surface of the Landside Beach Installation Case at Shore St. for the Project Submarine Export Cables.



Notes:
A RMS = Amperes Root Mean Square; EMF = Electric and Magnetic Field; ft = foot; m = Meter; mG = Milligauss.
Modeling results are based on three submarine export cables each carrying 1,200 A RMS, cable burial depth of 6.6 ft (2 m), and cable separation of 16.4 ft (5 m). The conductor locations on the graphs are not to scale and are provided to show relative locations. Notably, the results project magnetic fields at the ground surface, rather than the 3.3 ft (1 m) above grade height typically used for onshore EMF analyses.

Figure 3.6. Magnetic Field Modeling Results at the Ground Surface of the Transition Joint Bay Installation Case at Worcester Ave. for the Project Submarine Export Cables.



Notes:
A RMS = Amperes Root Mean Square; EMF = Electric and Magnetic Field; ft = foot; m = Meter; mG = Milligauss.
Modeling results are based on three submarine export cable carrying 1,200 A RMS, cable burial depth of 6.6 ft (2 m), and cable separation of 90 ft (27.4 m). The conductor locations on the graphs are not to scale and are provided to show relative locations. Notably, the results project magnetic fields at the ground surface, rather than the 3.3 ft (1 m) above grade height typically used for onshore EMF analyses.

Figure 3.7. Magnetic Field Modeling Results at the Ground Surface of the Transition Joint Bay Installation Case at Shore St. for the Project Submarine Export Cables.

As shown in Figure 3.3, the installation of the submarine cables directly on the seafloor surface rather than at the anticipated burial depth of 6.6 ft (2 m) is predicted to result in significantly higher MF levels in close proximity to the cables. In particular, the peak MF level directly above the cables, as predicted at the seafloor surface above the buried cables or on top of a 1-ft thick (0.3-m thick) concrete mattress for the cables laid on the seafloor surface, increased from about 86 mG to 1,859 mG. However, as illustrated in Figure 3.3 and Table 3.2, the MF levels rapidly decrease with distance from the cables when they are laid on the seafloor surface, such that at distances (both laterally and vertically) of 25 ft (7.6 m) and greater, MF levels are indistinguishable from levels for the buried cables.

These modeled MF are not expected to adversely impact marine organisms, including benthic organisms. This is because: (1) the design and installation of the submarine cables result in 60-Hz EMFs that diminish very rapidly with distance from the cables, (2) the AC EMF averages to zero every 1/60th of a second, and (3) the spatial extent of the fields is very limited, dropping to low values horizontally within about 25 ft (7.6 m) from the cable centerline and likewise vertically beyond about 25 ft (7.6 m) above the seafloor. While the ability of certain marine life to sense small changes in the size and direction of steady DC MF (such as the Earth's MF of >500 mG) has been documented, sensory ability and navigation related to AC

MF of the magnitude considered in this report have not been demonstrated in marine species. That is, for rapidly changing (AC) MF, sensitivity has not been reported (and may not exist); thus, undersea species would not be expected to respond to 50- to 60-Hz MFs, such as those associated with submarine electric-power cables (CSA Ocean Sciences Inc. and Exponent, 2019). In general, AC MF acting on a compass-like magnetic sensing system (e.g., ferromagnetic particles) would have a time-average force of zero over a complete cycle (0.017 seconds). Therefore, such rapidly time-changing fields would not be detected as an MF deviation and would not be expected to interfere with the navigation sense of magnetosensitive marine organisms. Recognizing that these fields are also of a different frequency than the bioelectric fields generated by marine organisms (60 Hz versus a typical bioelectric field frequency of 0 to 10 Hz), the weak AC electric fields induced by the AC MFs produced by submarine cables are known to be substantially smaller in strength than marine organism bioelectric fields (CSA Ocean Sciences Inc. and Exponent, 2019).

Figures 3.4 and 3.5 show the results of MF modeling for the landside edge of the beaches at the potential landfall sites on Worcester Ave. and Shore St., respectively. MF levels are predicted directly at the ground surface, assuming that people may be lying or sitting on the beach. The highest modeled peak MF level at Shore St. is 39 mG. The highest modeled peak MF level at Worcester Ave. is about tenfold lower, at 3.8 mG, which can be attributed to the greater cable burial depth (53 ft [16.1 m] compared to 10 ft [3 m]).

Figures 3.6 and 3.7 show the results of MF modeling for the transition joint bays at the landfall sites on Worcester Ave. and Shore St., respectively. MF levels are predicted directly at the ground surface, assuming that the transition joint bays will be located near a beach or in an open space where people may sit or lie down on the ground surface. The highest modeled peak MF level at the Shore St. transition joint bay is 86 mG, and the peak MF level at the Worcester Ave. transition joint bay is 77 mG. Note that, at the Worcester Ave. location, the peak MF levels occur above the outer cable centerlines, due to partial MF cancellation over the center cable. These results are higher than their respective landside beach locations due to the shallower burial depth (6.6 ft [2 m] at both transition joint bays). Similar to the other submarine cable installation scenarios, MF levels drop off very rapidly with lateral (and vertical) distance from the cables, falling to MF levels of about 10 mG (Worcester Ave.) and 6.8 mG (Shore St.) at a distance of 25 ft (7.6 m) laterally from the outer cables. For the landside beach and transition joint bay installation scenarios, the modeled MFs at the ground surface are well below the ICNIRP health-based guideline of 2,000 mG for allowable public exposure to 60-Hz magnetic fields (ICNIRP, 2010.

3.5 EMF Avoidance, Minimization and Mitigation Measures for Submarine Cable Installation Scenarios

As discussed throughout this report, several elements of the Project design will contribute to the avoidance, minimization, and mitigation of EMF produced by the submarine export cables. These design components include:

- The anticipated burial depth of 3 – 53 ft (2 – 16 m) for the submarine cables;
- The cable design, which includes compact conductor bundling in a trefoil formation and twisting of the conductors;
- Both ends bonding of the submarine cable metallic sheaths that will result in induced sheath currents producing MFs that act to decrease the overall cable MF; and
- An offshore cable route that minimizes the number of crossings with other submarine cables where practicable.

4 MF Modeling for Onshore Transmission Route

4.1 Software Program Used for Modeling MF Levels for Onshore Cable Installation Scenarios

MF modeling was conducted by Burns & McDonnell using the CYMCAP ampacity program (version 8.0, revision 2) from the CYME suite of power engineering software tools (www.cyme.com/software). The magnetic fields module in CYMCAP computes the 2-D magnetic flux density as a function of the x,y coordinates of the cables and the location where the magnetic flux is to be computed. To perform the magnetic fields calculations, the following assumptions are used:

- The length of the cable is much larger than the cross-sectional area that was modeled and therefore the infinite-length thin-wire two-dimensional approach is used;
- All media is assumed homogenous, isotropic, and linear electromagnetically speaking;
- Balanced currents were assumed;
- The earth resistivity effects (eddy currents in the earth) are neglected;
- The induced currents in any component in the installation are neglected; and
- No provisions are made to account for field distortions and saturations caused by any magnetic component at or near the cable installation (above ground or underground).

Burns & McDonnell provided Gradient with spreadsheets containing the CYMCAP MF modeling inputs (Tables 4.1 and 4.2) and output results (Table 4.3 and Figures 4.8 through 4.13) for presentation in this report.

4.2 Onshore Export Cable Specifications

Table 4.1 provides a summary of the onshore export cable specifications used in the MF modeling analysis and Figure 4.1 provides an example schematic of the type of onshore export cable for Project usage. The onshore underground cable options consist of up to three circuits with three cables per circuit for a total of up to nine cables. The circuits are planned to be installed in one or more duct banks. Each duct bank will contain 8-in (20.32-cm) polyvinyl chloride (PVC) or PE conduits for cables and 2-in (5.08-cm) conduits for fiber optic cables and ground continuity cables.

The cable studied is from the 300-kV rated voltage class. The high voltage cable system may be up to 362 kV in rating. Such cables from the 245-kV and 362-kV voltage class very closely resemble the cable from the 300-kV rated cable, the main difference being the thickness of insulation. It is very likely the same duct layouts would be used if the nominal voltage of the export cables were to go up or down a voltage class.

Table 4.1. Indicative Onshore Cable Specifications for a Maximum Conductor Size Used for EMF Modeling.

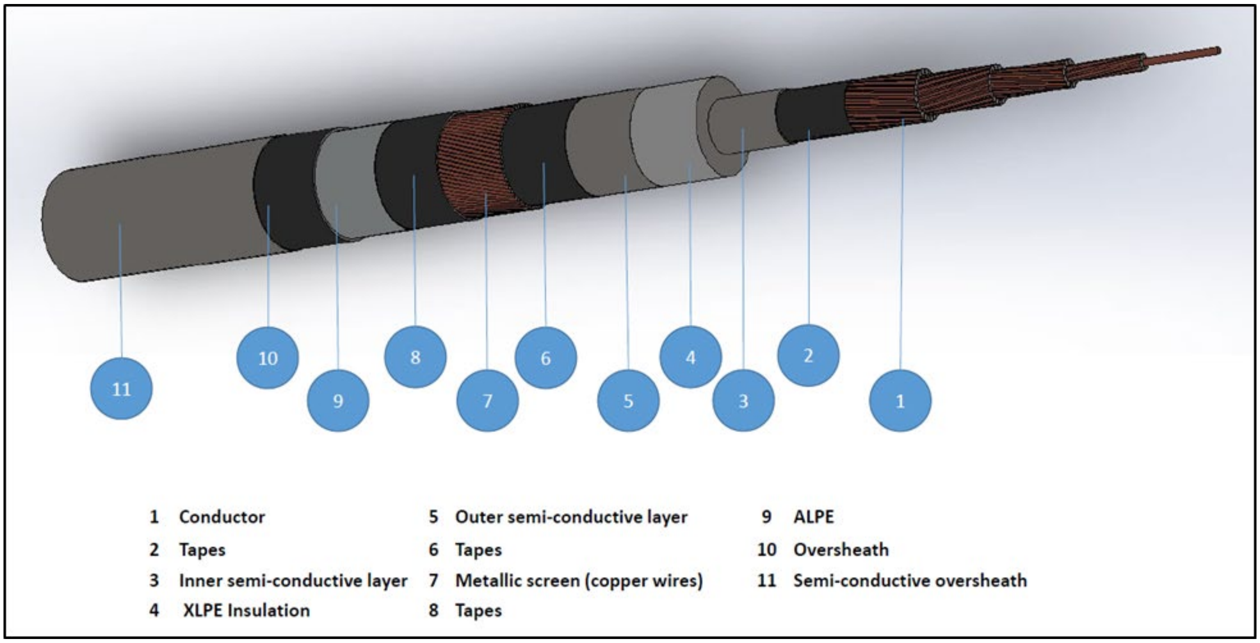
Cable Specification or Feature	Parameter[(a)]
Mechanical Parameters	
Conductor Area	2,500 mm^2
Cable Overall Diameter	129.2 mm
Conductor Material	Copper
Conductor Diameter	61.4 mm
Conductor Shield Thickness	2.0 mm
Conductor Shield Diameter	65.4 mm
Insulation Material	XLPE Unfilled
Insulation Thickness	25.0 mm
Insulation Diameter	115.3 mm
Insulation Screen Material	Semi Conducting Screen
Insulation Screen Thickness	1.5 mm
Insulation Screen Diameter	118.3 mm
Concentric Skid Wire Material	Copper
Number of Skid Wires	56
Skid Wire Gauge	14
Skid Wire Thickness	1.6 mm
Skid Wire Diameter	121.6 mm
Jacket Material	Polyethylene
Jacket Thickness	3.81 mm
Jacket Diameter	129.2 mm
Electrical Parameters[(a)]	
Current type and frequency	Alternating current 60 Hz
Rated voltage	300 kV
Conductor current (RMS)[(b)]	1,200 A

Notes:

A = Ampere; Hz = Hertz; kV = Kilovolt; mm = Millimeter; RMS = Root Mean Square.

(a) Data are for steady-state conditions only, not fault conditions.

(b) The currents include the effects of charging currents (*i.e.*, the additional electric current that occurs as the line proceeds from the offshore substation platforms toward the onshore substation, because the cable system power cores act to some degree like a capacitor that needs to be charged and discharged in addition to delivering actual electrical power to the onshore substation).



Notes:
ALPE = Aluminum Bonded Polyethylene; XLPE = Cross-Linked Polyethylene.
Source: Hellenic Cables

Figure 4.1. Example Onshore Export Cable Cross Section Illustration.

4.3 Modeled Onshore Export Cable Installation Scenarios

Modeling was performed for six representative installation scenarios consisting of up to 3 underground circuits, with three export cables per circuit, for a total of up to nine cables, each with a maximum RMS current of 1,200 A:

- Three cable circuits arranged in a 2-deep-by-5-wide (2D×5W) duct bank configuration;
- Two cable circuits in a 3-deep-by-2-wide (3D×2W) duct bank configuration;
- One cable circuit in a 2-deep-by-2-wide (2D×2W) duct bank configuration;
- One cable circuit in a 1-deep-by-4-wide (1D×4W) duct bank configuration;
- One cable circuit in a splice vault 3-deep-by-2-wide (3D×2W) duct bank configuration; and
- Three cable circuits in a buried trefoil (delta) configuration.

Table 4.2 summarizes the modeling parameters of the Mayflower Wind onshore export cable MF modeling cases. The cable currents in Table 4.2 represent maximum loadings for the cables that are conservative values from a power simulation assuming maximum wind turbine output (100 percent capacity). While the cable and loading are based on a 275-kV nominal operating voltage, Mayflower Wind does not expect the RMS cable currents to exceed these values even for other operating voltages, due to thermal constraints on the cable system. Balanced phase currents were assumed for the cables.

Table 4.2. Summary of Modeling Parameters for Onshore Export Cable Installation Scenarios.

Installation Scenario	Burial Depth[a]	No. of Cable Circuits	Max. Cable Current (A RMS)
2D×5W Duct Bank	3 ft (0.9 m)	3	1,200
3D×2W Duct Bank	3 ft (0.9 m)	2	1,200
2D×2W Duct Bank	3 ft (0.9 m)	1	1,200
1D×4W Duct Bank	3 ft (0.9 m)	1	1,200
Splice Vault	3 ft (0.9 m)	1	1,200
Trefoil Duct Arrangement	3 ft (0.9 m)	3	1,200

Notes:
A RMS = Ampere Root Mean Square; ft = Foot; m = Meter.
(a) Burial depth to top of duct bank.

The configurations and phasing arrangements of the onshore export cable circuits in the six installation scenarios are shown in Figures 4.2 through 4.7. For each onshore export cable cross section, aboveground MF strengths were modeled as a function of horizontal distance, perpendicular to the direction of current flow. Per standard industry practices (IEEE Power Engineering Society, 1995a,b), MF levels were modeled at a height of 3.28 ft (1 m) above the ground surface to represent the exposure of an upright person. With the exception of the direct burial installation scenario, each phase conductor was assumed to lie in the bottom of 8-in (20.32-cm) PVC conduits. A minimum cover depth of 3 ft (0.91 m) was assumed to the top of the duct bank for all duct bank variations, or to the top of the directly buried cables.

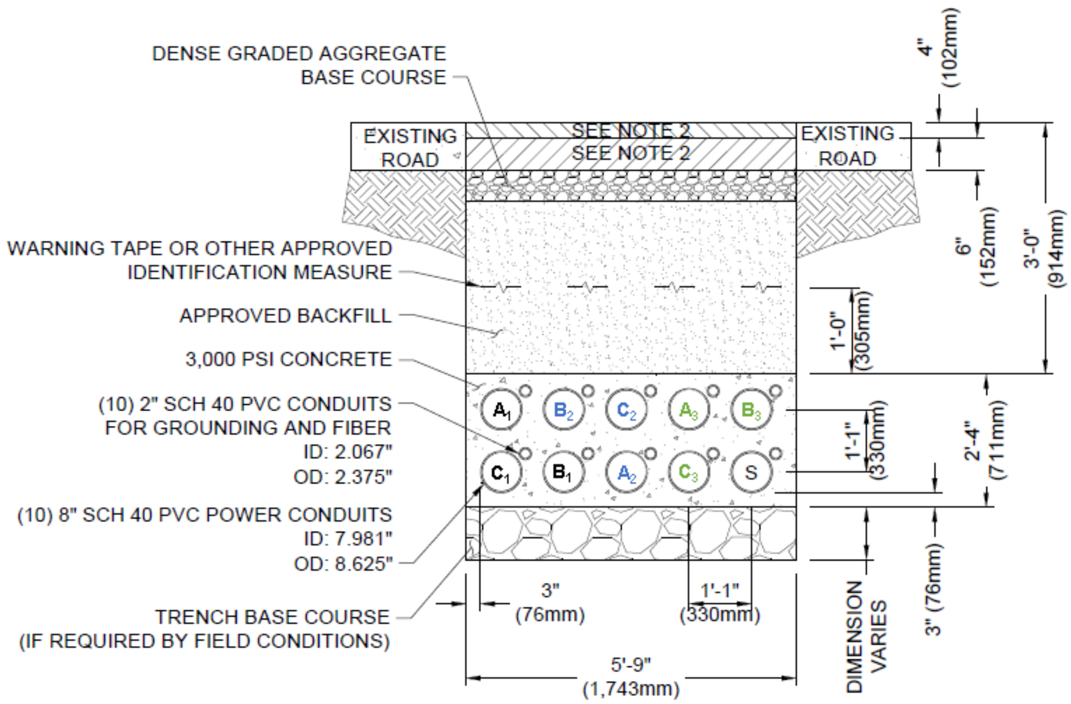


Figure 4.2. Cross-Sectional View of Three-Circuit 2D×5W Duct Bank for the Onshore Export Cables.

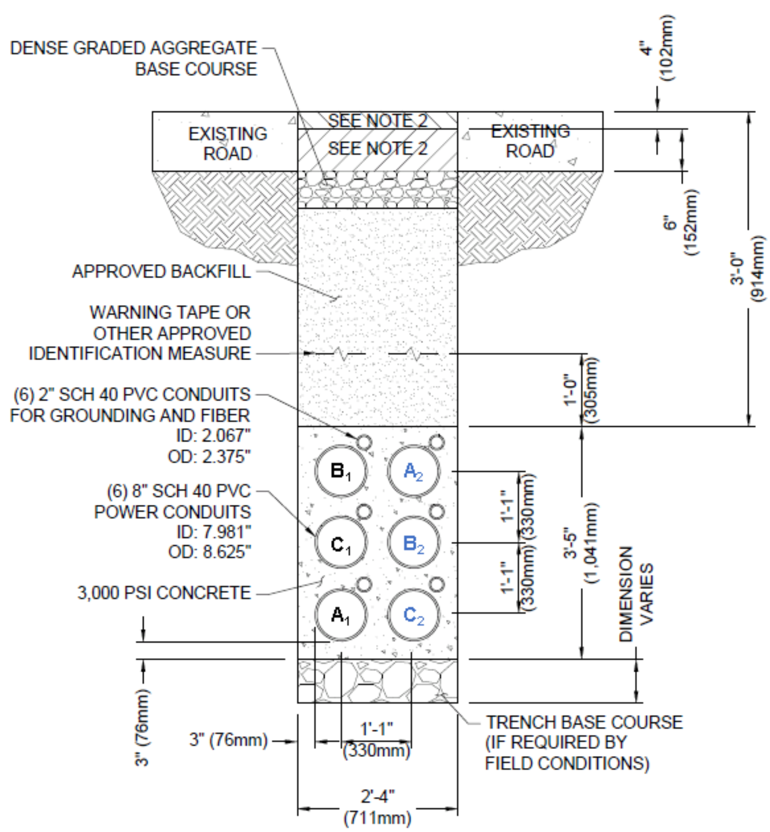


Figure 4.3. Cross-Sectional View of Two-Circuit 3D×2W Duct Bank for the Onshore Export Cables.

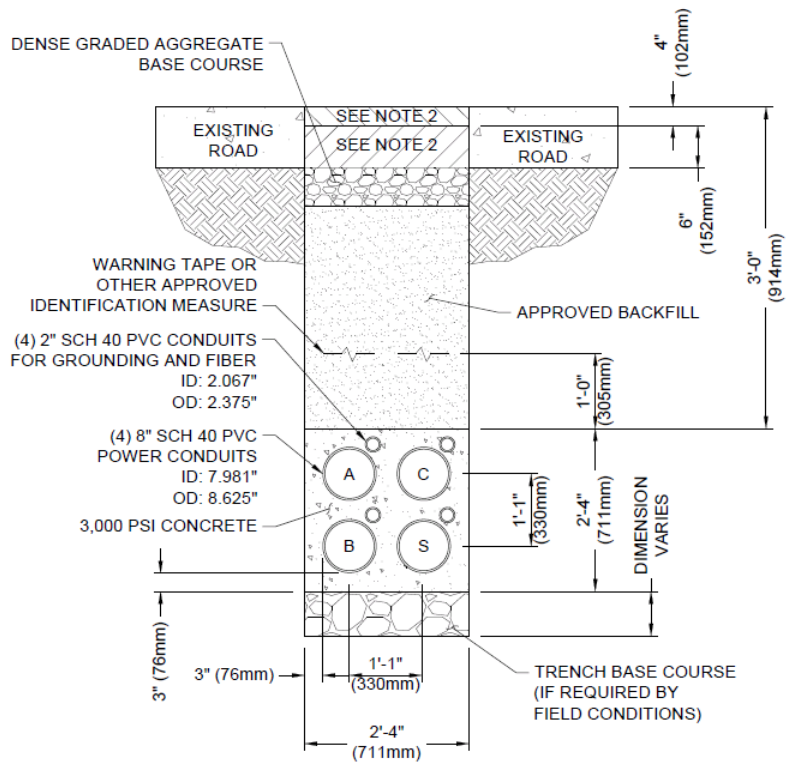


Figure 4.4. **Cross-Sectional View of Single Circuit 2D×2W Duct Bank for the Onshore Export Cables.**

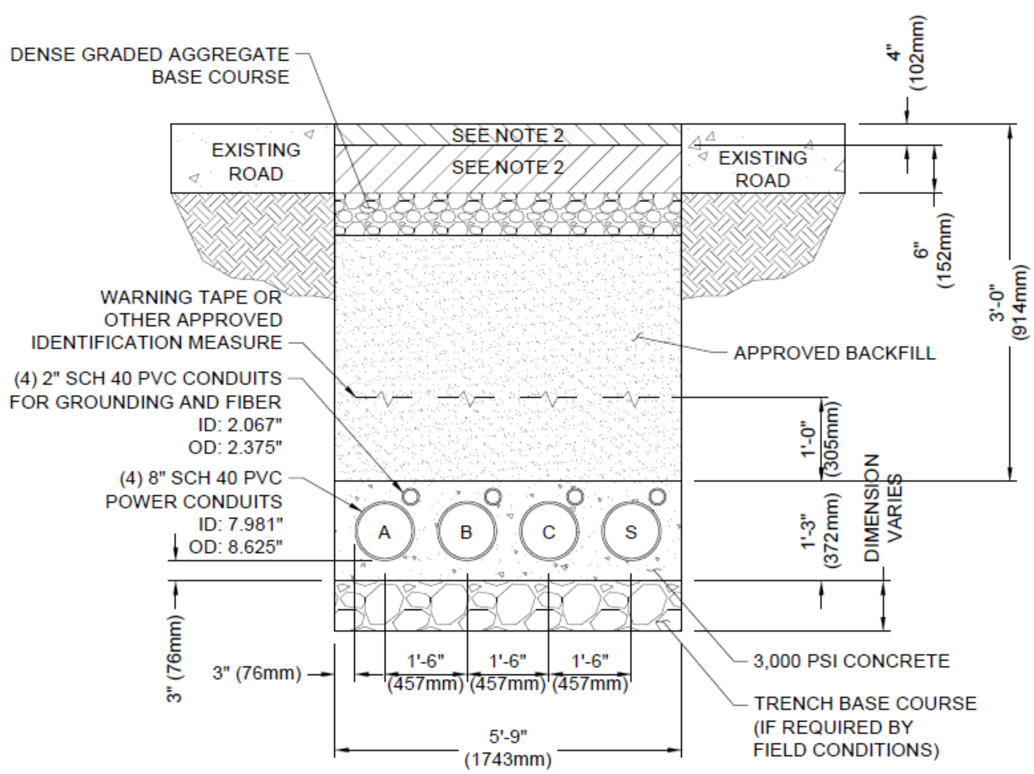


Figure 4.5. **Cross-Sectional View of Single Circuit 1D×4W Duct Bank for the Onshore Export Cables.**

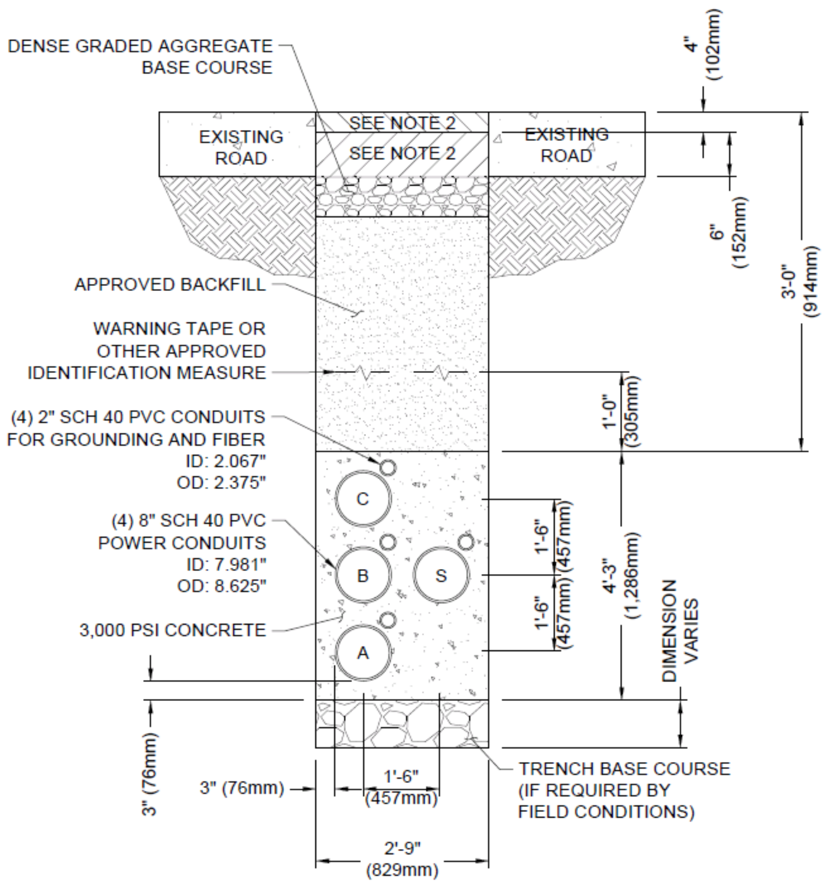


Figure 4.6. **Cross-Sectional View of Single Circuit Splice Vault for the Onshore Export Cables.**

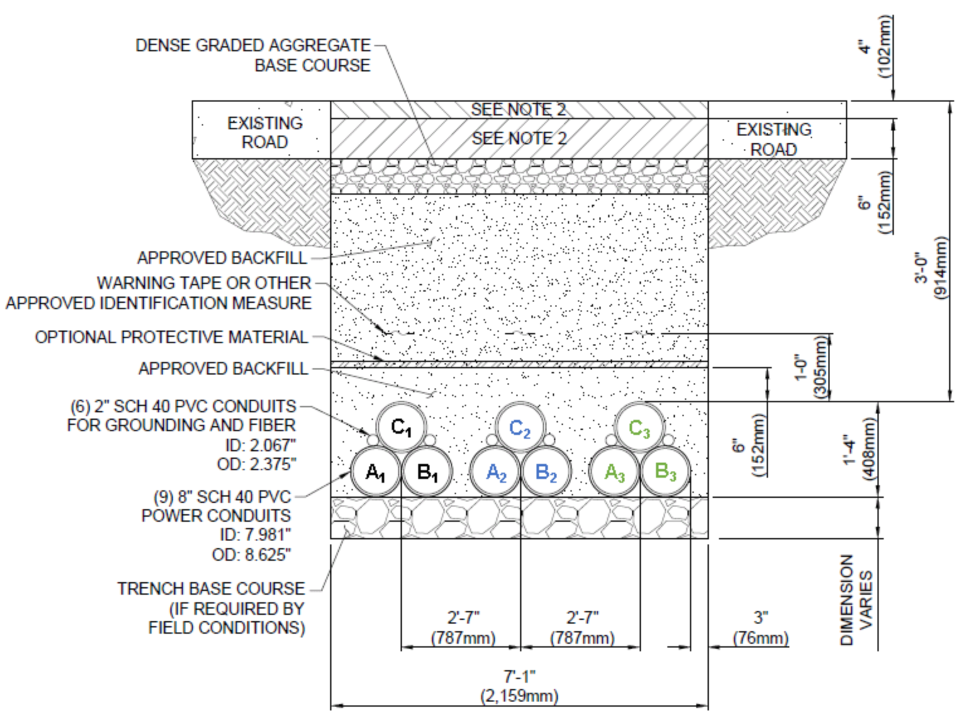


Figure 4.7. **Cross-Sectional View of Three-Circuit Trefoil Ducts for the Onshore Cables.**

Conductor phasing for the circuits was arranged to achieve cancellation of MFs for the three-circuit 2D×5W duct bank installation case. It bears mentioning that the modeling for the underground onshore export cables is expected to overpredict the magnitude of aboveground MF levels associated with the installed onshore export cables. This is because minimum expected burial depth was assumed, and the currents used for the phase conductors assume maximum wind turbine output (100 percent capacity). In addition, the MF modeling analyses did not account for the phase conductors' main currents inducing currents on ground continuity conductors in the duct banks. Any induced currents on ground conductors would be expected to produce an MF that would tend to oppose (partially cancel) the MF arising from the phase conductor currents (Istenic *et al*., 2001).

4.4 EMF Modeling Results for the Onshore Cable Installation Scenarios

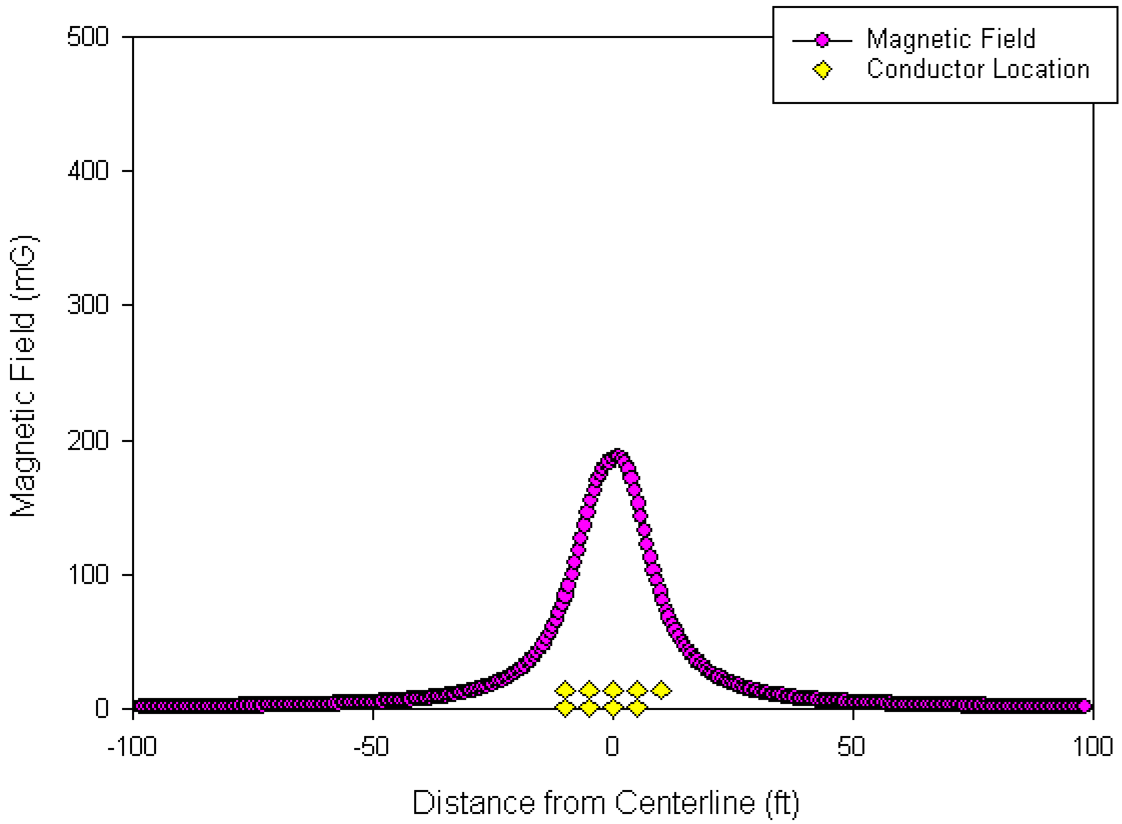
The results of the MF modeling for the representative onshore underground duct bank cross sections are summarized in Table 4.3 and Figures 4,8 through 4.13. As shown in the table and each of the figures, the highest modeled MF levels for the underground duct bank cross sections occur directly above the duct banks. These plots show reductions in MF with increasing distance from the duct bank centerlines (e.g., >80 percent reductions in MF levels at lateral distances of ±25 ft [±7.6 m] from the cables).

The modeled MFs, including those directly above the underground conductors, are all less than the ICNIRP health-based guideline of 2,000 mG for allowable public exposure to 60-Hz magnetic fields (ICNIRP, 2010). While MF levels at lateral distances of ±10 ft (~±3 m) from the cables, for most of the modeled installation scenarios, are greater than the Massachusetts guideline of 85 mG for MFs at ROW edges, it should be noted that this guideline is not health-based and was instead adopted in the 1980s to maintain the *status quo* for EMF levels on and near overhead transmission line ROWs. Nonetheless, together with the corresponding edge-of-ROW electric field guideline level of 1.8 kV/m and an emphasis on EMF mitigation, the MA EFSB has now used this MF guideline level in analyses and decisions on transmission-line projects for more than three decades. In more recent analyses and decisions on transmission-line projects, the MA EFSB has put greater emphasis on mitigation strategies for MF levels rather than a specific MF guidance level (MA EFSB, 2019).

Table 4.3. Modeled Magnetic Fields at 3.28 ft (1 m) Above the Ground Surface for Project Onshore Export Cables

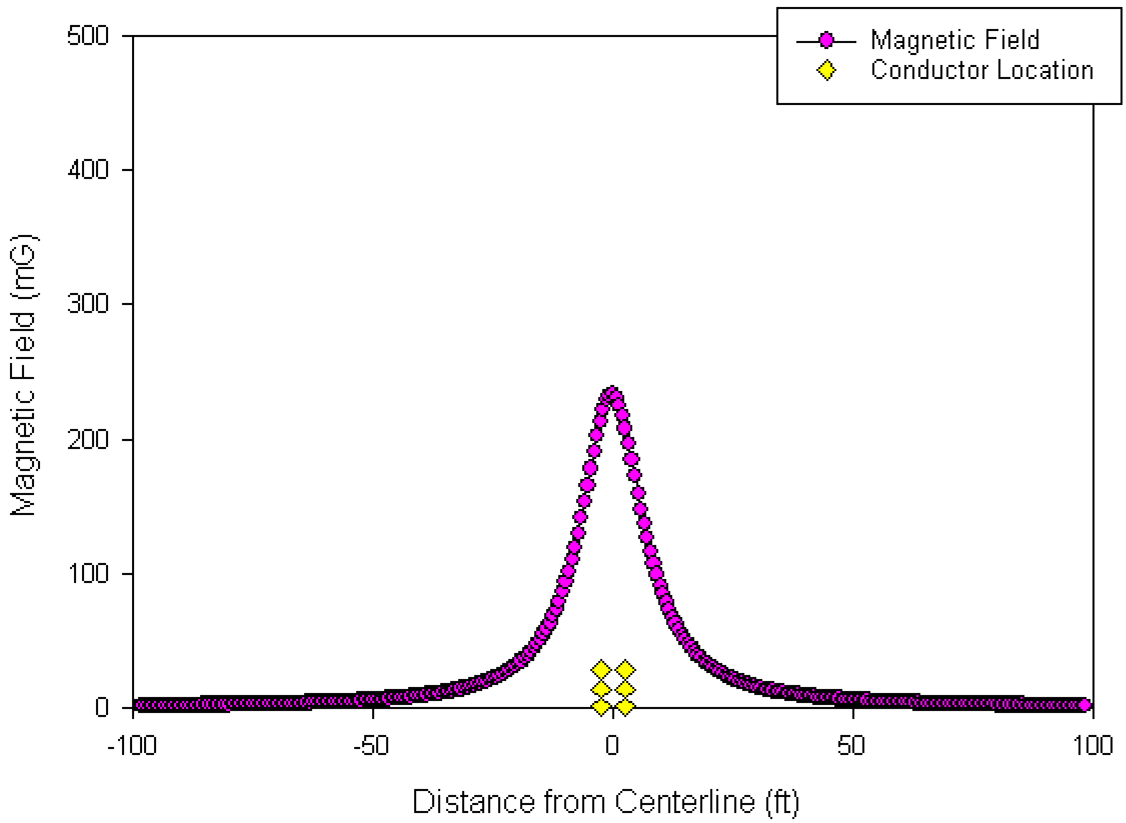
	Maximum Above Duct Bank[(a)]	±10 ft (±3 m) from Duct Bank Centerline[(b)]	±25 ft (±7.6 m) from Duct Bank Centerline[(b)]
2D×5W Duct Bank	187.1	84.0 / 86.9	18.3 / 18.6
3D×2W Duct Bank	223.4	93.0 / 91.1	21.6 / 21.5
2D×2W Duct Bank	220.0	80.8 / 78.4	18.0 / 17.7
1D×4W Duct Bank	403.3	156.7 / 128.1	32.4 / 29.0
Splice Vault	292.7	132.0 / 110.6	31.0 / 27.9
Trefoil Duct Arrangement	321.5	145.0 / 145.0	31.7 / 31.7

Notes:
ft = Foot; m = Meter; mG = Milligauss.
(a) The maximum magnetic field is the field projected to occur at the location of closest approach to the duct bank at 3.28 ft (1 m) above the ground surface.
(b) The values presented are the modeled fields at the given lateral distances from the duct bank centerline. The two values presented correspond to the fields to the left and right of the centerline, respectively.



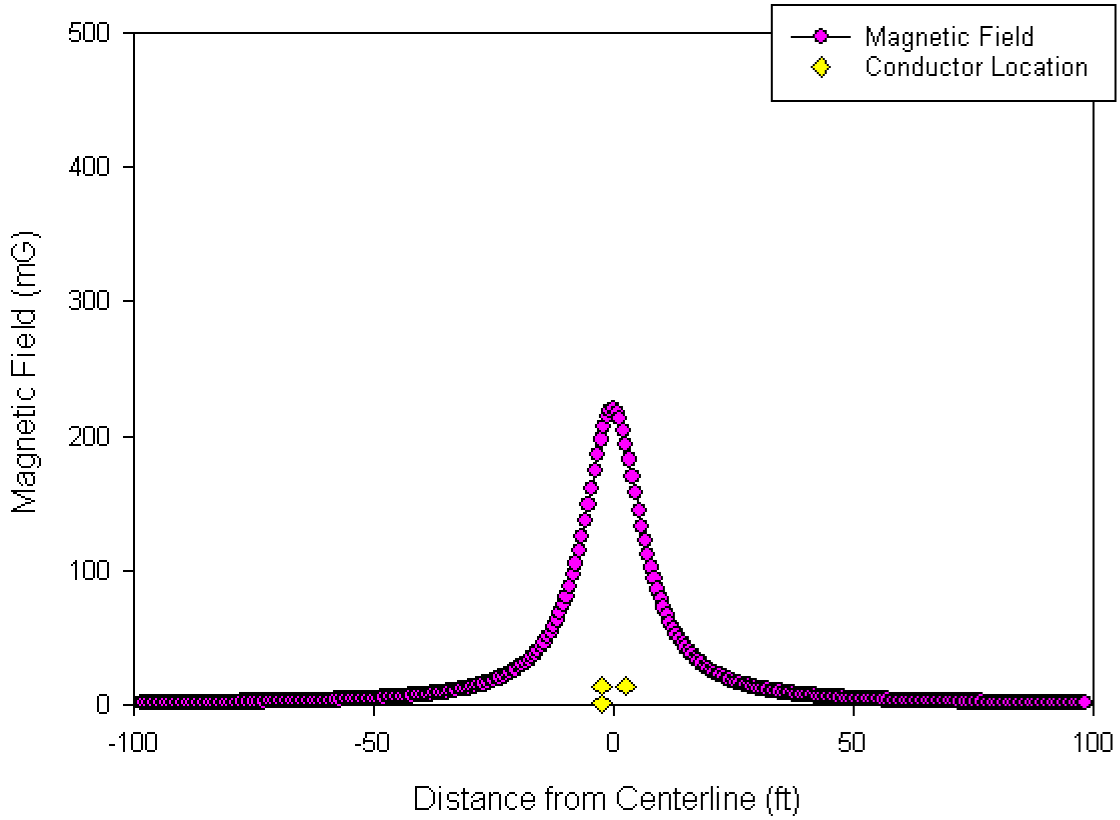
Notes:
A RMS = Amperes Root Mean Square; ft = foot; m = Meter; mG = Milligauss.
Modeling results are based on nine onshore export cables, each carrying 1,200 A RMS.
The top of the duct bank was assumed to be buried 3 ft (0.9 m) below ground surface.
The conductor locations on the graph are not to scale and are provided to show relative locations.

Figure 4.8. Magnetic Field Modeling Results for the 2D×5W Duct Bank Installation Scenario at 3.28 Feet (1 Meter) Above the Ground Surface for the Onshore Export Cables.



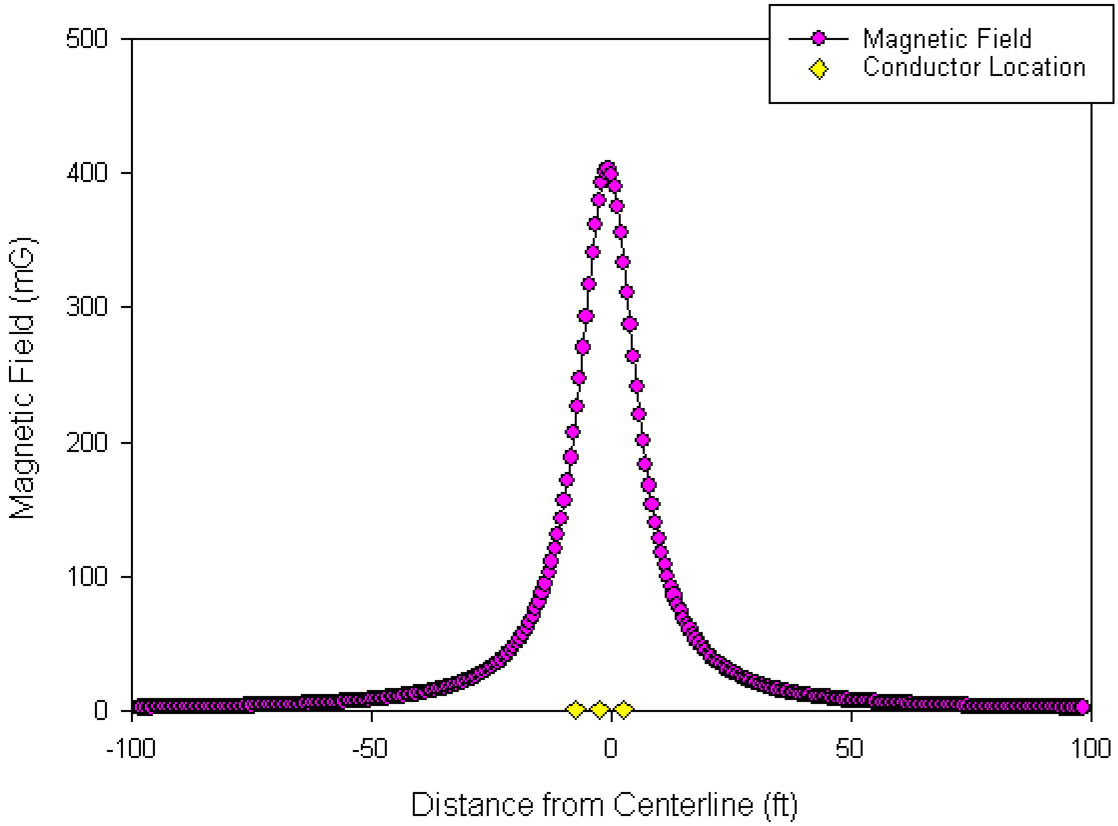
Notes:
A RMS = Amperes Root Mean Square; ft = foot; m = Meter; mG = Milligauss.
Modeling results are based on six onshore export cables, each carrying 1,200 A RMS.
The top of the duct bank was assumed to be buried 3 ft (0.9 m) below ground surface.
The conductor locations on the graph are not to scale and are provided to show relative locations.

Figure 4.9. Magnetic Field Modeling Results for the 3D×2W Duct Bank Installation Scenario at 3.28 Feet (1 Meter) Above the Ground Surface for the Onshore Export Cables.



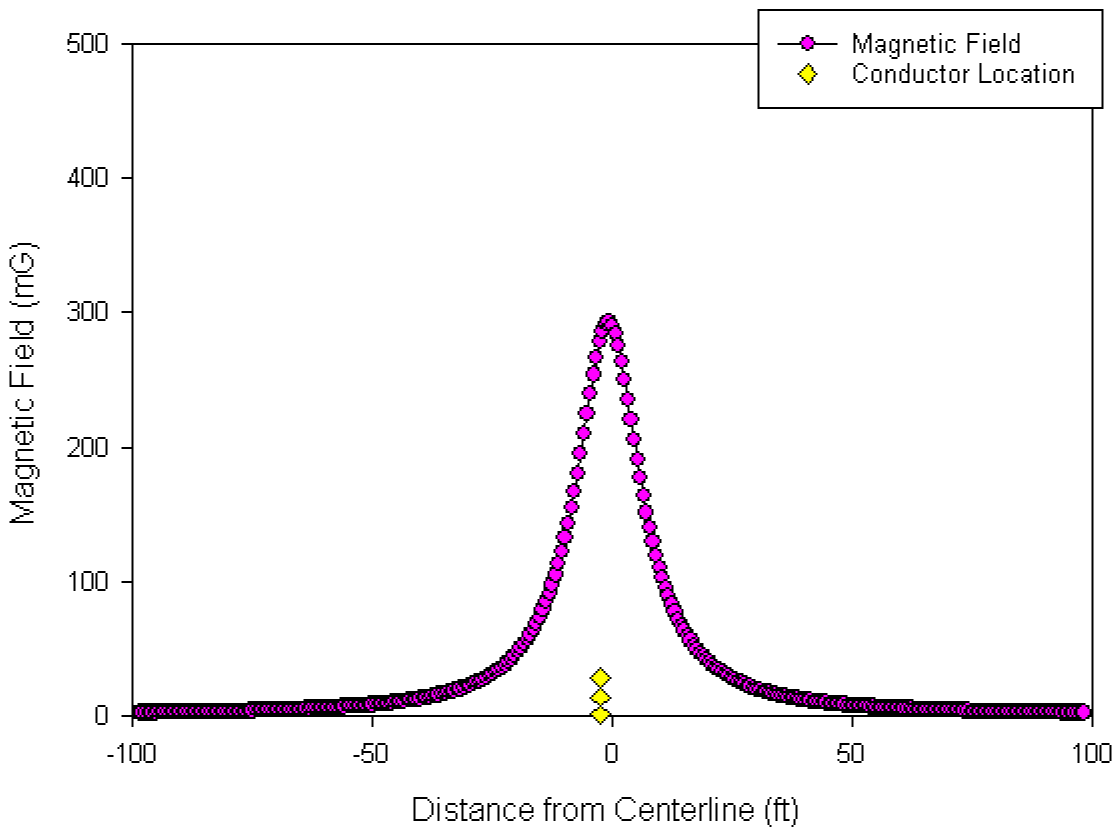
Notes:
A RMS = Amperes Root Mean Square; ft = foot; m = Meter; mG = Milligauss.
Modeling results are based on three onshore export cables, each carrying 1,200 A RMS.
The top of the duct bank was assumed to be buried 3 ft (0.9 m) below ground surface.
The conductor locations on the graph are not to scale and are provided to show relative locations.

Figure 4.10. Magnetic Field Modeling Results for the 2D×2W Duct Bank Installation Scenario at 3.28 Feet (1 Meter) Above the Ground Surface for the Onshore Export Cables.



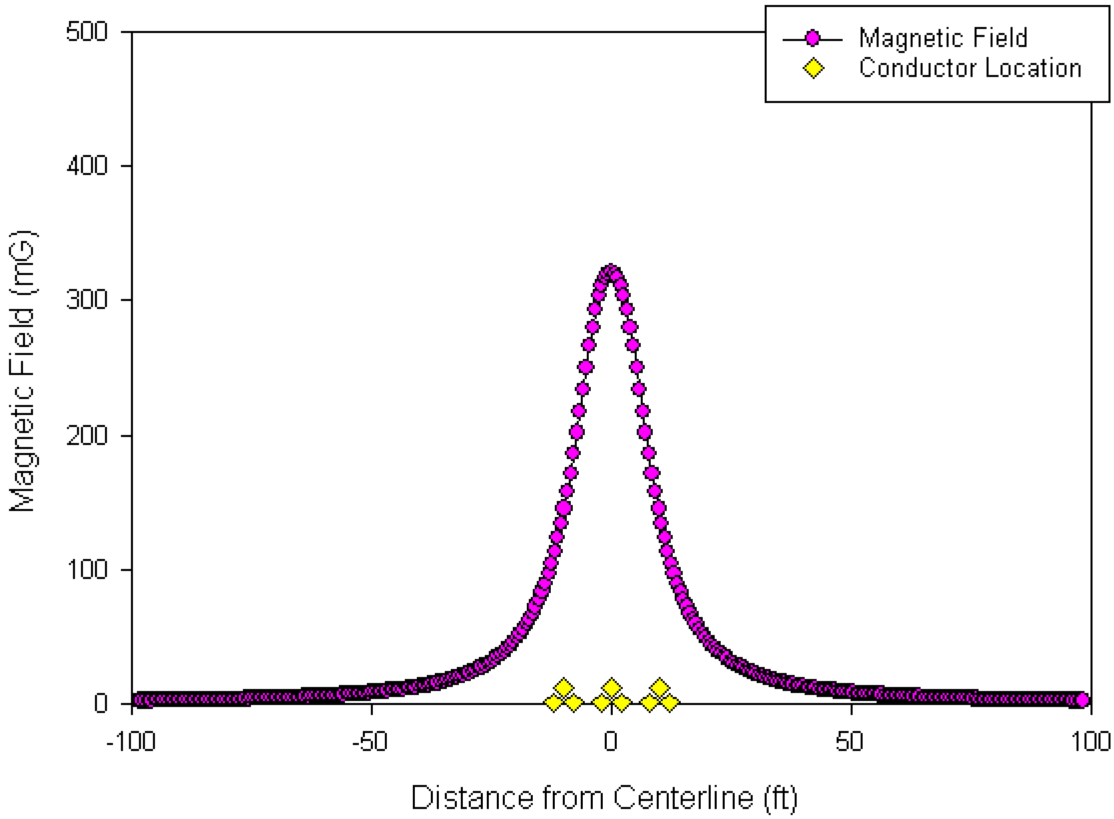
Notes:
A RMS = Amperes Root Mean Square; ft = foot; m = Meter; mG = Milligauss.
Modeling results are based on three onshore export cables, each carrying 1,200 A RMS.
The top of the duct bank was assumed to be buried 3 ft (0.9 m) below ground surface.
The conductor locations on the graph are not to scale and are provided to show relative locations.

Figure 4.11. Magnetic Field Modeling Results for the 1D×4W Duct Bank Installation Scenario at 3.28 Feet (1 Meter) Above the Ground Surface for the Onshore Export Cables.



Notes:
A RMS = Amperes Root Mean Square; ft = foot; m = Meter; mG = Milligauss.
Modeling results are based on three onshore export cables, each carrying 1,200 A RMS.
The top of the duct bank was assumed to be buried 3 ft (0.9 m) below ground surface.
The conductor locations on the graph are not to scale and are provided to show relative locations.

Figure 4.12. Magnetic Field Modeling Results for the Splice Vault Installation Scenario at 3.28 Feet (1 Meter) Above the Ground Surface for the Onshore Export Cables.



Notes:
A RMS = Amperes Root Mean Square; ft = foot; m = Meter; mG = Milligauss.
Modeling results are based on nine onshore export cables, each carrying 1,200 A RMS.
The top of the ducts was assumed to be buried 3 ft (0.9 m) below ground surface.
The conductor locations on the graph are not to scale and are provided to show relative locations.

Figure 4.13. Magnetic Field Modeling Results for the Trefoil Installation Scenario at 3.28 Feet (1 Meter) Above the Ground Surface for the Onshore Export Cables.

4.5 EMF Avoidance, Minimization and Mitigation Measures for the Onshore Cable Installation Scenarios

As discussed throughout this report, several elements of the Project design will contribute to the avoidance, minimization, and mitigation of EMF produced by the onshore transmission system. For the underground onshore export cables, these design components include:

- The underground placement of the onshore export cables- *e.g.*, subject to thermal constraints, it may be possible to place phase conductors relatively close to each other in underground duct banks, contributing to a great degree of MF self-cancellation;[6]
- The minimum target burial depth of 3 ft (0.91 m) for the underground duct banks;

[6] The closer spacing also results in more rapid fall-off of the MF levels with distance away from the circuit centerline (*i.e.*, more rapid decay with distance) than is the case with overhead circuits.

- Onshore underground cable construction consists of 2,500 mm^2 copper or aluminum conductors, each covered by insulation and a metallic sheath which carries induced currents that produce MFs that oppose (partially cancel) the phase conductor MF.
- The installation of ground continuity conductors in the underground duct banks, which may carry currents induced by the MF from the phase conductors and generate MFs that oppose (partially cancel) the phase conductor MF; and
- The arrangement of conductor phasing to achieve maximum MF cancellation from multiple circuits where practicable.

5 Conclusions

Gradient has performed an independent EMF assessment for submarine export cables and onshore transmission lines for the Mayflower Wind Project, which will deliver offshore wind electricity generation to the New England energy grid. These circuits will consist of up to three high voltage cable circuits, consisting of three-core submarine export cables and up to nine single-core onshore export cables. This report summarizes Gradient's EMF Assessment for both the offshore submarine export cables to be used to bring Project electricity from the Lease Area to the landfall site, as well as the portion of the onshore transmission system that will bring Project electricity from the offshore export cable landfall location(s) to a new onshore substation located in Falmouth, Massachusetts.

The MF modeling was conservatively performed assuming cable currents based on maximum wind farm output (100 percent capacity). The wind farm is expected to operate at an annual-average capacity factor of around 50 percent. Thus, much of the time, the actual output and MF attributable to Project export cables will be correspondingly lower than predicted herein for maximum output. In addition, we provide details regarding how model-predicted MF levels for the submarine and onshore export cables are expected to be conservative overestimates of actual MF levels from the installed cables. For the submarine cables, the modeling assumed a reasonable maximum MF scenario of three cable circuits and did not account for several factors associated with the cable design (potential MF shielding associated with the outer metallic armoring of the cables – subject to armor design, partial MF cancellation associated with the twisting of the conductor bundles, and partial MF cancellation associated with induced metallic sheath currents) that will act to reduce MF levels from the cables. For the onshore export cables, the modeling did not account for the partial MF cancellation associated with induced currents in the ground continuity conductors that will act to reduce MF levels from the cables. No electric field levels are included in this report because there will be no direct electric field effects from the Project export submarine cables, since the cables are to be contained in grounded metallic armoring that will serve to shield the electric fields produced by the voltage on the conductors. The onshore export cables will be contained in underground duct banks, and thus will not produce aboveground electric fields.

For the offshore portion of the transmission route, MF effects were modeled for two representative seabed installation scenarios of the submarine cables, a likely installation case for the anticipated burial depth of 6.6 ft (2 m) and 164-ft (50-m) cable spacing, and a conservative installation scenario where the cable is laid on the seafloor (but cable spacing remains unchanged). These calculations show that the highest modeled MF levels for these submarine installation scenarios would occur directly above the submarine export cables, with rapid reductions in MF levels with lateral and vertical distance from the cables. Given the rapid reductions in MF levels with increasing distance from the cables and the 164-ft (50-m) spacing between submarine cables, there is negligible interaction of MF from adjacent cables.

MF effects from the submarine export cables were modeled at the ground surface for potential installation scenarios at two landfall sites (Worcester Ave., and Shore St.). At each site, model inputs were chosen to represent onshore locations at the landside edge of the beaches (52.8-ft [16.1-m] burial depth and 16.4-ft [5.0-m] cable spacing at Worcester Ave.; 9.8-ft [3.0-m] burial depth and 90.0-ft [27.4-m] cable spacing at Shore St.), and where the submarine cables are approaching the ground surface at transition joint bays farther onshore (6.6-ft [2.0-m] burial depth and 16.4-ft [5-m] cable spacing at Worcester Ave.; 6.6-ft [2-m] burial depth and 90.0-ft [27.4-m] cable spacing at Shore St.), for a total of four modeled landfall site scenarios. MF levels are predicted directly at the ground surface, assuming that people may sit or lie down on the ground surface at the four locations. Peak MF levels of 3.8 mG and 39 mG were obtained for the beach locations at Worcester Ave. and Shore St., respectively. The peak MF levels at the transition joint bays where the cables come closer to the ground surface were higher (77 mG at Worcester Ave., 86 mG at Shore St.). Similar to the other submarine cable installation scenarios, MF levels drop off very rapidly with lateral distance from the cables, for example, falling from peak MF levels of 86 mG directly above the cable at the transition joint bay location at Shore St. to MF levels of 6.8 mG at 25 ft (7.6 m) from the cable centerline.

For the onshore transmission route, MF effects were modeled for six representative underground installation scenarios of the onshore export cables: one installation case of three circuits arranged in a 2D×5W underground duct bank; one installation case of two circuits arranged in a 3D×2W underground duct bank; a single-circuit installation case in a 2D×2W duct bank; a single-circuit installation case in a 1D×4W duct bank; a single-circuit installation case in a splice vault; and finally, a three-circuit installation case where the cables are buried in a trefoil configuration. In all cases, the duct bank or cables in the case of the direct burial installation case will be buried at a minimum target depth of 3 ft (0.91 m) below ground surface. These modeling calculations show that the highest MF levels for the onshore underground duct bank cross sections would occur directly above the duct banks, with reductions in MF levels with lateral and vertical distance from the duct banks. The peak modeled MF levels for the duct bank cases range from 187 mG (three circuits in a 2D×5W duct bank) to 403 mG (single circuit in a 1D×4W duct bank), which are all less than the ICNIRP health-based guideline of 2,000 mG for allowable public exposure to 60-Hz magnetic fields.

References

American Conference of Governmental Industrial Hygienists (ACGIH). 2020. "2020 TLVs and BEIs: Based on the Documentation of the Threshold Limit Values for Chemical Substances and Physical Agents & Biological Exposure Indices." American Conference of Governmental Industrial Hygienists (ACGIH), Cincinnati, OH, 314p.

Australian Radiation Protection and Nuclear Safety Agency (ARPANSA). 2006. "Radiation Protection Standard; Exposure Limits for Electric & Magnetic Fields – 0 Hz to 3 kHz (Draft)." 163p., December 7.

Australian Radiation Protection and Nuclear Safety Agency (ARPANSA). 2008. "Forum on the Development of the ELF Standard." 1p., June 12.

CSA Ocean Sciences Inc.; Exponent. 2019. "Evaluation of Potential EMF Effects on Fish Species of Commercial or Recreational Fishing Importance in Southern New England." Report to US Department of the Interior, Bureau of Ocean Energy Management (BOEM). OCS Study BOEM 2019-049. 62p., August.

Electric Power Research Institute (EPRI). 1982. "Transmission Line Reference Book. 345-kV and Above, 2nd Edition." Transmission Engineering, General Electric Co. EL-2500.

Electric Power Research Institute (EPRI). 1993. "Transmission Cable Magnetic Field Management." Power Technologies, Inc. Wilmerding, Pennsylvania. EPRI TR102003.

Electric Power Research Institute (EPRI); High Voltage Transmission Research Center (HVTRC). 1994. "Nantucket Cable Electric Company, Inc. Buried Transmission Line Demonstration (Final)." Report to Nantucket Cable Electric Company, Inc. 22p., March 1.

Florida Dept. of Environmental Protection (FLDEP). 2008. "Electric and Magnetic Fields." Rule 62-814, F.S.C. 13p., June 1.

Hutchison, Z; Sigray, P; He, H; Gill, A; King, J; Gibson, C. 2018. "Electromagnetic Field (EMF) Impacts on Elasmobranch (shark, rays, and skates) and American Lobster Movement and Migration from Direct Current Cables." Report to US Department of the Interior, Bureau of Ocean Energy Management (BOEM) OCS Study BOEM 2018-003. 254p., March.

IEEE Power Engineering Society. 1995a. "IEEE Standard Procedures for Measurement of Power Frequency, Electric and Magnetic Fields from AC Power Lines." Institute of Electrical and Electronics Engineers, Inc. IEEE Std. 644-1994, March 7.

IEEE Power Engineering Society. 1995b. "IEEE Recommended Practice for Instrumentation: Specifications For Magnetic Flux Density and Electric Field Strength Meters – 10 Hz to 3 kHz." Institute of Electrical and Electronics Engineers, Inc. IEEE Std. 1308-1994, April 25.

International Commission on Non-Ionizing Radiation Protection (ICNIRP). 2010. "ICNIRP Guidelines for limiting exposure to time-varying electric and magnetic fields (1 Hz to 100 Hz)." *Health Phys*. 99(6):818-836. doi: 10.1097/HP.0b013e3181f06c86.

Istenic, M; Kokelj, P; Zunko, P; Cestnik, B; Zivic, T. 2001. "Some Aspects of Magnetic Shielding of a Transformer Substation Using Alternative Shielding Techniques." Presented at the 16th International Conference and Exhibition on Electricity Distribution (CIRED 2001), June 18-21. 6p. doi: 10.1049/cp:20010737.

Lucca, G. 2013. "Analytical evaluation of sub-sea ELF electromagnetic field generated by submarine power cables." *Progress in Electromagnetics Research B* 56:309-326.

Mamishev, AV; Russell, BD. 1995. "Measurement of magnetic fields in the direct proximity of power line conductors." *IEEE Trans. Power Deliv.* 10(3):1211-1216. doi: 10.1109/61.400898.

Massachusetts Energy Facilities Siting Board (MA EFSB). 2009. "Final decision [In the Matter of the Petition of Pioneer Valley Energy Center, LLC for Approval to Construct a Generating Facility in the City of Westfield, Massachusetts and the Petition of Pioneer Valley Energy Center, LLC and Westfield Gas & Electric for Approval to Construct a Natural Gas Pipeline in the City of Westfield, Massachusetts]." EFSB 08-1. 80p., October 19.

Massachusetts Energy Facilities Siting Board (MA EFSB). 2019. "Final decision [re: Petitions of Vineyard Wind LLC for approval to construct and operate transmission facilities and lines, and related matters]." EFSB 17-05, DPU 18-18, DPU 18-19, 179p.

National Institute of Environmental Health Sciences (NIEHS). 2002. "Questions and Answers about EMF Electric and Magnetic Fields Associated with the Use of Electric Power." 65p., June.

Normandeau Associates, Inc.; Exponent, Inc. Tricas, T; Gill, A. 2011. "Effects of EMFs from Undersea Power Cables on Elasmobranchs and Other Marine Species (Final)." Report to US Dept. of the Interior, Bureau of Ocean Energy Management, Regulation and Enforcement, Pacific OCS Region. OCS Study BOEMRE 2011-09. 426p., May.

World Health Organization (WHO). 2020. "Electromagnetic fields (EMF): Standards and guidelines." Accessed at http://www.who.int/peh-emf/standards/en.