Electric and Magnetic Field Assessment: The Kings Highway Substation

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Notice

At the request of Public Service Enterprise Group – Long Island (PSEG-LI), Exponent modeled the magnetic-field levels associated with the proposed Kings Highway Substation in the Hamlet of Hauppauge, Town of Islip, Suffolk County, New York. This report summarizes work performed to date and presents the findings resulting from that work. In the analysis, we have relied on geometry, material data, usage conditions, specifications, and various other types of information provided by PSEG-LI. We cannot verify the correctness of this input data, and rely on the client for the data's accuracy. Although Exponent has exercised usual and customary care in the conduct of this analysis, the responsibility for the design and operation of the Project remains fully with the client. PSEG LI has confirmed to Exponent that the summary of data provided to Exponent contained herein is not subject to Critical Energy Infrastructure Information (CEII) restrictions.

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

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

Executive Summary

Public Service Enterprise Group of Long Island (PSEG-LI) has proposed the construction of the Kings Highway Substation (The Project) fronting Rabro Drive, adjoining the existing Pilgrim-West transmission line right-of-way (ROW) in the Hamlet of Hauppauge, NY. At the request of PSEG-LI, Exponent modeled the magnetic fields associated with the proposed substation equipment and adjacent overhead transmission lines. In the proposed configuration, the southernmost of the two existing transmission lines will be divided into two new transmission lines terminating at the proposed substation.

The effect of the substation on existing magnetic-field levels was evaluated by modeling magnetic fields for pre- and post-Project conditions. For the pre-Project conditions, the loading on the existing overhead circuits was calculated without any of the proposed equipment in service. Exponent also measured background magnetic-field levels at the proposed substation site on March 24, 2017.

The post-Project condition includes magnetic-field contributions from the proposed substation equipment and a new 138-kilovolt (kV) loop in and out of the new substation yard. In the post-Project condition, two load cases were studied, corresponding to average load and peak load for the proposed equipment and overhead 138-kV transmission lines. Electric fields from the substation were not modeled because they are effectively blocked by the metal fence and landscaping around the substation yard.

The modeling shows that the substation equipment and proposed 138-kV interconnection have little effect on the calculated magnetic field levels at workplaces and residences in the neighborhood. The overhead interconnection would be located on the north edge of the substation parcel, set back from Rabro Drive and Wheeler Road by approximately 250 feet. At workplaces along Wheeler Road, for instance, the calculated magnetic field would increase on average by less than 2.6 mG with operation of the Project. These changes can be attributed to an increase in loading on the 138 kV transmission line on the existing ROW west of the Kings Highway Substation, and an increase in distribution loads along Wheeler Road.

The greatest Project-related increase in calculated magnetic-field level would occur near the western edge of the proposed site, where proposed underground feeders pass below the substation fence. Directly over the proposed feeders, the calculated magnetic-field level would be approximately 40 mG for average-load conditions and 100 milligauss (mG) for peak-load conditions. The region where the calculated magnetic fields would be elevated above background levels extends for approximately 50 feet on either side of the proposed underground feeders.

Overall, the calculated and measured magnetic field levels associated with the Project fall within the range of typical levels encountered within homes and businesses. The Project-related increases in the calculated magnetic field are small, and are on average below 2.6 mG at workplaces and dwellings in the vicinity of the proposed substation.

Proposed Configuration

The proposed location for the Kings Highway Substation is located on a 3.6-acre property at 225 East Rabro Drive, on the east side of Wheeler Road and south of the existing Pilgrim-West 138 kV ROW. *See* Figure 1.

The proposed substation equipment includes a new 138-kV ring bus having two circuit positions, six gas circuit breakers, three 138/13.8-kV transformers, and three power centers with metal-clad switchgear. In the proposed configuration, the 13.8-kV feeders exit west from the substation, and continue north along Wheeler Road in underground duct banks.

In addition to the new equipment inside the substation fence, the Project includes two overhead interconnections to the existing 138-kV transmission line adjoining the proposed site to the north. In the proposed configuration, the existing 138-kV Transmission Line "B" will be segmented into two transmission lines, Transmission Line "B" West and "B" East, terminating at the substation.

Figure 2 shows the existing and proposed structures located on the existing ROW. Presently, Transmission Lines "A" and "B" are supported on double-circuit steel monopoles in the center of the existing 80-foot ROW. Figure 2a shows the existing double-circuit structure design at locations where the transmission centerline changes direction. Figure 2b shows the existing double-circuit structures at tangent locations where the transmission-line alignment is straight. Transmission Lines "A" and "B" are operated at 138 kV and built with 345 kV clearances. The existing lines having a vertical conductor spacing of 20-21 feet and a conductor height of 36 feet above ground at midspan (the point of greatest conductor sag between structures). Figure 2c shows the dimensions of two proposed dead-end monopoles located to the north of the proposed King Highway Substation. These single-circuit structures support the conductors of Transmission Line "B" West and "B" East where they turn south to terminate within the substation yard.

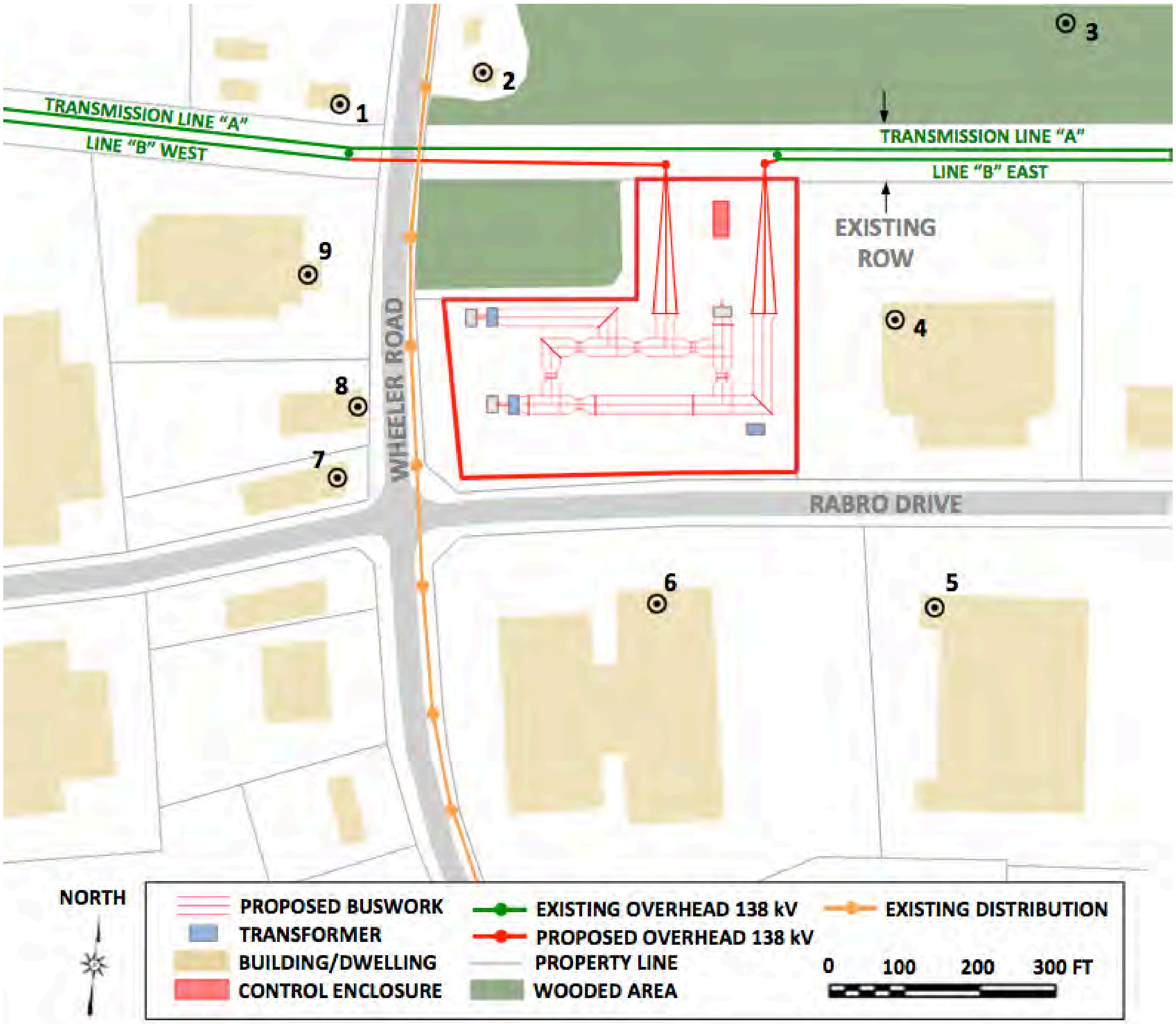

Figure 1. Proposed layout of the Kings Highway Substation and existing overhead circuits in relation to the existing ROW.

The numbered labels designate reporting locations for Project-related magnetic fields, which are summarized in Table 5.

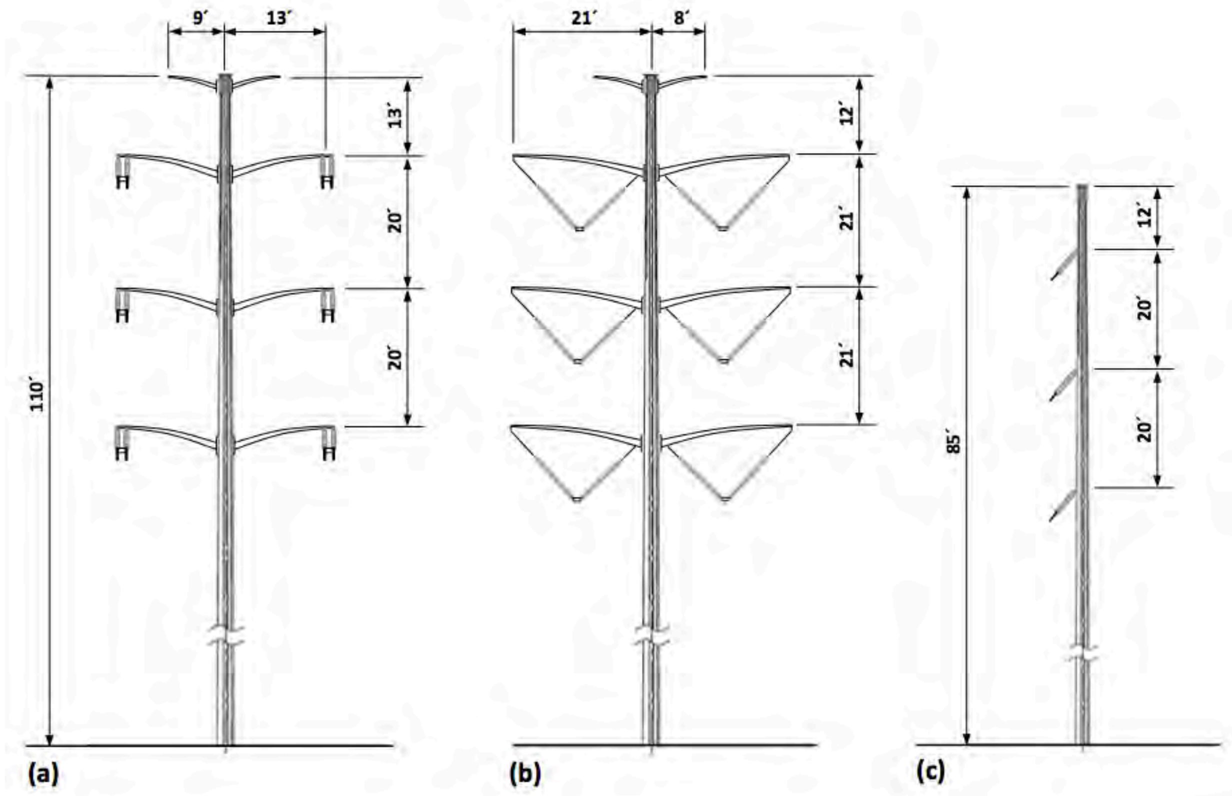

Figure 2. Structure dimensions used in SUBCALC model: (a) existing double-circuit structure at angle locations; (b) existing double-circuit monopole at tangent locations; and (c) proposed dead-end structures where Transmission Lines "B" West and East turn south to terminate within the proposed Kings Highway Substation.

Methods

Magnetic Field Modeling

The magnetic field around the perimeter of the proposed Kings Highway Substation and surrounding neighborhood was calculated using SUBCALC, which is part of the Enertech EMF Workbench Suite. SUBCALC models the magnetic fields in and around substations, accounting for the transformers and the three-dimensional arrangement of buswork and transmission-line interconnections (Figure 4). The SUBCALC model was built using the substation plan and profile data provide by PSEG-LI. The inputs to the program include data on the voltage, current flow, circuit phasing, and conductor configurations, which were also provided by PSEG-LI.[1] In particular, the SUBCALC model incorporates sag elevation data for each transmission line span and the elevation of conductor attachments.

Exponent calculated the magnetic field along four profiles perpendicular to the substation fence, directed outward towards adjoining properties as shown in Figure 3:

Profile 1 is aligned with the southwest transformer bank in the substation yard, and proceeds west across Wheeler Road.

Profile 2 starts at the middle of the south substation fence, and crosses Rabro Drive.

Profile 3 begins near the overhead interconnection to Transmission Line "B" East, and proceeds east onto adjoining property.

Profile 4 models the magnetic field starting at the north edge of the substation yard between Transmission Line "B" West and "B" East, and proceeds north across the existing ROW

Additional Profiles 5 and 6, shown in Figure 3, characterize the magnetic field along transects perpendicular to the overhead route of the existing overhead 138 kV transmission lines. As described in greater detail below, measurements of background magnetic field levels were recorded along Profiles 1 – 4 on March 24, 2017. All magnetic fields were calculated at heights referenced to the elevation of the substation yard.

[1] The sources of the electric field within the substation are set back by 25 feet or more within the property line and their intensity diminishes quickly with distance. In addition, many objects are conductive—including fences, shrubbery, and buildings—and thus shield electric fields. Thus, the electric field from the Kings Highway Substation was not calculated since it will be effectively shielded by the substation fence and landscaping.

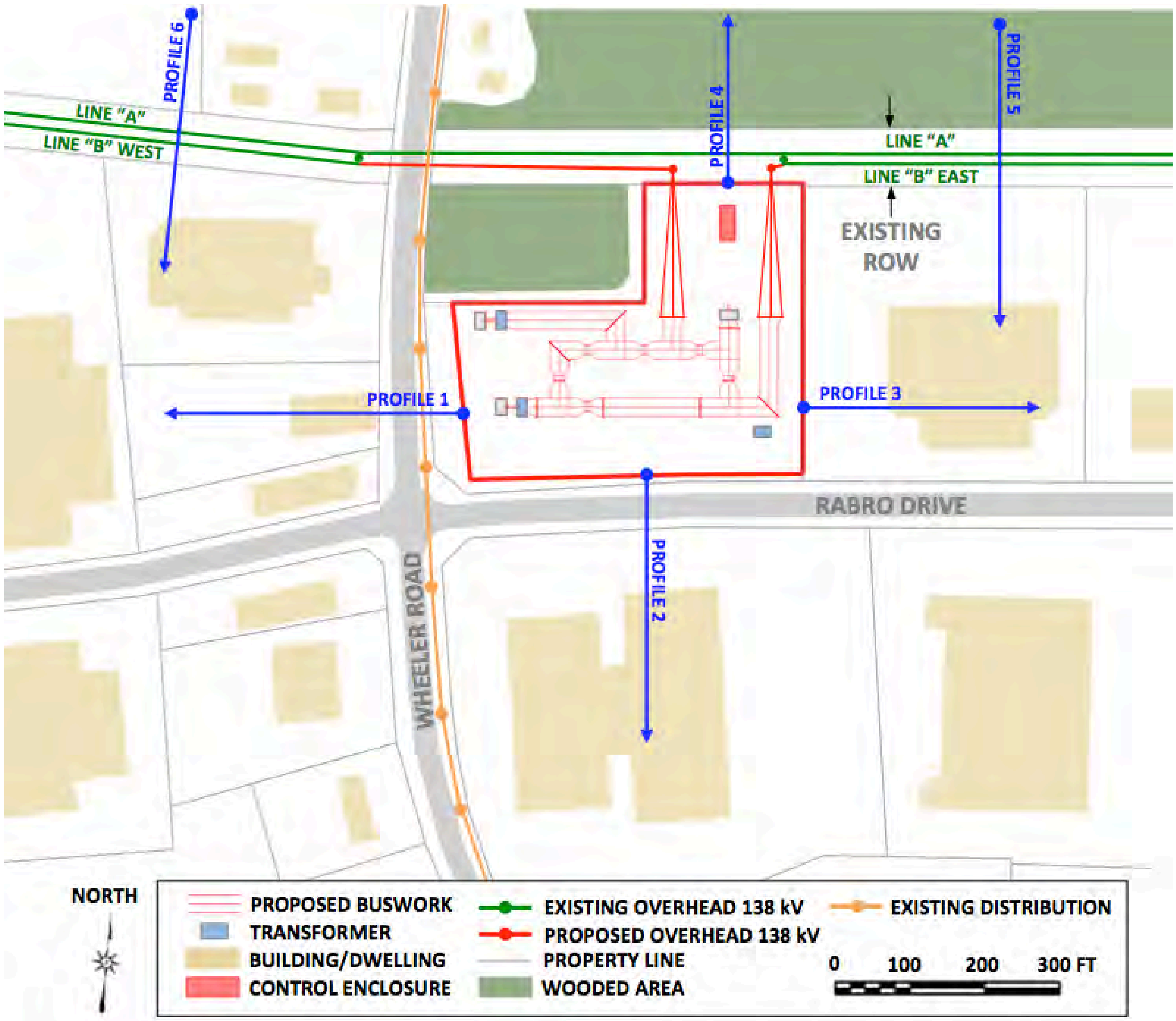

Figure 3. Plan view of the proposed Kings Highway Substation, showing the location of magnetic-field profiles and the overhead route of 138 kV transmission lines.

Along the perimeter of the substation property and Profiles 1-6, the magnetic field was calculated at 1 meter (3.28 feet) above ground, in accordance with IEEE Std. C95.3.1-2010.[2] Calculated magnetic fields are reported as the resultant of x, y and z magnetic field vectors in units of milligauss (mG).[3]

Magnetic fields surrounding conductors depend on current, which increases with increasing load. The current flows (loadings) for the transmission lines and transformers used in the model

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[2] Institute of Electrical and Electronics Engineers (IEEE). IEEE Recommended Practice for Measurements and Computations of Electric, Magnetic, and Electromagnetic fields with respect to Human Exposure to Such Fields, 0 Hz to 100 kHz. New York: IEEE. IEEE Std. C95.3.1™-2010.

[3] The resultant magnetic field is the Euclidian norm (square root of the sum of the squares) of the component magnetic-field vectors calculated along vertical, transverse, and longitudinal axes.

are summarized in Appendix A. Appendix A provides average loads for the in-service year of 2017, as well as a peak loads, corresponding to the highest load anticipated during the summer months in the year 2017.

Figure 4. Overview of the three-dimensional SUBCALC model used to calculate magnetic-field profiles in the vicinity of the proposed Kings Highway Substation for the average and peak loading cases.

Orange lines represent overhead transmission-line conductors, including the proposed 138 kV loop in and out of the Kings Highway Substation. Not shown in the perspective view are underground distribution feeders, which proceed north along Wheeler Road and are proposed as part of the reinforcement project in the surrounding community.

Measurements

In order to characterize background EMF levels at the proposed site of the Kings Highway Substation, magnetic fields were measured outside the proposed substation fence on March 24, 2017. The measurements were taken at a height of 1 meter (3.28 feet) above ground in accordance with the standard methods for measuring near power lines (IEEE Std. 644-1994a). Measured magnetic fields are expressed as the total field computed as the resultant of field vectors measured along vertical, transverse, and longitudinal axes.[4] The magnetic field was measured in units of mG by orthogonally-mounted sensing coils whose output was logged by a digital recording meter (EMDEX II) manufactured by Enertech Consultants. This instrument meets the Institute of Electrical and Electronics Engineers (IEEE) instrumentation standard for obtaining accurate field measurements at power line frequencies (IEEE Std.1308-1994b). The meter was calibrated by the manufacturer by methods like those described in IEEE Std. 644-1994a.

[4] The resultant magnetic field is the Euclidian norm (square root of the sum of the squares) of the component magnetic-field vectors calculated along vertical, transverse, and longitudinal axes. Root mean square refers to the common mathematical method of defining the effective voltage, current, or field of an AC system.

Results and Discussion

The measured and calculated magnetic fields around the fence line of the proposed Kings Highway Substation are depicted in Figure 5. To characterize the background sources along the perimeter of the proposed site, the pre-Project profile in Figure 5 shows the magnetic-field levels measured on March 24, 2017. The measured profile reflects pre-Project conditions, in which no proposed facilities are constructed or in service.[5] The measured magnetic-field levels are highest at the north side of the property (approximately 10 mG), closest to the existing 138-kV transmission lines on the existing ROW. Along the east, west, and south sides of the substation property, the measured magnetic fields were on average below 2 mG, with a maximum of 5 mG in the vicinity of existing distribution sources along Wheeler Road.

The "post-Project" profile in in Figure 5 shows the magnetic field calculated using SUBCALC along the property line of the proposed Kings Highway Substation for average-load conditions. The calculated field reflects the contribution of proposed substation equipment within the yard and the proposed overhead interconnections to Transmission Line "B" West and "B" East. The SUBCALC model also includes proposed underground distribution feeders exiting the substation to the west, and proceeding north on Wheeler Road in underground duct banks. Both the measured and calculated profiles in Figure 5 begin at the southeast corner of the substation property, and continue counter-clockwise along the fence to the southwest, northwest, and northeast corners of the property.

The highest calculated magnetic field at the substation property line (42 mG) occurs beneath the conductors of Transmission Line "B" West where they pass above the north fence. On the east side of the substation property, adjacent to the terminal structures of Transmission Line "B" East, the calculated magnetic field is less (below 20 mG at average load). Fronting Rabro Drive to the south, the calculated magnetic field is 6 mG or less at average load. Along the west side of the substation property, the highest calculated magnetic field is approximately 41 mG directly over the proposed underground feeders exiting the substation onto Wheeler Road. The calculated magnetic field from the underground feeders falls off rapidly with distance, and is equal to background levels at distances of approximately 50 feet from the underground cables.

Figure 6 shows the calculated magnetic-field profile along the same path as in Figure 5 modeled using peak loading rather than average loading. The highest calculated magnetic field at the substation property line (230 mG) is again set back more that 300 feet from Wheeler Road and Rabro Drive, beneath the conductors of Transmission Line "B" West where they pass above the north fence. Fronting Wheeler Road, the highest calculated magnetic field is approximately 100 mG directly over the proposed underground feeders.

Figures 7 – 12 depict the calculated magnetic field levels along Profiles 1 – 6 for average-load conditions in 2017. Figures 7 – 9 include background magnetic-field measurements recorded on

[5] The measured profile in Figure 5 provides a "snapshot" of background magnetic-field levels. On a given day, throughout a week, or over the course of months and years, the measured magnetic field can change depending upon the patterns of power demand within the surrounding community. In general, the measured magnetic will increase during summer months when power demand on Long Island is higher.

March 24, 2017. Table 1 summarizes calculated magnetic-field levels at various distances from the substation fence in Profiles 1 – 4, for average load conditions. Table 2 likewise summarizes calculated magnetic fields for Profiles 5 – 6, at various distances from the centerline of the overhead circuits, for average-load conditions. Tables 3 and 4 include the calculated magnetic fields at the same locations as Tables 1 and 2, but for peak-load rather than average-load conditions.

Referring to the calculated profiles in Figures 7 – 9, operation of the Project elevates calculated magnetic field levels above existing background levels within about 100 feet of the substation fence. These results are consistent with IEEE Standard 1127-2013 that states "[i]n a substation, the strongest fields near the perimeter fence come from the transmission and distribution lines entering and leaving the substation. The strength of fields from equipment inside the fence decreases rapidly with distance, reaching very low levels at relatively short distances beyond substation fences." (IEEE Std. 1127-2013). The greatest Project-related increase in calculated magnetic-field levels is encountered in Profile 1 (Figure 7), proceeding west from the proposed substation yard. These changes can be attributed to an increase in loading on the Transmission Line "B" West compared the existing Transmission Line "B," and an increase in distribution loads along Wheeler Road. As presented in Appendix A, the loading of proposed Transmission Line "B" East is less that the loading of the existing Transmission Line "B." As a result, calculated magnetic fields 100 feet or more to the east of the substation property tend to decrease compared to the existing conditions. In Profile 3 for instance (Figure 9), the calculated magnetic field decreases slightly (1.6 mG) compared to existing conditions (1.8 mG) at 150 feet from the substation fence. *See* Table 1 and Table 3.

Referring to Profiles 5 and 6 (Figure 11 and Figure 12), the results show that operation of the Project slightly decreases calculated magnetic fields across the ROW to the east of the Kings Highway Substation (Figure 11), and slightly increases calculated magnetic fields across the ROW west of the substation (Figure 12). This effect is due to the decreased loading of Transmission Line "B" East and increased loading of Transmission Line "B" West, compared to the loading of existing Transmission Line "B." *See* Table 2 and Table 4. .

Table 1. Summary of calculated magnetic fields (mG) for Profiles 1-4, average-load case

Profile	Condition	Distance from Substation Fence (ft)			
		0	50	100	150
1	Pre-Project	0.7	0.7	0.7	0.7
	Post-Project	16.9	*14.5	5.1	2.1
2	Pre-Project	0.5	0.4	0.3	0.2
	Post-Project	9.3	2.0	0.9	0.6
3	Pre-Project	1.8	1.8	1.8	1.8
	Post-Project	14.1	3.5	2.0	1.6
4	Pre-Project	21.2	26.5	13.1	5.9
	Post-Project	2.0	15.5	10.3	5.2

* Underground distribution circuits are present at this location.

Table 2. Summary of calculated magnetic fields (mG) for Profiles 5-6, average-load case

Profile	Load case	Offset from existing ROW				
		100 ft north of ROW edge	ROW edge north	Max on ROW	ROW edge south	100 ft south of ROW edge
5	Pre-Project	4.0	21.5	34.0	24.6	4.3
	Post-Project	3.5	19.2	28.5	19.5	3.5
6	Pre-Project	4.1	22.8	34.0	23.2	4.1
	Post-Project	4.5	26.0	41.6	29.1	5.4

Table 3. Summary of calculated magnetic fields (mG) for Profiles 1-4, peak-load case

Profile	Condition	Distance from Substation Fence (ft) 0	50	100	150
1	Pre-Project	3.6	3.6	3.5	3.4
	Post-Project	43.2	*37.9	14.2	7.1
2	Pre-Project	2.4	1.8	1.5	1.2
	Post-Project	24.4	5.9	3.0	1.9
3	Pre-Project	9.2	9.2	9.1	9.0
	Post-Project	56.8	15.1	9.4	8.0
4	Pre-Project	109	136	67.0	30.2
	Post-Project	9.9	77.9	51.3	25.1

* Underground distribution circuits are present at this location.

Table 4. Summary of calculated magnetic fields (mG) for Profiles 5-6, peak-load case

Profile	Load case	Offset from existing ROW: 100 ft north of ROW edge	ROW edge north	Max on ROW	ROW edge south	100 ft south of ROW edge
5	Pre-Project	20.3	110	175	127	22.2
	Post-Project	17.8	97.5	146	100	18.0
6	Pre-Project	21.1	117	175	120	21.3
	Post-Project	24.0	134	215	150	27.1

Structures and Buildings

Table 5 shows the magnetic field calculated at reporting locations 1 – 9 (see Figure 1), which are workplaces and dwellings around the proposed site of the Kings Highway Substation. Table 5 provides the calculated magnetic field levels at both average and peak loading, before and after operation of the Project. The "average" column was calculated using the average loads provided in Appendix A. The "peak" column reflects the peak loads provided in Appendix A, and is anticipated to occur for a few days and hours during the year when power demand is highest in the surrounding community. Closest to the existing ROW east of the proposed substation (locations 8 and 9), the increase in calculated magnetic field is approximately 2.6 mG for average-load conditions and 6-8 mG for peak-load conditions. This change reflects an increase in loading of Transmission Line "B" West compared to the existing Transmission Line "B," as well as increased loading on distribution circuits along Wheeler Road.

At other reporting locations, operation of the Project has a small effect on calculated magnetic fields. To the east of the proposed substation, for instance, post-Project magnetic fields at structures 3 and 4 decrease slightly compared to existing conditions (pre-Project). This change reflects the decrease loading of Transmission Line "B" East compared to the existing Transmission Line "B."

Table 5. Summary of calculated magnetic fields (mG) at designated structures

	Average Load		Peak Load	
Building designator*	**pre-Project**	**post-Project**	**pre-Project**	**post-Project**
1	10.1	9.4	51.5	54.2
2	9.7	12.1	49.2	53.0
3	2.0	1.8	10.1	8.9
4	2.1	2.1	10.6	10.0
5	0.2	0.2	0.9	0.8
6	0.2	0.6	1.2	2.0
7	0.4	1.2	2.2	4.1
8	0.8	3.3	4.1	10.2
9	3.2	5.8	16.6	24.6

* The location of each building is shown in Figure 1.

Comparison with Background Levels

Since electricity is such an integral part of our infrastructure (e.g., transportation systems, homes, and businesses), people living in modern communities are surrounded by sources of electric and magnetic fields. Figure 13 describes typical EMF levels measured in residential and occupational environments, compared to levels measured on or at the edge of transmission-line rights-of-way. While EMF levels decrease with distance from the source, any home, school, or office tends to have a "background" EMF level as a result of the combined effect of the numerous EMF sources. In general, the background magnetic-field level in a house away from appliances is typically less than 20 mG, while levels can be hundreds of mG in close proximity to appliances.

Little research has been done to characterize the general public's exposure to magnetic fields, although some basic conclusions are available from the literature. The vast majority of people in the United States have a *time-weighted average* (TWA) exposure to magnetic fields less than 2 mG.[6] The highest magnetic-field levels are typically found directly next to appliances.[7] For example, Gauger (1985) reported the maximum AC magnetic field at 3 centimeters from a sampling of appliances as 3,000 mG (can opener), 2,000 mG (hair dryer), 5 mG (oven), and 0.7 mG (refrigerator).[8]

Overall, the calculated and measured magnetic field levels associated with the Project fall within the range of typical levels encountered within homes and businesses. The Project-related increases in the calculated magnetic field are small, and are on average less than 2.6 mG at workplaces in the vicinity of the proposed Kings Highway Substation.

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[6] TWA is the average exposure over a given specified time period (i.e., an 8-hour workday or a 24-hour day) of a person's exposure to magnetic fields. The average is determined by sampling the exposure of interest throughout the time period. *See* Zaffanella LE and Kalton GW. Survey of Personal Magnetic Field Exposure Phase II: 1,000 Person Survey. EMF Rapid Program, Engineering Project #6. Lee, MA: Entertech Consultants, 1998.

[7] *See* Zaffanella LE. Survey of Residential Magnetic Field Sources. Volume 2: Protocol, Data Analysis, and Management. EPRI TR-102759-V2. Palo Alto, CA: EPRI, 1993.

[8] *See* Gauger JR. Household appliance magnetic field survey. IEEE Trans Power App Syst 104: 2436-2444, 1985.

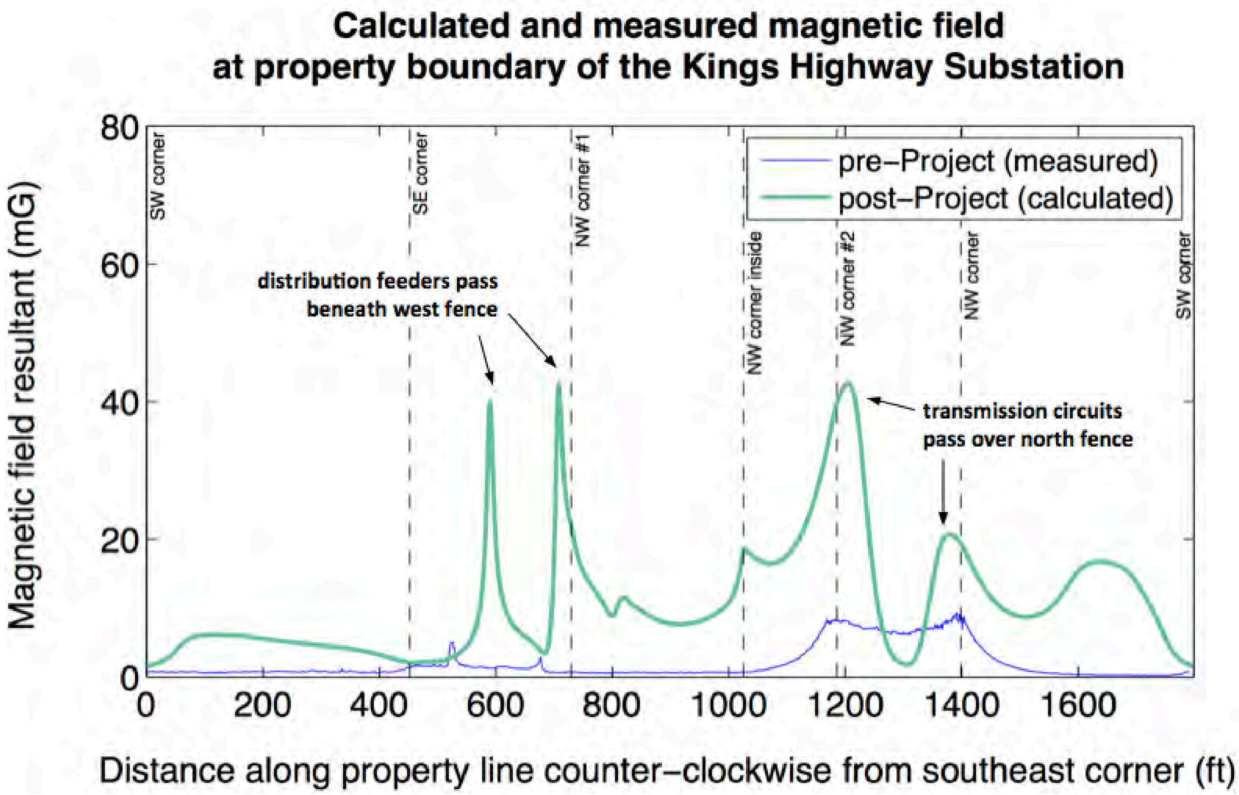
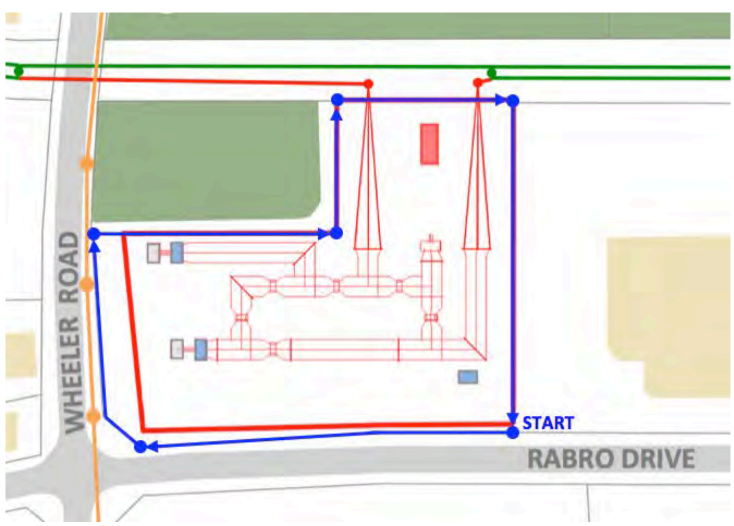


Figure 5. Calculated and measured magnetic-field levels around the property line of the proposed Kings Highway Substation for average-load conditions in 2017.



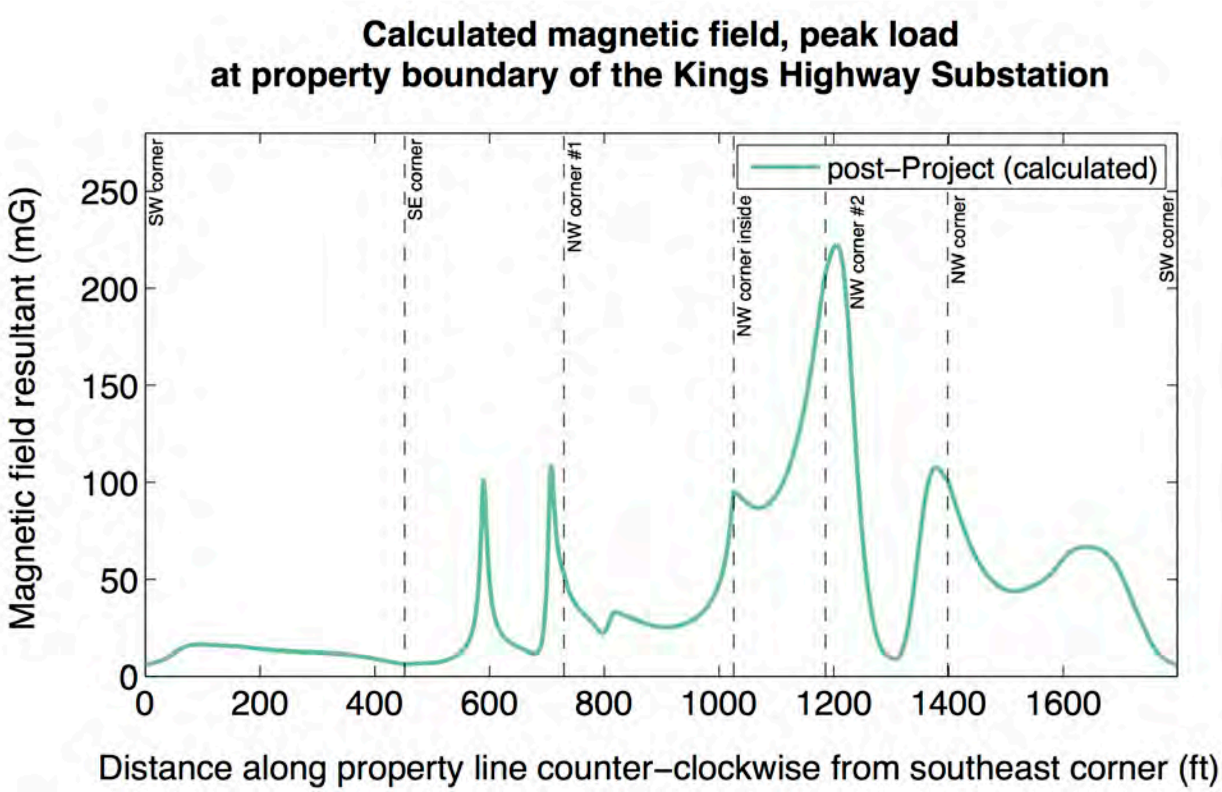


Figure 6. Calculated magnetic-field levels around the property line of the proposed Kings Highway Substation for peak-load conditions in 2017.

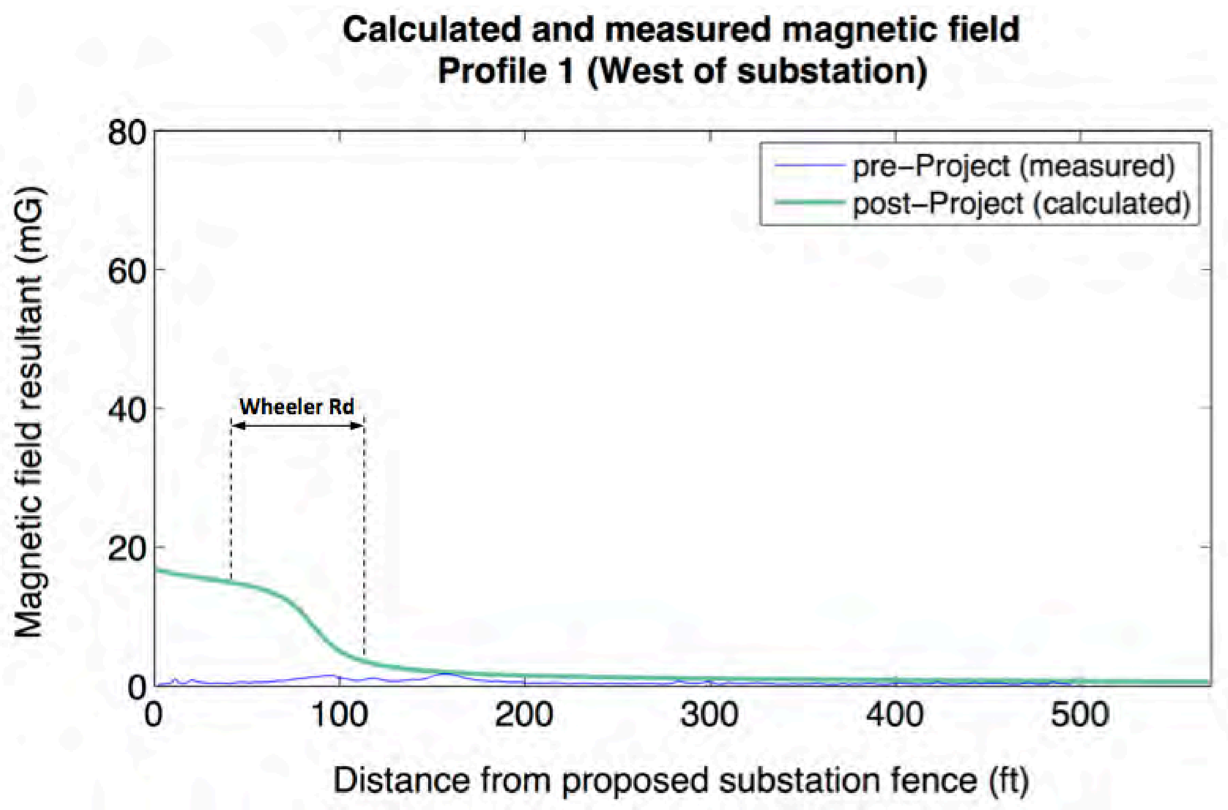


Figure 7. Calculated and measured magnetic-field levels along Profile 1 going to the west across Wheelrer Road for average-load conditions in 2017.

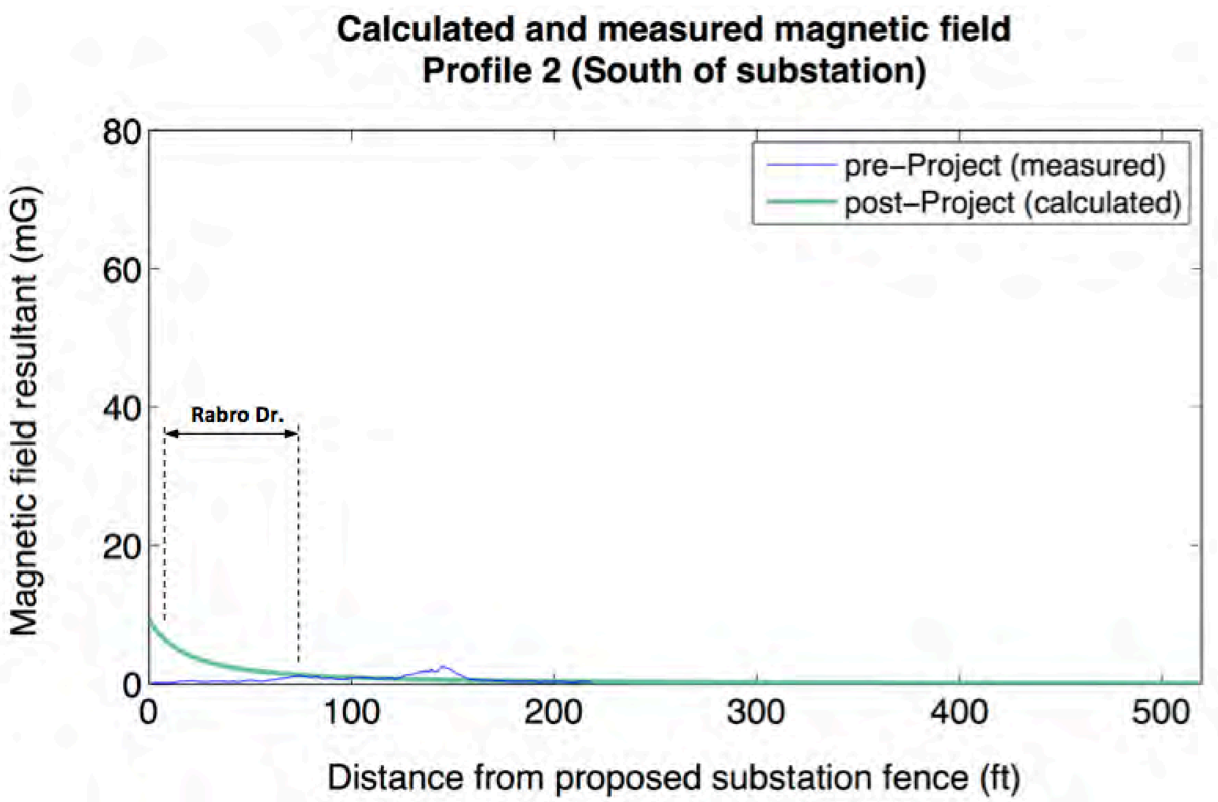


Figure 8. Calculated and measured magnetic-field levels along Profile 2 going to the south across Rabro Drive for average-load conditions in 2017.

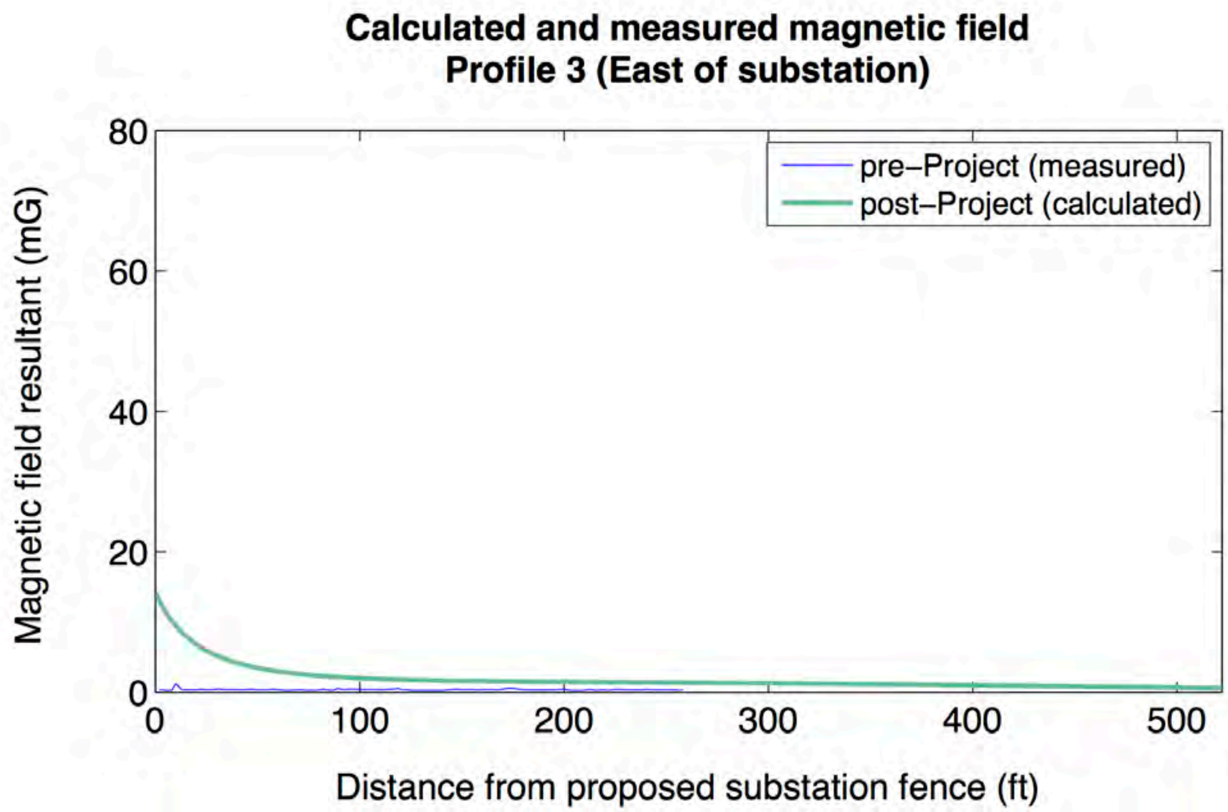


Figure 9. Calculated and measured magnetic-field levels along Profile 3 going to the east for average-load conditions in 2017.

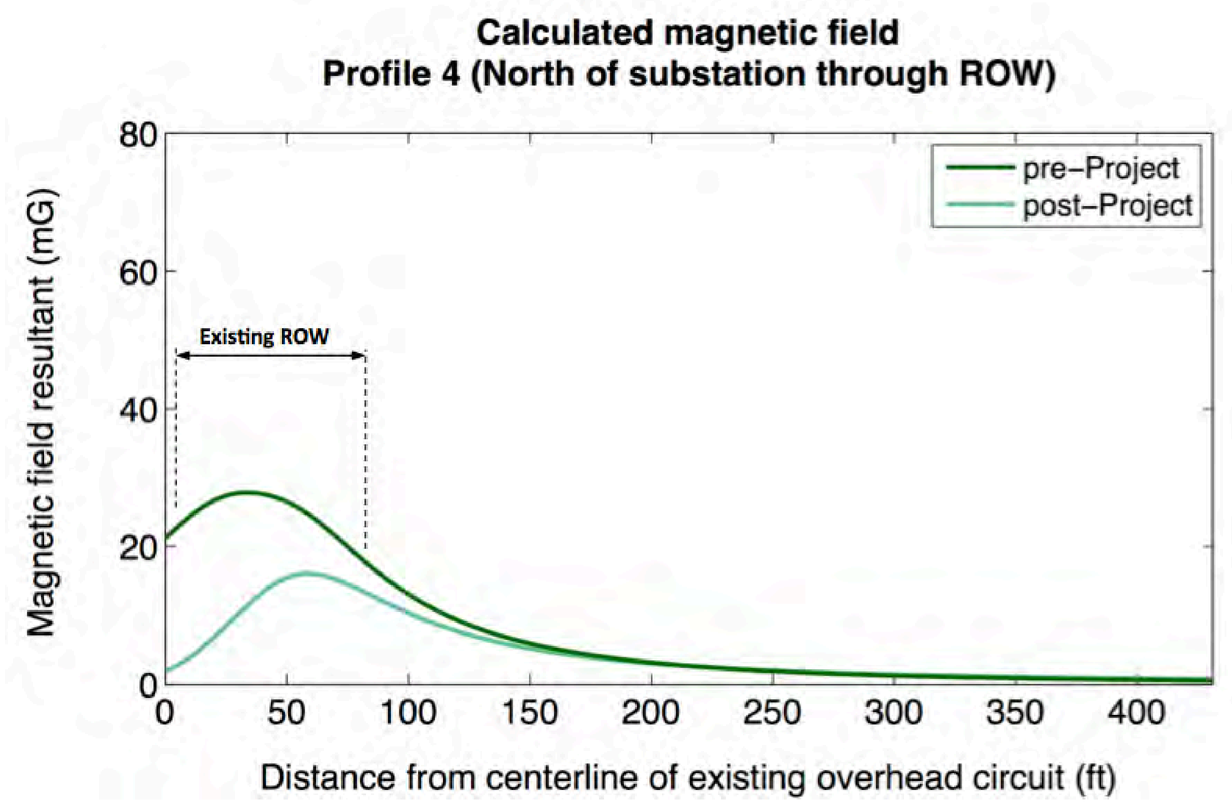


Figure 10. Calculated magnetic-field levels along Profile 4 going to the north across the existing ROW for average-load conditions in 2017.

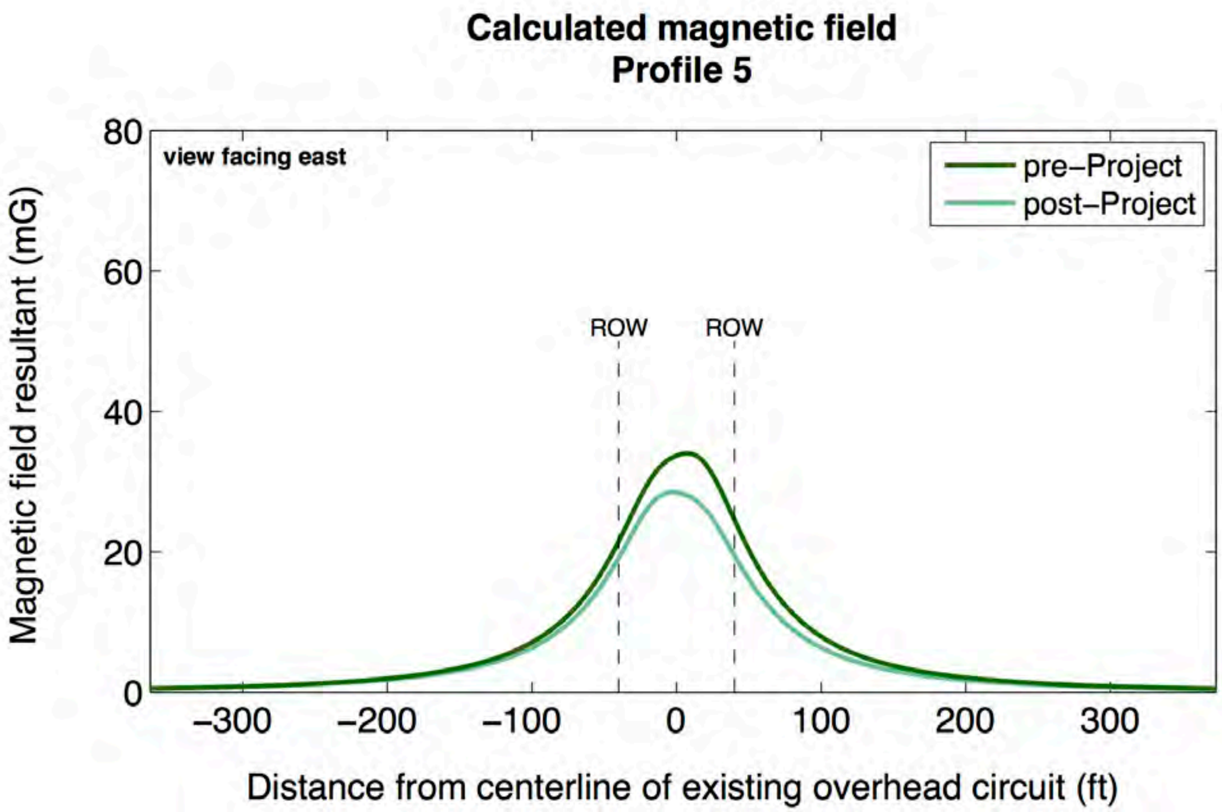


Figure 11. Calculated magnetic-field levels along Profile 5 (east of substation along the ROW) for average-load conditions in 2017.

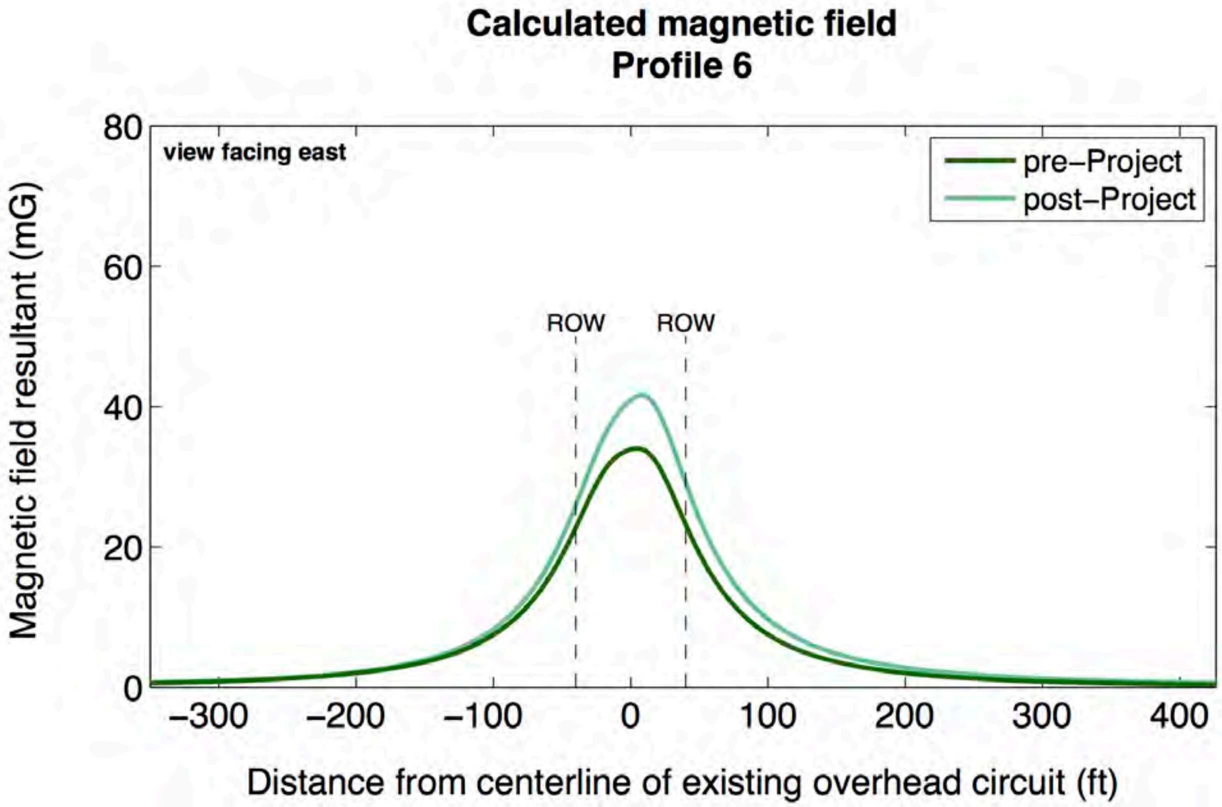


Figure 12. Calculated magnetic-field levels along Profile 6 (west of substation along the ROW) for average-load conditions in 2017.

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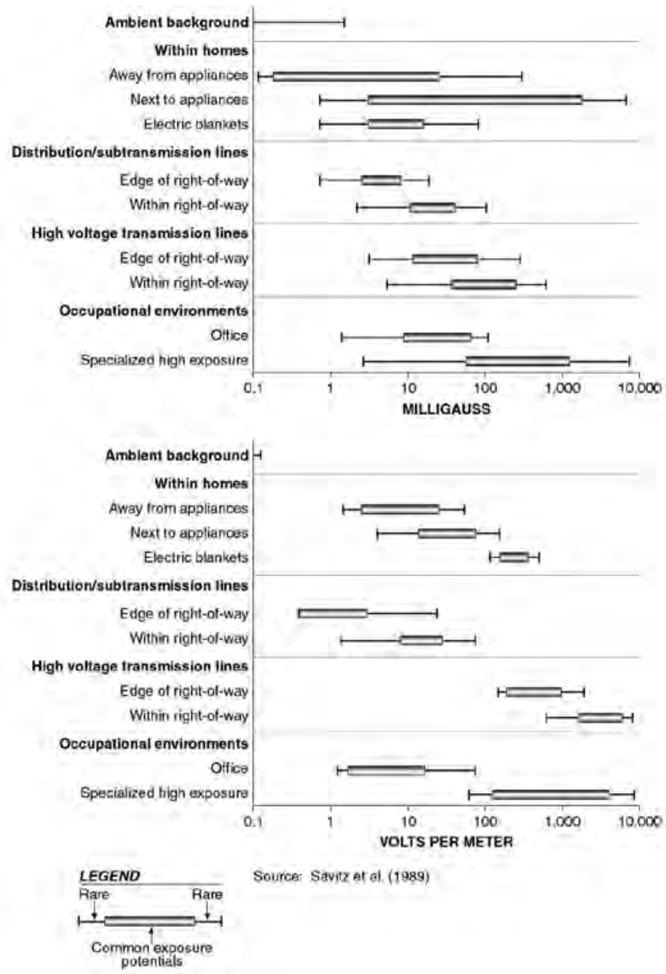

Figure 13. Electric- and magnetic-field strengths in the environment.

Appendix A

Magnetic fields surrounding conductors depend on current, which increases with increasing load. The current flows (loadings) for transmission lines and transformers used in the model are summarized in Table A1. Table A1 provides the average and peak loadings in amperes under existing conditions over the past five years (without Kings Highway), as well as the estimated average and peak loadings in amps under proposed conditions (with Kings Highway). For the existing conditions, loadings are provided for circuit 138-881 (the existing circuit on the south side of the ROW that will be segmented into circuits 13-880 and 13-881) and circuit 138-882 (located on the north side of the ROW). For the existing conditions, loadings are provided for circuits 138-880, 138-881, and 138-882.

Table A1. Circuit and equipment loading (amperes) used in the SUBCALC model

Circuit or Equipment	Voltage (kV)	Existing (Without Kings Highway)		Proposed (Estimates With Kings Highway)	
		Average	Peak	Average	Peak
138-881*	138	241	1256	166	867
138-882†	138	190	962	196	991
138-880	138	—	—	321	1671
Transformer 1	138/13.8	—	—	308	749
Transformer 2	138/13.8	—	—	308	749
Transformer 3	138/13.8	—	—	308	749

*Existing circuit will be tapped creating circuits 138-880 (Transmission Line “B” West) and 138-881 (Transmission Line “B” East).
†Transmission Line “A”