Electric and Magnetic Field (EMF) Analysis for the Bayonne Energy Center Project

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October 1, 2008

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1 Introduction

On behalf of the Bayonne Energy Center Project, ESS Group, Inc. requested that Gradient Corporation (1) examine the electric and magnetic field (EMF) impact of the proposed Cable System from the new Generating Facility in Bayonne, NJ to landfall in Brooklyn, NY and (2) examine compliance of the cable system with New York state interim EMF standards (NJ does not have applicable regulations for power line frequencies). The proposed cable system has two distinct sections. The primary and longest section is a submarine cable that will carry power approximately 6 miles from Bayonne, NJ across Upper New York Bay and Gowanus Bay and into Brooklyn, NY. The second, shorter section of the cable system is an underground, upland cable that transitions the submarine cable to Gowanus substation at the NY landfall.

In the submarine portion of the cable system, we examined EMF field strengths as well as ecological impacts of the EMF generated. Our analysis showed that the submarine cable portion of the proposed cable system will produce maximum magnetic fields on the order of 439 mG at the point of closest approach on the seafloor. To put this value in perspective, it is well below human health-based standards (833 mG [ICNIRP, 1998]); furthermore, it is not expected to have negative ecological impact. At the water surface, depending on the depth of the water, the maximum magnetic field will range from 55 to 170 mG.

For the upland portion of the cable system, EMF field strengths and compliance with relevant NY standards were examined. Modeling was performed at the nominal power rating of the conductors, assumed to be maximum "winter-normal" loading of the conductors, as stipulated by the NY interim standard. The right of way (ROW) width for the upland cable was taken as the voltage-dependent default width (150 feet for 345 kV lines) indicated by the interim standard. The upland cable will produce magnetic fields of 2 mG at the ROW edges. Importantly, the fields produced will be well below the relevant New York EMF standard of 200 mG at ROW edges. In addition, the maximum magnetic field produced within any of the upland ROW cross-sections (147 mG) will be well below the available health-based standard of 833 mG (ICNIRP, 1998).

Electric fields will not be produced by either the submarine cable or the upland cable. In the water, the shielding around the cable and the surrounding water effectively 'screen' the electric field produced by the cable. On land, the soil surrounding the upland cable screens the electric field that might be produced by the cable.

The cable system is not expected to interfere with communications infrastructure. 60-Hz frequencies do not interfere with frequencies used for TV, cell phones and other forms of communication. In addition, the magnetic fields produced by the cable system are measurable only within short distances of the line as fields fall off rapidly with distance.

As described in this report, the magnetic field levels at all locations analyzed fall well below guidelines for acceptable public exposure to EMF and will not be harmful to marine life or existing communications infrastructure. In this report, Part 1 is the Introduction, Part 2 describes the nature of EMF and provides values for EMF levels both from common sources and in regard to available exposure guidelines. Part 3 details the ecological impacts of EMF from submarine cables on marine life, while Part 4 examines possible interference between communications infrastructure and the proposed cable system. Part 5 outlines the EMF modeling procedures for projecting electric and magnetic field strengths as a function of distance laterally away from the centerline of the proposed circuits. Part 6 provides our conclusions, and Part 7 lists the bibliographic references. Appendix A contains tabulated field strengths as a function of perpendicular distance from the circuit for the submarine cable and the underground line.

2 Nature of Electric and Magnetic Fields

All matter contains electrically charged particles. Most objects are electrically neutral because positive and negative charges are present in equal numbers. When the balance of electric charges is altered, we experience electrical effects, such as the static-electricity attraction between a comb and our hair, or drawing sparks after walking on a synthetic rug in the wintertime. Electrical effects occur both in nature and because of our society's use of electric power (generation, transmission, consumption).

2.1 Units for EMF Are Kilovolts per Meter (kV/m) and MilliGauss (mG)

The electrical tension on utility power lines is expressed in volts or kilovolts (kV; 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 ground results in an "electric field," usually expressed in units of kilovolts per meter (kV/m). The size of the electric field depends on the voltage, the separation between the lines and ground, and other factors.

Power lines also carry electric current that results in a "magnetic field." The units for electric current are amperes (A) and are a measure of the "flow" of electricity. Electric current can be envisioned as analogous to the flow of water in a plumbing system. The magnetic field produced by an electric current is usually expressed in units of gauss (G) or milliGauss (mG), where 1 G =1,000 mG. Another unit for magnetic field levels is the microtesla (μT), where 1 μT = 10 mG. The size of the magnetic field depends on the size of the electric current, the distance to the wire, and other factors.

2.2 There are Many Natural and Man-made Sources of EMF

Everyone experiences a variety of natural and man-made electric and magnetic fields. EMF can be slowly varying or steady (often called "DC fields"), or can vary in time (often called "AC fields"). When the time variation of interest corresponds to that of power line currents, *i.e.*, 60 changes per second, the fields may be called "60-Hz" EMF. Man-made magnetic fields are common in everyday life. Many childhood toys contain magnets, which create DC-fields. That is, permanent magnets generate strong, steady magnetic fields, but also time-varying magnetic fields, should the magnet be moving. Typical toy magnets (*e.g.*, "refrigerator door" magnets) have fields of 100,000 to 500,000 mG. The earth's core creates a steady magnetic field that can be easily demonstrated with a compass needle. The size of the earth's magnetic field in the Northern U.S. is about 570 mG. Knowing the strength of the earth's magnetic field provides a perspective on the size of power-line magnetic fields. The earth's steady field does not have the 60-cycles-per-second (60-Hz) time variation characteristic of power-line EMF, but is experienced as a changing magnetic field as you move around in it. Or, as another example, a magnet spinning at 60 times a second will produce a 60-Hz magnetic field indistinguishable from that near electric power lines carrying the appropriate current. Even the rotating steel-belted radial tires on your car produce time-varying magnetic fields. Magnetic resonance imaging ("MRI") is a diagnostic procedure that puts humans in much larger, but steady, magnetic fields (20,000,000 mG) and is preferred over an X-ray because, contrary to X-rays, these large magnetic fields used in MRI's are not the ionizing radiation characteristic of X-rays, and are not known to have health risks.

2.3 Power-frequency EMF are Produced by Both Lines and Appliances

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 EMF nearby. The size of the magnetic field is proportional to the current, and the size of the electric field is proportional to the voltage. The EMF associated with electrical wires and electrical equipment decreases rapidly as the distance away from the electrical wires increases.

When EMF derive from different sources (*e.g.*, adjacent wires), the size of the net EMF produced will be somewhere in the range between the sum of EMF from the individual sources and the difference of the EMF from the individual sources. That is, EMF may partially add, or partially cancel. Inside residences, typical baseline 60-Hz magnetic fields (far away from appliances) range from 0.5 to 5.0 mG. EMF in the home arise from electric appliances, outdoor distribution wiring, indoor wiring, and grounding currents. The power line magnetic fields add or subtract to the steady field of the earth (570 mG), so that the sum total magnetic field has both a steady part and a time-varying part.

Higher 60-Hz magnetic field 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 magnetic fields in the size range of 40 – 300 mG at distances of 1 foot (NIEHS, 2002). Magnetic fields from personal care appliances held within ½ foot (*e.g.*, shavers, hair dryers, massagers) can produce 600 – 700 mG. In the school and work environment, copy machines, vending machines, video-display terminals, electric tools, lights, and motors are all sources of magnetic fields. All these magnetic fields decrease in size rapidly as the distance from the source increases.

2.4 Available State, National, and International Guidelines for EMF

The U.S. has no federal standards limiting public exposure to 60-Hz EMF. Table 2-1 shows guidelines suggested by national and international health organizations. Table 2-2 lists guidelines that have been adopted by various states in the U.S. The first table shows levels, which were developed to be protective against any adverse health effects, but which should not be viewed as demarcation lines between safe and dangerous levels of EMF. The second table shows (state) guidelines that have generally been adopted to maintain the *status quo* of typical EMF on and near transmission-line rights-of-way (ROWs), and are not health-based.

Table 2-1
60-Hz EMF Guidelines Established by Health & Safety Organizations

Organization	**Magnetic Field**	**Electric Field**
American Conference of Governmental and Industrial Hygienists (ACGIH) (occupational)	10,000 mG [a] 1,000 mG [b]	25 kV/m [a] 1 kV/m [b]
International Commission on Non-Ionizing Radiation Protection (ICNIRP) (general public, continuous exposure)	833 mG	4.2 kV/m
Non-Ionizing Radiation (NIR) Committee of the American Industrial Hygiene Assoc. (AIHA) endorsed (in 2003) ICNIRP's occupational EMF levels for workers	4,170 mG	8.3 kV/m
Institute of Electrical and Electronics Engineers (IEEE) Standard C95.6 (general public, continuous exposure)	9,040 mG	5.0 kV/m
U.K., National Radiological Protection Board (NRPB) [now Health Protection Agency (HPA)]	833 mG	4.2 kV/m
Australian Radiation Protection and Nuclear Safety Agency (ARPANSA), Draft Standard, Dec. 2006 [c]	3,000 mG	4.2 kV/m
*Comparison to **steady** (DC) EMF, encountered as EMF outside the 60-Hz frequency range:*		
Earth's magnetic field and atmospheric electric fields, steady levels, typical of environmental exposure [d]	[550 mG]	[0.2 kV/m up to > 12 kV/m]
Magnetic Resonance Imaging Scan, static magnetic field intensity [d]	[20,000,000 mG]	---

Notes:

[a] *ACGIH guidelines for the general worker.*

[b] *ACGIH guideline for workers with cardiac pacemakers.*

[c] *http://www.arpansa.gov.au/pubs/comment/dr_elfstd.pdf; and http://www.arpansa.gov.au/News/events/elf.cfm*

[d] *These EMF are steady fields, and do not vary in time at the characteristic 60-cycles-per-second that power-line fields do. However, if a person moves in the presence of these fields, the body experiences a time-varying field.*

Table 2-2
State EMF Standards and Guidelines for Transmission Lines

State / Line Voltage	**Electric Field**		**Magnetic Field**	
	On ROW	**Edge ROW**	**On ROW**	**Edge ROW**
69 – 230 kV Florida [c] 500 kV	8.0 kV/m 10.0 kV/m	} 2.0 kV/m [f]		150 mG 200 mG, 250 mG [e]
Massachusetts		1.8 kV/m		85 mG
Minnesota	8.0 kV/m			
Montana	7.0 kV/m [a]	1.0 kV/m [b]		
New Jersey		3.0 kV/m		
New York [c]	11.8 kV/m 11.0 kV/m [d] 7.0 kV/m [a]	1.6 kV/m		200 mG
Oregon	9.0 kV/m			

Key: ROW = right of way; mG = milliGauss; kV/m = kilovolts per meter

Notes:

[a] *Maximum for highway crossings*
[b] *May be waived by the landowner*
[c] *Magnetic fields for winter-normal, maximum line-current capacity*
[d] *Maximum for private road crossings*
[e] *500 kV double-circuit lines built on existing ROW's*
[f] *Includes the property boundary of a substation*

Sources: "Questions and Answers About EMF." National Institute of Environmental Health Sciences and U.S. Department of Energy, 2002. http://www.niehs.nih.gov/health/topics/agents/emf/docs/emf2002.pdf

Florida, see: ftp://ftp.dep.state.fl.us/pub/siting/Rules/62-814-EMF.doc.

3 EMF and Communications Infrastructure

High-voltage electric-power utility lines can produce interference with radio-wave communications systems under some circumstances. For high-voltage overhead lines, the intense electric field in the immediate vicinity of the transmission-line conductors cause background free electrons and ions to be accelerated to kinetic energies that can ionize the neutral molecules in air. These additional charged particles cause further ionization and the air immediately next to the conductor is in a state of erratic electrical breakdown called "corona discharge." The electrical energy in the corona ionization process generates air ions, as well as a substantial amount of non-coherent radio frequency (RF) noise, much like a electrical spark discharge. The frequency spectrum of this corona-produced RF noise is broadband, although its impact is most often greatest in the AM-radio band of frequencies (~ 1 MHz).

For the circuits analyzed in this report, it can be confidently predicted that radiofrequency interference will not be generated by the conductors for two reasons: (1) The underground and under-seafloor conductors are insulated with composite materials, and are not in contact with air. Consequently, the corona discharge described above cannot occur, and radiofrequency waves will not be generated. (2) Even if a radiofrequency spark discharge of some kind did actually occur in the neighborhood of the high-voltage conductors, the underground and under-seafloor alignment of the conductors would prevent any of this RF energy from propagating out into the ambient environment. In summary, RF interference with communications can only result from overhead lines that have sufficient voltage on them (~ 100 kV and higher), which utilize air as the insulating medium, and which are not shielded by an electrically-conducting medium such as water or soil.

Finally, in terms of the 60-Hz magnetic fields produced by the cable system, such fields are ubiquitous within the operating circuits of any device powered by electric power at 60-Hz frequencies, and hence cannot be expected to interfere with the electronic operation of communications infrastructure. The 60-Hz frequencies *per se*, are far below, and do not interfere with the frequencies used for TV, cell phones and other forms of broadcast communication. Thus, no impacts on communications infrastructure are anticipated.

4 EMF Impacts on Marine Organisms

Gradient Corporation reviewed the current scientific literature concerning the detection of EMF by marine mammals (whales and seals), turtles, and elasmobranchs (sharks, rays, and skates). Our literature review, which included scientific papers reporting on both laboratory and field studies, also focused on identifying the authors' estimates of numerical EMF detection thresholds, predictions of sensitivity as a function of EMF frequency, and observations on organism responses to EMF.

4.1 Marine Organism Sensitivity to Weak Electric Fields

The research has, to date, demonstrated that, although electrical sensitivity is common, very few species have been shown to possess an electrosensory system sophisticated enough to differentiate weak power-line electrical or magnetic fields from background EMF noise in any important way (Kalmijn, 2000a). In addition, the proposed cable system contains metallic shielding that effectively blocks any electric field generated by voltages on the conductors within the cable systems.

4.2 Marine Organism Sensitivity to Weak Magnetic Fields

Sensitivity of organisms to steady (or "DC") magnetic fields appears to be a reliably demonstrated phenomenon for some species. In contrast to the relatively weak electrical fields present in the ocean, the strength of the Earth's steady north-south magnetic field (~500 mG) is of sufficient magnitude so as to play a part in the directional orientation and navigation of some marine animals. However, the mechanism underlying the magnetic sense in marine animals is limited to steady or slowly varying fields (frequencies of 0 to 15 Hz) and would not be expected to respond to rapidly time-varying fields such as the 60-Hz magnetic fields generated by the proposed cable system. The scientific literature supports several conclusions regarding the response of organisms to weak magnetic fields:

- The magnitudes of magnetic flux density required to affect birds and honey bees (and probably whales) are in the order of 0.1 to 2 mG for steady, DC fields. The proposed submarine cable produces 60 Hz time-varying AC fields, which would average to zero over the time scales used by organisms. Hence, navigation of these organisms would be expected to be immune to the magnitude of 60-Hz external magnetic fields generated by the cable system considered here.

- Total magnetic intensity variations of less than 0.5 mG (steady state DC field, changing by 0.5 mG as a function of location) have been statistically related to stranding events in several species of whales. As mentioned above, the proposed submarine cable will produce 60 Hz time-varying AC fields, which would average to zero over the time scales used by organisms for navigation or migration. Power-line magnetic fields have not been related to stranding events.

- The detection threshold for magnetic-field gradients (*i.e.*, changes in magnetic field levels with distance) is postulated to be ~0.1% of the total intensity fluctuation of the Earth's magnetic field in whales and turtles. These magnetic intensity gradients are all based on slow changes in the earth's steady DC field as a function of location. The proposed submarine cable produces 60 Hz time-varying AC fields, averaging to zero, which would not affect an organisms' ability to detect magnetic gradients in the Earth's field.

Another type of magnetic sensory function that is distinct from the one above is associated with specialized cells containing magnetic iron oxide particles (magnetite). This sensory function has been demonstrated in several organisms and may be present in all animals. The magnetic particles contained in the cells may act as tiny compasses, and the sensitivity to magnetic flux that has been reported in some marine organisms could be accomplished by less than a million magnetite-containing cells (Kirschvink, 1997). It has been suggested that dolphins may be able to detect magnetic fields by using magnetite contained in nerve fibers (Zoeger *et al*., 1981).

However, even in this type of mechanism, the "compass-needle" particles would not be affected by power-line, 60-Hz magnetic fields, which alternate in direction and average to zero over 1/60th of a second. That is, AC magnetic fields in the bipolar magnetic sensing system would cancel, resulting in a time-average magnitude of zero (Kalmijn, 2000a); therefore, they would not be detected as a magnetic-field deviation and would not interfere with the navigation sense of marine organisms.

In summary, considering both the magnitude and time-variation of the magnetic fields produced by the submarine cable and the upland underground cable, adverse ecological effects are not to be expected.

5 Modeled Electric and Magnetic Field Strengths

5.1 Software Programs Used for Modeling EMF

The "FIELDS" computer program was used to project the electric and magnetic field strengths from the proposed cable system as a function of voltage, current, and perpendicular distance from the lines. The FIELDS program is based on Maxwell's equations, which accurately describe the laws of physics as they apply to electricity and magnetism. Modeled EMF results can be expected to be both precise and accurate, for the input parameters used in the calculations. The FIELDS program was designed by Southern California Edison and was extensively checked against other software (such as "CORONA" from the Bonneville Power Administration, U.S. Department of Energy, and an "EMF Workstation" program produced by the Electric Power Research Institute) to ensure that the implementation of the laws of physics was consistent among these widely used models. As expected, program results for EMF have been found to be in very good agreement with each other.

5.2 Power-Line Loads on Circuit Phase Conductors

Electric and magnetic fields produced by the proposed cable system were modeled using line loadings communicated by the ESS Group, Inc. and ABB. The current per phase satisfies the relationship:

$$P = \sqrt{3} \times V \times I_{phase} \tag{5.1}$$

where P is the power in kilovolt-amps (kVA), V is the line voltage in kilovolts (kV), and I_{phase} is the current per phase in amps (A). Thus, the current per phase conductor is:

$$I_{phase} = \frac{P}{\sqrt{3} \times V} \tag{5.2}$$

Power can also be given in megawatts (MW) or megavolt-amps (MVA). To convert between power quoted in megawatts to megavolt-amps, one must divide by the power factor, which expresses the degree to which the time variations of voltage and current are in phase with each other.

As the NY state interim standard is predicated on maximum "winter-normal" loading, we performed our EMF modeling using the nominal current capacity values, which are basically determined by conductor composition and diameter (*i.e.*, current-carrying capacity). For the submarine cable, we used a nominal current loading of 1020 amps; for the upland cable, we used a nominal current loading of 1030 amps.

5.3 Results of EMF Modeling of Proposed Configuration

The power loadings on all of the lines were taken to be the maximum "winter-normal" loading for the given conductor size. Magnetic fields are proportional to current and fall off rapidly with distance from the centerline of the conductor. The EMF levels plotted below are those that would be measured at the seafloor and at the water surface for the submarine cable. It can be seen that the field levels drop to lower values as the perpendicular distance away from the circuit centerline increases.

5.3.1 Submarine Cable

As indicated by Figure 5-1, the proposed configuration for the submarine cable consists of three parallel cables, with each cable in a separate trench. The 345-kV circuit carries a nominal or maximal load of 1020 amps. The cables will have a horizontal spacing of 33 feet and will be placed 15 feet below the top of the seabed. Modeling results for the proposed structure are shown in Figure 5-2.

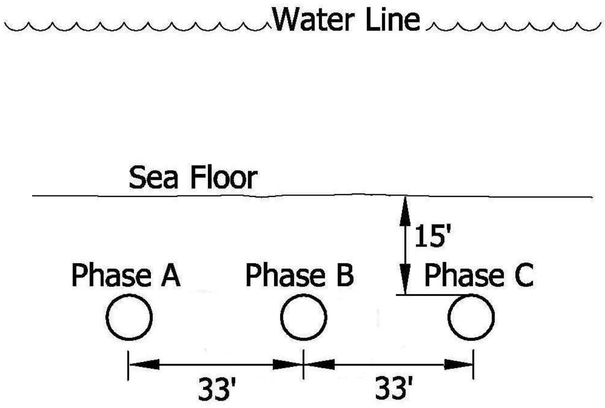

Figure 5-1: Schematic of the proposed configuration for the 345-kV submarine cable. Conductors are spaced 33 feet apart and 15 feet below the seafloor.

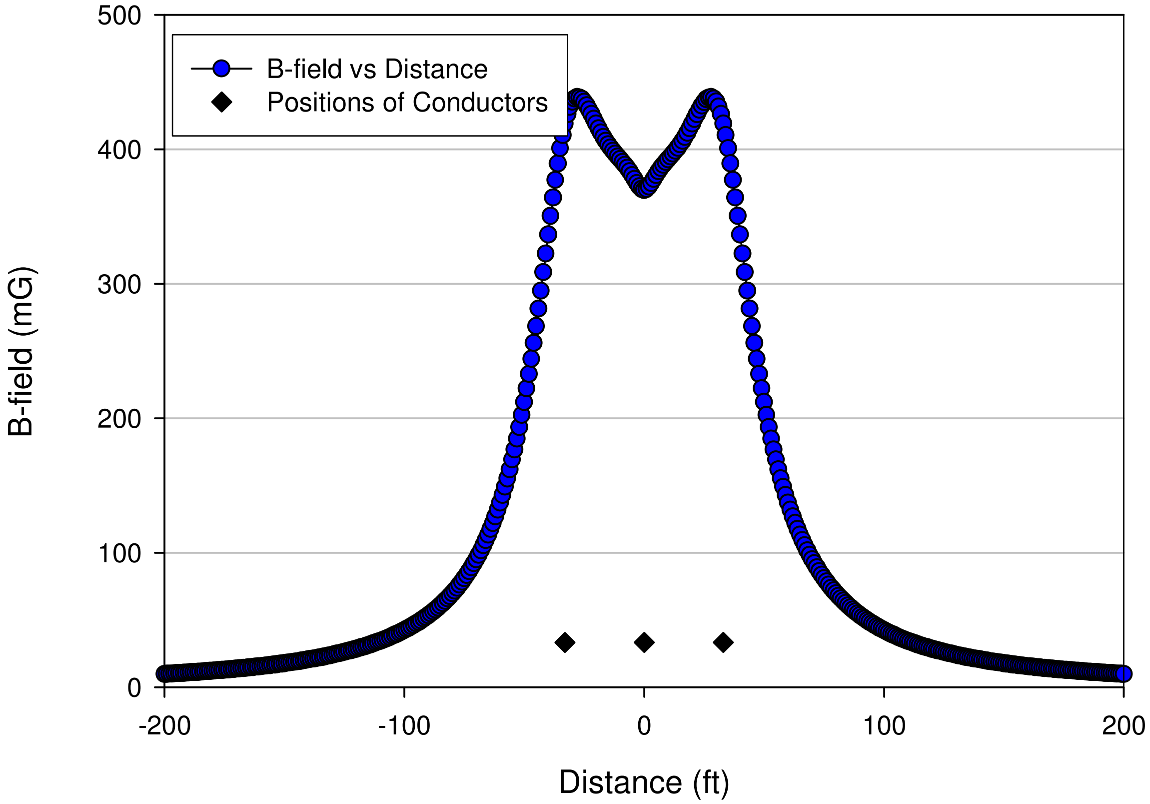

Figure 5-2: Magnetic fields from the proposed 345 kV submarine cable modeled at the seafloor. Fields are shown as a function of lateral distance away from the cable. Relative positions of the conductors are indicated.

We also modeled the magnetic field strength due to the submarine cable at the water surface. From the map received from ESS Group, we found the water depth varied anywhere from 20 to 65 feet along the submarine cable route. Figure 5-3 indicates the magnetic field strength modeling results for three different assumed water depths (20, 35, and 50 feet).

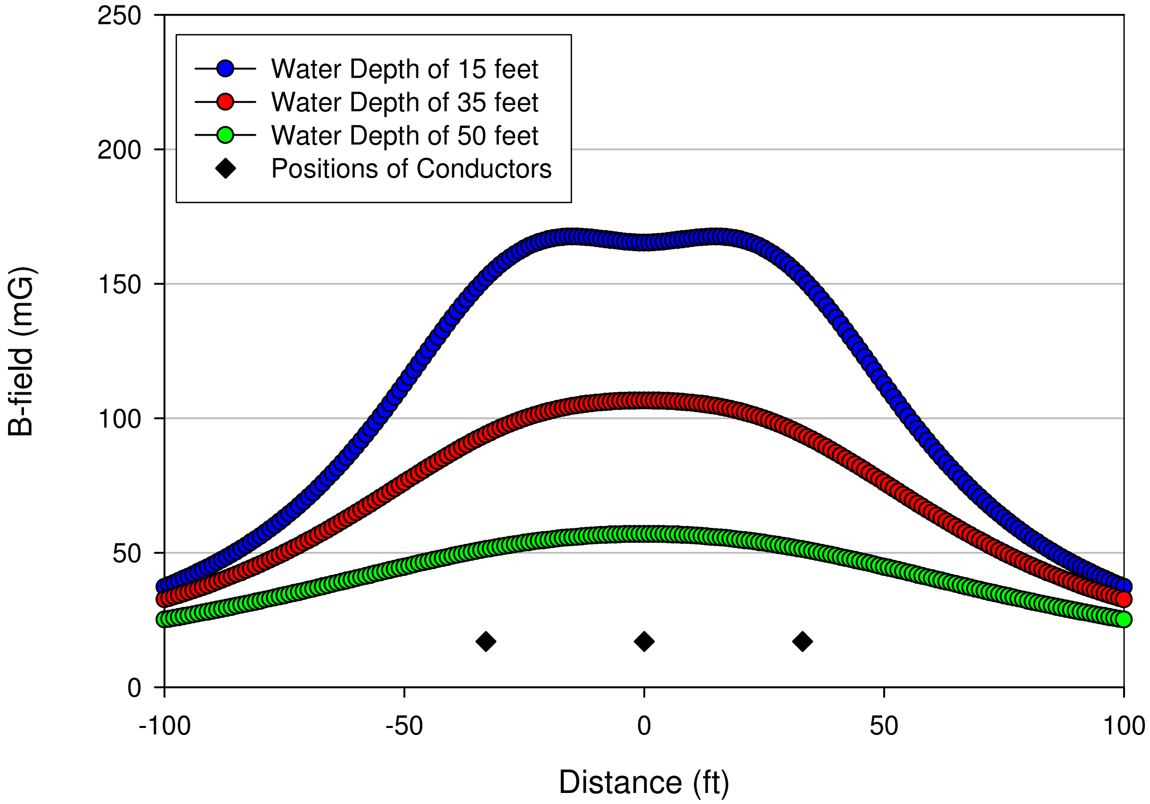

Figure 5-3: Magnetic fields for the proposed 345 kV submarine cable modeled at the surface of the water for varying water depths. Fields are shown as a function of lateral distance away from the cable. Relative positions of the conductors are indicated.

5.3.2 Upland Cable

The proposed configuration for the upland cable portion of the cable system is illustrated in Figure 5-4. The 345-kV circuit carries a load of 1,030 amps, and each phase conductor is placed in a separate duct. Horizontal separation for the phase-conductor center-to-center spacing is 11.5 inches, as communicated by ABB. The ducts will be placed 4.9 ft underground, and it is assumed that the phase conductors will be centered in the ducts. Modeling results for the proposed structure are shown in Figure 5-5. The EMF levels plotted below are those that would be measured at about 1 meter above grade (standard height at which EMF impact is assessed [IEEE, 1995a, 1995b]) for the upland, underground cable. It can be seen that the field levels drop to lower values as the perpendicular distance away from the circuit centerline increases.

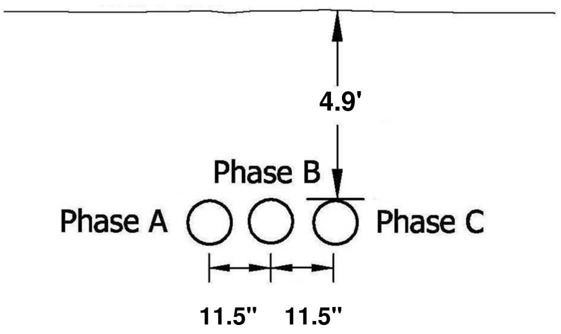

Figure 5-4: Schematic of the underground, 345-kV cable configuration.

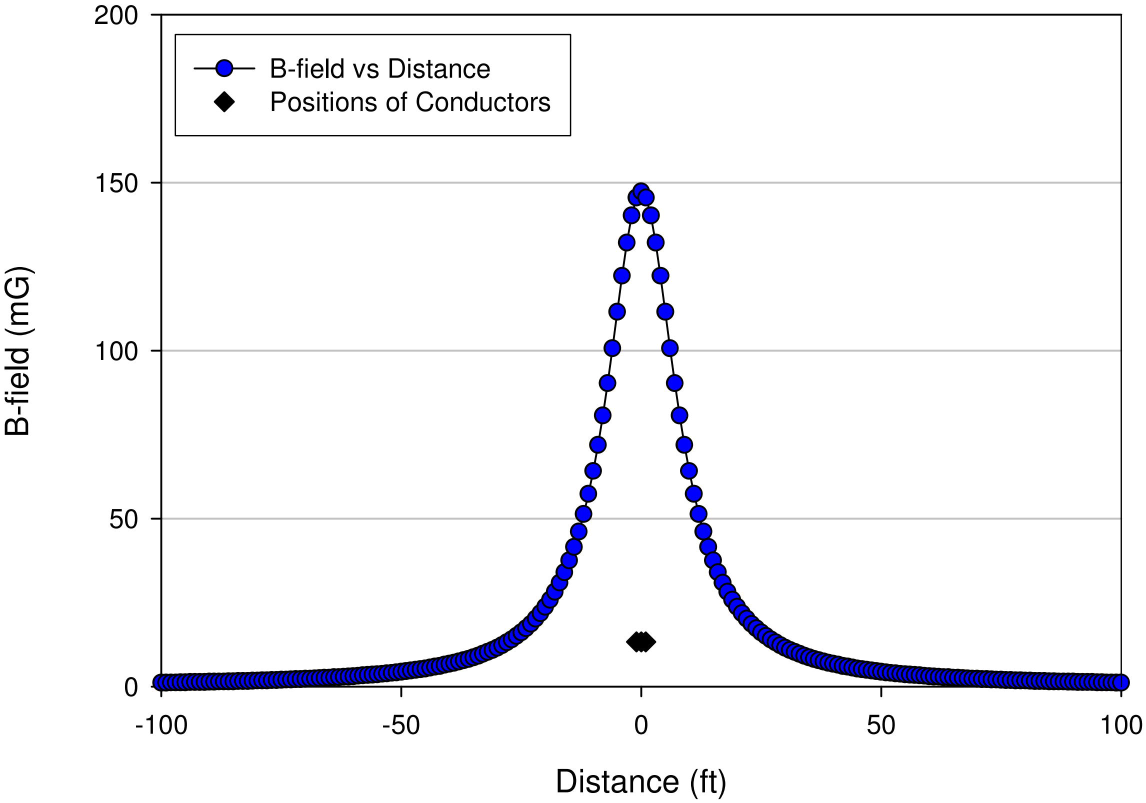

Figure 5-5: Modeled magnetic fields for the proposed underground 345-kV cable configuration. The implied ROW edges are at ± 75 feet.

6 Conclusions

For the two different sections of the cable system for the Bayonne Energy Center Project, we analyzed the magnetic field strengths at nominal current capacity, as a function of distance from the circuits. Table 6-1 summarizes these results.

Table 6-1
Magnetic Fields Within and at Edges of ROW for Proposed Configurations

Cable Section	Height Used in Modeling	Location in ROW	Magnetic Field (mG)
Submarine	Seafloor	At northern ROW edge (75 ft)	81
		At southern ROW edge (-75 ft)	81
		At point of maximum field within ROW	439
Submarine	Water Surface (Depth of 20 ft)	At northern ROW edge (75 ft)	63
		At southern ROW edge (-75 ft)	63
		At point of maximum field within ROW	168
Submarine	Water Surface (Depth of 35 ft)	At northern ROW edge (75 ft)	50
		At southern ROW edge (-75 ft)	50
		At point of maximum field within ROW	107
Submarine	Water Surface (Depth of 50 ft)	At northern ROW edge (75 ft)	34
		At southern ROW edge (-75 ft)	34
		At point of maximum field within ROW	57
Land (underground)	1 meter (IEEE standard)	At northern ROW edge (75 ft)	2
		At southern ROW edge (-75 ft)	2
		At point of maximum field within ROW	147

Our EMF analysis showed that magnetic field levels at the ROW edges for the upland cable (at ±75 ft) will be 2 mG and have strengths much lower than those found in the vicinity of some household appliances (*e.g.*, a can opener at 1 foot is about 100 mG) (NIEHS, 2002). In addition, magnetic field levels at the ROW edges will fall well below the New York interim standard of 200 mG at ROW edges. Importantly, even the maximum predicted field within the ROW (147 mG) will fall below both the NY interim standard and the available health-based exposure guidelines for public exposure (833 mG; [ICNIRP, 1998]).

For the submarine cable under maximum loading, about 439 mG was projected at the seafloor, immediately above the cables. Although AC magnetic field levels are the same order of magnitude as the

Earth’s DC field in a small defined area in the immediate vicinity of the submarine cable, the magnetic sensory system of marine animals would likely not be affected by power-line, 60-Hz magnetic fields, which alternate in direction and average to zero over 1/60th of a second. In particular, 60-Hz alternating power-line EMF fields such as those generated by the submarine cable have not been reported to disrupt marine organism behavior, orientation, or migration. Moreover, within ±100 feet of the submarine-circuit centerline, the AC magnetic field levels will fall to below one-tenth the magnitude of the earth's DC magnetic field.

At the water surface, the submarine cable is projected to produce maximal fields in the range of 55 to 170 mG, depending on the water depth. The maximal field occurs above the submarine cables and field strengths fall off rapidly with increasing lateral distance from the cables. In addition, the deeper the water at any point, the lower the magnetic field due to the submarine cable. Even at the shallowest water depth, within ±100 feet of the submarine-circuit centerline, the AC magnetic field levels will fall to below one-tenth the magnitude of the earth's DC magnetic field.

Neither portion of the cable system is expected to interfere with communications infrastructure. 60-Hz frequencies do not interfere with frequencies used for TV, cell phones and other forms of communication, and no corona discharge will produce RF frequencies, because the cables are not air-insulated. In addition, the magnetic fields produced by the cable system are measurable only within short distances of the line, and field magnitudes fall off rapidly with distance.

In summary, a comparison of these project-specific EMF values with the values provided in Table 2-1 and 2-2 and the literature review compiled in Section 3 shows that the levels predicted here fall well below the generally accepted guidelines for allowable public exposure to EMF and are not expected to adversely affect marine life. There is no expectation of adverse effects due to EMF exposure at any of the modeled locations for the proposed cable system.

7 References

Adair, RK. 1994. "Constraints of thermal noise on the effects of weak 60-Hz magnetic fields acting on biological magnetite." *Proc. Natl. Acad. Sci. USA* 91:2925-2929.

Adair, RK; Astumian, RD; Weaver, JC. 1998. "Detection of weak electric fields by sharks, rays and skates." *Chaos* 8(3):576-587.

Brown, HR; Andrianov, GN; Ilyinsky, OB. 1974. "Magnetic field perception by electroreceptors in Black Sea skates." *Nature* 249(5453):178-179.

CMACS (Centre for Marine and Coastal Studies, University of Liverpool). 2003. "A Baseline Assessment of Electromagnetic Fields Generated by Offshore Windfarm Cables." COWRIE Report EMF – 01-2002 66.

CMACS (Center for Marine and Coastal Studies, University of Liverpool). 2005. "The Potential Effects of Electromagnetic Fields Generated by Sub-sea Power Cables Associated with Offshore Wind Farm Developments on Electrically and Magnetically Sensitive Marine Organisms – A Review." COWRIE Report EM FIELD – 2-06-2004.

Gill, AB; Taylor, H. 2002. "The potential effects of electromagnetic fields generated by cabling between offshore wind turbines upon elasmobranch fishes." Report to the Countryside Council for Wales (CCW Contract Science Report No 488). 60 pp.

Gould, JL. 1985. "Are animal maps magnetic?" In *Magnetite Biomineralization and Magnetoreception in Organisms.* (Eds.: Kirschvink, JL; Jones, DS; and MacFadden, BL), Plenum, NY, pp257-268.

International Commission for Non-Ionizing Radiation Protection (ICNIRP). 1998. "Guidelines for limiting exposure to time-varying electric, magnetic, and electromagnetic fields (up to 300 GHz)." *Health Physics* 74:494-522.

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., New York, NY. 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., New York, NY. IEEE Std. 1308-1994. April 25.

Kalmijn, AJ. 1966. "Electro-perception in sharks and rays." *Nature* 212:1232-1233.

Kalmijn, AJ. 1982. "Electric and magnetic field detection in elasmobranch fishes." *Science* 218:916-918.

Kalmijn, AJ. 2000a. "Detection and biological significance of electric and magnetic fields in microorganisms and fish." In *Effects of Electromagnetic Fields on the Living Environment: Proceedings International Seminar on Effects of Electromagnetic Fields on the Living Environment, Ismaning, Germany, October 4 and 5, 1999.* (Eds.: Matthes, R; Bernhardt, JH; Repacholi, MH).

Kalmijn, AJ. 2000b. "Detection and processing of electromagnetic and near-field acoustic signals in elasmobranch fishes." *Philo. Trans. R. Soc. Lond. B. Biol. Sci.* 355:1135-1141.

Kalmijn, AJ. 2003. "Physical principles of electric, magnetic, and near-field acoustic orientation." In *Sensory Processing in Aquatic Environments* (Eds.: Collins, SP; Marshall, NJ), Springer, New York. p77-91.

Kirschvink, JH; Dizon, AE; Westphal, JA. 1986. "Evidence from strandings for geomagnetic sensitivity in cetaceans." *J. Exp. Biol.* 120:1-24.

Kirschvink, JL. 1997. "Homing in on vertebrates." *Nature* 390: 339-340.

Klimley, AP. 1993. "Highly directional swimming by scalloped hammerhead sharks, *Sphyrna lewini*, and subsurface irradiance, temperature, bathymetry, and geomagnetic fields." *Marine Biol.* 117(1):1-22.

Kullnick, UH. 2000. "Influences of electric and magnetic fields on aquatic ecosystems." In *Effects of Electromagnetic Fields on the Living Environment: Proceedings International Seminar on Effects of Electromagnetic Fields on the Living Environment, Ismaning, Germany, October 4 and 5, 1999.* (Eds:. Matthes, R; Bernhardt, JH; Repacholi, MH).

Montgomery, JC; Bodznick, D. 1999. "Signals and noise in the elasmobranch electrosensory system." 202:1349-1355.

NIEHS. 2002. "Questions and Answers About EMF." National Institute of Environmental Health Sciences and U.S. Dept. of Energy. Accessed at http://www.niehs.nih.gov/health/topics/agents/emf/docs/emf2002.pdf.

Kajiura, SM; Holland, KN. 2002. "Electroreception in juvenile scalloped hammerhead and sandbar sharks." *J. Exp. Biol.* 205:3609-3621.

Papi, F; Luschi, P; Akesson, S; Capogrossi, S; Hays, GC. 2000. "Open-sea migration of magnetically disturbed sea turtles." *J. Exp. Biol.* 203:3435-3443. [205-4034]

Ritz, T; Adem, S; Schulten, K. 2000. "A model for photoreceptor-based magnetoreception in birds." *Biophys. J.* 78:707-18.

Viguier, C. 1882. *"Le sense de l'orientation et ses organes chez les animaux et chez l'homme*." Rev. Phil. 14, 1-36.

Walker, MM; Diebel, CE; Haugh, CV; Pankhurst, PM; Montgomery, JC; Green, CR. 1997. "Structure and function of the vertebrate magnetic sense." *Nature* 390:371-376.

Walker, MM; Diebel, CE; Kirschvink, JL. 2003. "Detection and use of the Earth's magnetic field by aquatic vertebrates." In *Sensory Processing in Aquatic Environments.* (Eds.: Collins, SP; Marshall, NJ), Springer, New York. p53-74.

Wallraff, HG. 1999. "The magnetic map of homing pigeons: an evergreen phantom." *J. Theor. Biol.* 197:265-269.

Wiltschko, R; Wiltschko, W. 1995. *Magnetic Orientation in Animals.* Springer Verlag, Berlin:

Zoeger, J; Dunn, JR; Fuller, M. 1981. "Magnetic material in the head of the common Pacific dolphin." *Science* 213:892-894.

Appendix A

Input Parameter and Tabulated Field Strength (± 100 ft) Summary

Submarine Cable

Table A-1
Modeling Input Parameter Summary for the Submarine Portion of the Cable System

Table: Parameter values used in the FIELDS modeling program to project EMF levels

Cable system characteristics	**Parameter values**
Line voltage	345 kV
Number of circuits	1
Number of phases per circuit	3 (0 degrees, 120 degrees, and 240 degrees)
Number of conductors per phase	1
Conductor diameter	1.42 inch for all conductors
Cable system configuration	Phase conductors of each circuit are oriented horizontally
Vertical placement	15 feet below seafloor
Horizontal separation between the phases	33 feet
Current [a]	1,020 amps

[a] The specific values for electric current per phase are chosen to represent a nominal current capacity.

Table A-2
Modeled Field Strengths at Varying Distances from the Centerline for the 345 kV Submarine Cable Portion of the Cable System

	B-field (mG)			
Distance from Centerline (ft)	At Seafloor	At Water Surface (Depth of 20 ft)	At Water Surface (Depth of 35 ft)	At Water Surface (Depth of 50 ft)
-100	42	37	33	25
-99	43	38	33	25
-98	44	39	34	26
-97	45	40	34	26
-96	46	40	35	26
-95	47	41	35	27
-94	49	42	36	27
-93	50	43	37	27
-92	51	44	37	28
-91	52	45	38	28
-90	53	45	38	28
-89	55	46	39	29
-88	56	47	40	29
-87	58	48	41	29
-86	59	49	41	30
-85	61	50	42	30
-84	62	52	43	31
-83	64	53	43	31
-82	66	54	44	31
-81	68	55	45	32
-80	70	56	46	32
-79	72	58	47	33
-78	74	59	47	33
-77	76	60	48	33
-76	79	62	49	34
-75	81	63	50	34
-74	84	64	51	35
-73	86	66	52	35
-72	89	67	53	35
-71	92	69	54	36
-70	95	71	55	36
-69	98	72	56	37
-68	102	74	57	37
-67	105	76	58	37
-66	109	78	59	38
-65	113	80	60	38
-64	118	81	61	39
-63	122	83	62	39
-62	127	85	63	40

	B-field (mG)			
Distance from Centerline (ft)	At Seafloor	At Water Surface (Depth of 20 ft)	At Water Surface (Depth of 35 ft)	At Water Surface (Depth of 50 ft)
-61	132	87	64	40
-60	137	90	65	40
-59	143	92	66	41
-58	149	94	67	41
-57	155	96	68	42
-56	162	98	69	42
-55	169	101	70	43
-54	177	103	72	43
-53	185	105	73	44
-52	193	108	74	44
-51	202	110	75	44
-50	212	113	76	45
-49	222	115	77	45
-48	233	118	78	46
-47	244	120	80	46
-46	256	123	81	46
-45	269	125	82	47
-44	281	128	83	47
-43	295	130	84	48
-42	309	133	85	48
-41	323	135	86	48
-40	337	137	87	49
-39	351	140	88	49
-38	364	142	89	50
-37	377	144	90	50
-36	389	146	91	50
-35	401	148	92	51
-34	411	150	93	51
-33	419	152	94	51
-32	426	154	95	52
-31	432	155	96	52
-30	436	157	96	52
-29	438	158	97	53
-28	439	160	98	53
-27	439	161	99	53
-26	437	162	99	53
-25	435	163	100	54
-24	433	164	101	54
-23	430	165	101	54
-22	426	165	102	54
-21	423	166	102	55
-20	419	167	103	55
-19	416	167	103	55

	B-field (mG)			
Distance from Centerline (ft)	At Seafloor	At Water Surface (Depth of 20 ft)	At Water Surface (Depth of 35 ft)	At Water Surface (Depth of 50 ft)
-18	412	167	103	55
-17	409	167	104	55
-16	406	168	104	56
-15	404	168	105	56
-14	401	168	105	56
-13	399	167	105	56
-12	397	167	105	56
-11	395	167	106	56
-10	393	167	106	56
-9	391	167	106	57
-8	388	167	106	57
-7	386	166	106	57
-6	384	166	106	57
-5	381	166	106	57
-4	378	166	106	57
-3	375	166	107	57
-2	372	165	107	57
-1	370	165	107	57
0	370	165	107	57
1	370	165	107	57
2	372	165	107	57
3	375	166	107	57
4	378	166	106	57
5	381	166	106	57
6	384	166	106	57
7	386	166	106	57
8	388	167	106	57
9	391	167	106	57
10	393	167	106	56
11	395	167	106	56
12	397	167	105	56
13	399	167	105	56
14	401	168	105	56
15	404	168	105	56
16	406	168	104	56
17	409	167	104	55
18	412	167	103	55
19	416	167	103	55
20	419	167	103	55
21	423	166	102	55
22	426	165	102	54
23	430	165	101	54
24	433	164	101	54

	B-field (mG)			
Distance from Centerline (ft)	At Seafloor	At Water Surface (Depth of 20 ft)	At Water Surface (Depth of 35 ft)	At Water Surface (Depth of 50 ft)
25	435	163	100	54
26	437	162	99	53
27	439	161	99	53
28	439	160	98	53
29	438	158	97	53
30	436	157	96	52
31	432	155	96	52
32	426	154	95	52
33	419	152	94	51
34	411	150	93	51
35	401	148	92	51
36	389	146	91	50
37	377	144	90	50
38	364	142	89	50
39	351	140	88	49
40	337	137	87	49
41	323	135	86	48
42	309	133	85	48
43	295	130	84	48
44	281	128	83	47
45	269	125	82	47
46	256	123	81	46
47	244	120	80	46
48	233	118	78	46
49	222	115	77	45
50	212	113	76	45
51	202	110	75	44
52	193	108	74	44
53	185	105	73	44
54	177	103	72	43
55	169	101	70	43
56	162	98	69	42
57	155	96	68	42
58	149	94	67	41
59	143	92	66	41
60	137	90	65	40
61	132	87	64	40
62	127	85	63	40
63	122	83	62	39
64	118	81	61	39
65	113	80	60	38
66	109	78	59	38
67	105	76	58	37

	B-field (mG)			
Distance from Centerline (ft)	At Seafloor	At Water Surface (Depth of 20 ft)	At Water Surface (Depth of 35 ft)	At Water Surface (Depth of 50 ft)
68	102	74	57	37
69	98	72	56	37
70	95	71	55	36
71	92	69	54	36
72	89	67	53	35
73	86	66	52	35
74	84	64	51	35
75	81	63	50	34
76	79	62	49	34
77	76	60	48	33
78	74	59	47	33
79	72	58	47	33
80	70	56	46	32
81	68	55	45	32
82	66	54	44	31
83	64	53	43	31
84	62	52	43	31
85	61	50	42	30
86	59	49	41	30
87	58	48	41	29
88	56	47	40	29
89	55	46	39	29
90	53	45	38	28
91	52	45	38	28
92	51	44	37	28
93	50	43	37	27
94	49	42	36	27
95	47	41	35	27
96	46	40	35	26
97	45	40	34	26
98	44	39	34	26
99	43	38	33	25
100	42	37	33	25

Underground Cable

Table A-3
Modeling Input Parameter Summary for the Upland Cable Portion of the Cable System

Table: Parameter values used in the FIELDS modeling program to project EMF levels

Cable system characteristics	**Parameter values**
Line voltage	345 kV
Number of circuits	1
Number of phases per circuit	3 (0 degrees, 120 degrees, and 240 degrees)
Number of conductors per phase	1
Conductor diameter	1.5 inch for all conductors
Cable system configuration	Phase conductors of each circuit are oriented horizontally
Vertical placement (burial depth + ½ of duct diameter)	5.3 feet underground
Horizontal separation between the phases	11.5 inches
Current [a]	1,020 amps

[a] The specific values for electric current per phase are chosen to represent a nominal current capacity.

Table A-4
Modeled Field Strengths at Varying Distances from the Centerline for the 345 kV Upland Cable Portion of the Cable System

Distance from Centerline (ft)	B-field (mG)
-100	1.1
-99	1.1
-98	1.2
-97	1.2
-96	1.2
-95	1.2
-94	1.3
-93	1.3
-92	1.3
-91	1.3
-90	1.4
-89	1.4
-88	1.4
-87	1.5
-86	1.5
-85	1.5
-84	1.6
-83	1.6
-82	1.7
-81	1.7
-80	1.7
-79	1.8
-78	1.8
-77	1.9
-76	1.9
-75	2.0
-74	2.0
-73	2.1
-72	2.1
-71	2.2
-70	2.3
-69	2.3
-68	2.4
-67	2.5
-66	2.5
-65	2.6
-64	2.7
-63	2.8
-62	2.9
-61	3.0
-60	3.1

Distance from Centerline (ft)	B-field (mG)
-59	3.2
-58	3.3
-57	3.4
-56	3.5
-55	3.6
-54	3.8
-53	3.9
-52	4.0
-51	4.2
-50	4.4
-49	4.5
-48	4.7
-47	4.9
-46	5.1
-45	5.4
-44	5.6
-43	5.8
-42	6.1
-41	6.4
-40	6.7
-39	7.0
-38	7.4
-37	7.8
-36	8.2
-35	8.6
-34	9.1
-33	9.7
-32	10.2
-31	10.9
-30	11.5
-29	12.3
-28	13.1
-27	14.0
-26	15.0
-25	16.1
-24	17.3
-23	18.6
-22	20.1
-21	21.8
-20	23.7
-19	25.8
-18	28.2
-17	30.9
-16	34.0
-15	37.5
-14	41.5

Distance from Centerline (ft)	B-field (mG)
-13	46.1
-12	51.3
-11	57.3
-10	64.2
-9	71.9
-8	80.6
-7	90.3
-6	100.7
-5	111.5
-4	122.3
-3	132.1
-2	140.2
-1	145.5
0	147.4
1	145.5
2	140.2
3	132.1
4	122.3
5	111.5
6	100.7
7	90.3
8	80.6
9	71.9
10	64.2
11	57.3
12	51.3
13	46.1
14	41.5
15	37.5
16	34.0
17	30.9
18	28.2
19	25.8
20	23.7
21	21.8
22	20.1
23	18.6
24	17.3
25	16.1
26	15.0
27	14.0
28	13.1
29	12.3
30	11.5
31	10.9
32	10.2

Distance from Centerline (ft)	B-field (mG)
33	9.7
34	9.1
35	8.6
36	8.2
37	7.8
38	7.4
39	7.0
40	6.7
41	6.4
42	6.1
43	5.8
44	5.6
45	5.4
46	5.1
47	4.9
48	4.7
49	4.5
50	4.4
51	4.2
52	4.0
53	3.9
54	3.8
55	3.6
56	3.5
57	3.4
58	3.3
59	3.2
60	3.1
61	3.0
62	2.9
63	2.8
64	2.7
65	2.6
66	2.5
67	2.5
68	2.4
69	2.3
70	2.3
71	2.2
72	2.1
73	2.1
74	2.0
75	2.0
76	1.9
77	1.9
78	1.8

Distance from Centerline (ft)	B-field (mG)
79	1.8
80	1.7
81	1.7
82	1.7
83	1.6
84	1.6
85	1.5
86	1.5
87	1.5
88	1.4
89	1.4
90	1.4
91	1.3
92	1.3
93	1.3
94	1.3
95	1.2
96	1.2
97	1.2
98	1.2
99	1.1
100	1.1