

ATTACHMENT F

Exponent EMF Study

Appendix

Electric and Magnetic Fields

Executive Summary

The United Illuminating Company (UI) seeks to rebuild approximately 2.1-miles of overhead 115-kilovolt transmission lines between the Baird Substation and the Housatonic River Crossing (HRX) in Stratford, Connecticut. This report evaluates the Project effect on existing levels of electric and magnetic fields (EMF) from the existing configurations of these transmission lines.

The loadings on the transmission lines are anticipated to remain nearly constant before and after the rebuild and the line voltage will not change. Therefore, the difference between the calculated EMF levels before and after the rebuild will depend entirely on the elevation, separation, and centerlines of the repositioned conductors. In the proposed configuration, the existing circuits are relocated outward onto new steel monopoles on either side of the Metro North Railroad (MNR) New Haven Line.

The shift in the centerline of the proposed circuits tends to increase the calculated magnetic fields at locations to the north and south of the Project route while the higher conductor elevations of the rebuilt lines tends to decrease calculated field levels. Because the effects of the conductor repositions tend to cancel one another, the calculated magnetic fields at the right of way (ROW) edges can increase, decrease, or remain approximately the same, depending on the proximity of the repositioned circuits to the ROW edge.

In the majority of spans along the Project route, the calculated magnetic field at the north ROW edge remains approximately constant for pre- and post-Project conditions, varying by less than 2.5 mG in the rebuilt configuration. West of the Stratford MNR Train Station, the calculated magnetic field is approximately 37 mG for average-load conditions and 32-33 mG for peak-load conditions. East of the Stratford Station, the calculated magnetic field is approximately 41-49 mG for average-load conditions and 37-44 mG for peak-load conditions.

On the south ROW edge, west of the Stratford Station, the calculated magnetic field decreases. Here, the calculated magnetic fields are approximately 49-50 mG for average load conditions (pre-construction) and decrease to 40-43 mG (post-construction). In the majority of spans east of the Stratford Station, the south ROW edge is 80 feet or more from the repositioned circuits.

Here, the increase in calculated magnetic-field levels (due to the lateral shift of the 115 kV circuits) is more pronounced than the decrease in magnetic-field levels (due to greater conductor elevation). The calculated magnetic field at the southern ROW edge in these spans is approximately 6 mG (pre-construction), and increases to 16-17 mG (post-construction) for average-load conditions. For peak-load conditions, the increase in calculated magnetic fields at the south ROW edge is comparable, between 9-10 mG.

The calculated electric fields associated with the Project are low, below 0.9 kV/m at all modeled locations. At the ROW edges in the majority of spans, the calculated electric fields are relatively unchanged or increase from approximately 0.4-0.5 kV/m (pre-construction) to 0.6-0.7 kV/m (post-construction). The increase in the electric field occurs because the rebuilt 115-kV circuits are relocated further away from the railroad tracks and closer to the ROW edges, which decreases mutual field cancellation from the two lines.

The calculated EMF levels associated with the Project are far below international safety- and health-based standards for EMF. The distribution and catenary conductors of the MNR were not included in the magnetic field modeling, because the contributions of those sources are not expected to change as a result of this Project and because of the intermittent exposure associated with the passage of trains on the New Haven Line.

The engineering design and other activities initiated by UI demonstrate compliance with the Connecticut Siting Council's EMF Best Management Practices.

Background

Any source that generates, transmits, or uses electricity produces electric and magnetic fields (EMF). Electricity travels as current from distant generating sources on high-voltage transmission lines, to substations, then on to local distribution lines, and finally to our homes and workplaces for consumption. All things connected to our electrical system—power lines; wiring in our homes, businesses, and schools; and all electric appliances and machines—are a source of EMF. In North America, the vast majority of electricity is transmitted as alternating current (AC) at a frequency of 60 cycles per second measured in Hertz (Hz), i.e., 60 Hz. The EMF from these AC sources is commonly referred to as power-frequency or extremely low frequency (ELF) EMF.

Both electric fields and magnetic fields are properties of the space near all electrical sources. Electric fields exert a force on electrical charges, while magnetic fields exert a force on moving electrical charges. Although commonly referred to together as EMF, they each have different properties.

Electric fields are produced by voltage applied to electrical conductors and equipment. The electric field is expressed in measurement units of volts per meter (V/m) or kilovolts per meter (kV/m), where 1 kV/m is equal to 1,000 V/m. The electric-field level increases as the voltage increases. Electric fields are present even when an appliance is turned off if it is still connected to the power source.

Since conducting objects such as buildings, fences, and trees easily block electric fields, the major sources of exposure to electric fields indoors are appliances, equipment, and machines within homes, office, and factories. Transmission lines, distribution lines, and other power-related infrastructure are the major source of electric fields outdoors.

Transmission line electric fields emanate radially outward from the charged conductor and terminate at any other conducting object such as trees, fences, vehicles, people, or transmission line towers. Electric fields are vector quantities meaning that they have both a magnitude and direction.

Magnetic fields are the result of the flow of electric currents through wires and electrical devices. The strength of a magnetic field is expressed as magnetic flux density in units called gauss (G) or mG, where $1 \text{ G} = 1,000 \text{ mG}$.¹ In general, the strength of a magnetic field increases as the current increases, but the strength also depends on characteristics of the source, including the arrangement and separation of the conductors. Unlike electric fields, magnetic fields are not easily blocked by conducting objects. In addition, a time-varying magnetic field (such as that used in power transmission systems) induces an electric field and currents in nearby conducting objects. Like electric fields, magnetic fields are vector quantities described by both their magnitude and direction.

The intensity of both electric fields and magnetic fields diminishes with increasing distance from the source. In the case of transmission lines, electric and magnetic fields generally decrease with distance from the conductors in proportion to the square of the distance. Since line voltage is quite stable and does not change very much over time, electric-field levels are also stable. Magnetic-field levels, however, can vary depending on load conditions (i.e., the currents flowing in a conductor).

¹ Scientists also refer to magnetic flux density at these levels in units of microtesla (μT). Magnetic flux density in mG units can be converted to μT by dividing by 10 (i.e., $1 \text{ mG} = 0.1 \mu\text{T}$).

EMF Guidance

After more than 30 years of research that includes hundreds of studies, none of the national and international health and scientific organizations that have reviewed the scientific and medical research literature has concluded that exposure to EMF in the ELF frequency range is a demonstrated cause of any long-term adverse effect on health. At high levels of exposure nerve stimulation may occur and so the World Health Organization (WHO) recommends compliance with exposure guidelines to protect public health.

The evidence in support of a causal relationship between exposure to EMF at the low levels in community and occupational environments is weak because it is founded largely, if not entirely, on epidemiology studies that have reported statistical associations between magnetic field exposure (or some proxy of exposure) and a disease. Most attention has been given to some studies that have reported an association between childhood leukemia and estimates of long-term exposure to high, average magnetic field levels (IARC, 2002). Scientists have placed less weight on this and other associations because they are weak, often inconsistent between studies, and possibly due to errors in the way the study was designed or conducted. Overall, animal studies have not reported an increase in cancer among animals exposed to high levels of EMF, and no mechanism has been discovered in laboratory studies that would explain how electric or magnetic fields could produce disease. Thus, the WHO and other agencies have concluded that the overall body of research does not indicate that this association, or any other, is causal in nature.

More relevant EMF assessment criteria are the exposure limits recommended by scientific organizations. These exposure limits were developed to protect health and safety and are based on reviews and evaluations of relevant health research. These guidelines include exposure limits for the general public recommended by the International Committee on Electromagnetic Safety (ICES) and the International Commission on Non-Ionizing Radiation Protection (ICNIRP) to address health and safety issues (ICES 2002/2007; ICNIRP 2010).

The only confirmed relationship between EMF and an adverse biological effect is when electric currents, at very high levels of exposure, are induced in the body and experienced as stimulation of nerves. The level at which such short-term effects occur is much higher than levels found under transmission lines, and still higher than levels found in most homes or commercial establishments. As mentioned, ICES and ICNIRP have recommended exposure guidelines (Reference Levels) to protect against the occurrence of these acute adverse effects from short-term exposures. Table 1 summarizes these guidelines for EMF exposure that ensure that basic restrictions on electric fields in the body are not exceeded.

Table 1. Reference Levels for whole body exposure to 60-Hz fields: general public

Organization	Magnetic fields	Electric fields*
ICNIRP, reference level	2,000 mG	4.2 kV/m
ICES, maximum permissible exposure (MPE)	9,040 mG	5 kV/m 10 kV/m†

*Both organizations judged that evidence for effects from long-term exposure was insufficient for setting exposure standards.

†Exception within a transmission line ROW.

The WHO established the International EMF Project in 1996, in response to public concerns about exposures to EMF and possible adverse health effects. The overall purpose of the Project is to assess any possible health and environmental effects of exposure to static and time-varying EMF. A key objective was to evaluate the scientific literature and make a status report on health effects, to be used as the basis for a coherent international response. The review was prepared by 21 scientists from around the world with expertise in a wide range of disciplines and published in June 2007 as part of WHO's Environmental Health Criteria (EHC) Programme.

The WHO concluded the following:

Acute biological effects have been established for exposure to ELF electric and magnetic fields in the frequency range up to 100 kHz that may have adverse consequences on health. Therefore, exposure limits are needed. International guidelines exist that have addressed this issue. Compliance with these guidelines provides adequate protection. Consistent epidemiological evidence suggests that chronic low-intensity ELF magnetic field exposure is associated with an increased risk of

childhood leukaemia. However, the evidence for a causal relationship is limited, therefore exposure limits based upon epidemiological evidence are not recommended, but some precautionary measures are warranted. (WHO, 2007, p. 355)

The absence of clear evidence for adverse effects after continued research and testing increases the certainty that there is not an adverse effect, or that any risk associated with exposure is small. Because of the inherent limitations of scientific investigation it is very difficult for a review panel to ever completely rule out the possibility that EMF in our communities and workplaces might have some adverse effect. Science cannot prove the absence of any effect but can effectively address uncertainty about effects by continued research. Given the amount and quality of research that has been conducted thus far, the opinions from the WHO and other agencies is consistent that ELF EMF is not a cause of long-term, adverse health effects.

The Connecticut Siting Council (CSC) has adopted “EMF Best Management Practices for the Construction of Electric Transmission Lines in Connecticut” (BMP) based upon a consensus of health and scientific agencies that the scientific evidence “*reflects the lack of credible scientific evidence for a causal relationship between MF [magnetic field] exposure and adverse health effects*” (CSC, 2014, p. 3). Nevertheless, the CSC concluded that precautionary measures for the siting of new transmission lines in the state of Connecticut are appropriate and advocates “*the use of effective no-cost and low-cost technologies and management techniques on a project-specific basis to reduce MF exposure to the public while allowing for the development of efficient and cost-effective electrical transmission projects*” (CSC, 2014, p.4).

The CSC’s EMF BMP guidance (CSC, 2014) expresses the CSC’s interest in “*evidence of any new developments in scientific research addressing MF and public health effects or changes in scientific consensus group positions regarding MF*” (p. 5). For this project, the CSC’s 2014 BMPs serve as the primary reference to new developments in EMF scientific research.

However, Exponent notes that in 2015, the Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR) of the European Union issued its opinion report in which the Committee concluded that research published up to 2014 did not confirm any adverse health effects of EMF exposure. The SCENIHR review was the most comprehensive of the reviews completed since the WHO review in 2007. The conclusions of the 2015 SCENIHR review are

consistent with the conclusions expressed in the WHO report and the BMPs published in 2014. In accordance with the CSC's BMPs, the Project has been designed with consideration to the following engineering controls:

- Distance — In the majority of spans, the proposed structures are now to be constructed further away from the railroad line in an area with less frequent public access and exposure;
- Height of Support Structures — The proposed structures are higher than the existing structures shared with Metro North; and
- Conductor Configuration — The line will be rebuilt on monopoles in a vertical configuration that serves in some configurations to increase the height of the conductors above ground.

The closest area where children congregate adjacent to the proposed rebuilt transmission lines in Stratford High School, which is located 900 feet or more from the Project. At this distance, the calculated magnetic-field level after rebuild of the lines diminishes to background levels. *See* Measurements section, below.

EMF Modeling

The Baird to Housatonic River Crossing (HRX) Line Upgrade Project (the Project) includes the reconductoring and modification of two existing transmission lines between the Baird Substation and the Housatonic River in Stratford, Connecticut. The Project includes two segments:

- 1) a first segment between HRX to the Barnum Substation; and
- 2) a second segment between the Barnum Substation and the Baird Substation.

Each segment includes a transmission line on the north side of the Metro North Railroad (MNR) New Haven Line (the north circuit) and a transmission line on the south side of the MNR New Haven Line (the south circuit). The conductors of existing circuits are mounted on metal support “bonnets” that are attached to MNR structures. The structures also support the distribution conductors and catenaries of the New Haven Line. The proposed upgrade would reposition the north circuit to new steel monopoles to the north of the existing structures, and reposition the south circuit to new steel monopoles to the south of the existing structures.

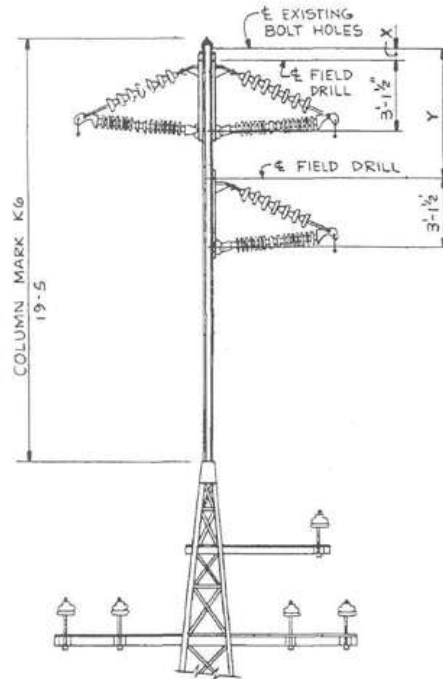


Figure 1. Existing “bonnet” supports for the existing 115-kV circuits between the Baird Substation and HRX.

Exponent modeled the EMF levels associated with the rebuild of the north and south transmission lines. The modeling of EMF included both existing and proposed configurations in five sections of the route:

- **Section HRXB-1** represents the existing and proposed configurations of the 115-kV lines between Structures 826 and 828, north of the Two Roads Brewery on Stratford Avenue (CT Route 130) and east of the Baird Substation in Stratford, Connecticut. The north line will be rebuilt on a steel monopole approximately 21 feet north of the existing centerline with 12-foot vertical conductor spacing. In Section HRXB-1, the south line has previously been rebuilt on a delta monopole south of MNR catenary support structure (to remain). The width of the right of way (ROW) in section HRXB-1 is 120 feet.
- **Section HRXB-2** includes the spans of the 115-kV lines between Structures 828 to 840, where the ROW is 118 feet wide. The north line will be rebuilt approximately 30 feet north of its existing centerline, and the south circuit will be moved approximately 6.5

feet south of its existing centerline. The rebuilt circuits are each supported by single-circuit monopoles with 12-foot vertical conductor spacing.

- **Section HRXB-3** includes the span around the Stratford MNR Station, between Structures 840 and 841. In the existing configuration, the north and south circuits are supported in a delta configuration on separate “bonnet” structures having 12-foot conductor separation. This same delta configuration will persist in the proposed configuration, with the conductors of the south circuit repositioned to the south by approximately 14 feet and raised by approximately 7 feet. The ROW width in section HRXB-3 is 274 feet.
- In **Section HRXB-4** includes one ROW configuration with two distinct loadings:
 - 1) a first set of loadings between Structure 841 and 846 (in spans southwest of the Barnum Substation interconnection); and
 - 2) a second set of loadings between Structure 847 and 853 (northeast of the Barnum Substation interconnection).

In Section HRXB-4, the north circuit will be rebuilt on a vertical steel monopole approximately 16.5 feet north of its existing centerline, and the south circuit will be rebuilt on a vertical steel monopole within approximately 14 feet south of its existing centerline. In the rebuilt configuration, both circuits have 12-foot vertical spacing. The ROW width in section HRXB-4 is 191 feet.

- **Section HRXB-5** includes the remaining spans east of structure 853 to HRX, where the existing ROW has width of 127 feet. The north circuit will be rebuilt outside of the existing ROW on a vertical steel monopole approximately 38 feet north of its existing centerline. The south circuit will also be rebuilt outside of the existing ROW, on a vertical steel monopole approximately 10 feet south of its existing centerline. In the rebuilt configuration, both circuits will have 12-foot vertical conductor spacing.

Methods

Existing and proposed levels of EMF were calculated using computer algorithms developed by the Bonneville Power Administration, an agency of the U.S. Department of Energy (BPA, 1991). These algorithms have been shown to accurately predict EMF levels measured near

transmission lines. The electric fields and magnetic fields were calculated as the resultant of x, y, and z field vectors. Exponent calculated electric- and magnetic-field levels at 1 meter (3.28 feet) above ground, in accordance with IEEE Std. C95.3.1-2010 and IEEE Std. 0644-1994a, as the root-mean-square value of the field ellipse at each location along a transect perpendicular to the transmission centerlines.

The inputs to the program are data regarding voltage, current flow, phasing, and conductor configurations. UI Transmission & Substation Engineering provided Exponent with data regarding the conductor position, size, voltage, and phasing of the existing and proposed circuits. The values of EMF associated with the transmission lines were calculated along profiles perpendicular to the transmission lines at the point of lowest conductor sag (mid-span), i.e., closest to the ground. The transmission line conductors were assumed to be positioned at maximum sag for the entire distance between structures and over flat terrain. An overvoltage condition of 5% was used for calculating electric fields from the transmission lines. These modeling assumptions are made to ensure that the calculated values represent the maximum expected EMF values for the cases analyzed. Distribution and catenary conductors operated by the MNR were not included in the model in order to limit the assessment to Project-related sources, rather than the intermittent exposure associated with the passage of trains on the New Haven Line. A further discussion of the EMF from the MNR conductors is included in the Pre-construction Measurements section, below.

Loading

UI Transmission Planning provided the pre- and post-Project loadings for the Baird to HRX Line Upgrades Project. UI selected dispatches in such a way as to bias power flows through the project area to maximize current flows on the north and south transmission lines associated with the Project. The current flows used for modeling are summarized in a table available from Exponent upon a request consistent with CEII restrictions.

UI is required by the CSC BMP to provide line loadings for “pre-project and post-project conditions under: 1) peak load level at the time of the application filing; and 2) at the projected seasonal maximum 24-hour average load level anticipated within five years” of operational in

service date. For peak load analysis, UI modeled the system to reflect the topology of New England’s transmission system in the year 2017 (including projects with in-service date of Q2 2017 or earlier). In addition, the study year 2025 was selected to calculate 24-hour average load level anticipated within five-years horizon from the in-service date of the Project.² For either load level, the loading of both the north and south circuits is anticipated to remain nearly constant before and after operation of the Project.

Results and Discussion

Calculated electric-field profiles are depicted in Figures 2-6 for Sections HRXB-1 through HRXB-5, respectively. Table 2 summarizes the calculated electric-field levels on the ROW, ROW edges, and at locations 100 feet beyond the ROW edges. Calculated magnetic-field profiles for average-loading conditions are depicted in Figures 7-12 for Sections HRXB-1 through HRXB-5, respectively.³ Table 3 summarizes the calculated magnetic-field levels for the average-load case on the ROW, ROW edges, and 100 feet beyond the ROW edges. Table 4 includes the calculated magnetic-field levels at the same reporting locations for peak-load conditions.

The loading of the north and south circuits is anticipated to remain nearly constant before and after operation of the Project. Changes in the calculated electric and magnetic field levels (Tables 2-4) therefore depend almost entirely on the elevation, separation, and centerline of the repositioned conductors. With the exception of a few spans in Section HRXB-1 (south side) and HRXB-3, existing circuits are relocated further away from the railroad tracks to new steel monopoles. Two principal field changes are evident when considering the changes in calculated magnetic field levels associated with operation of the Project:

² As provided by UI transmission planning, the term “seasonal maximum 24-hour average” load level was replaced by the term “peak daily average.” In this report, “average load” refers to this case. Given the increase of projected loads throughout the region with time, the peak loads provided by UI Transmission Planning (for the filing year 2017) are less than the average loads calculated for the year 2025 (5 years from the in-service date).

³ Two figures with calculated profiles for HRX-4 are provided. Figure 10 shows the calculated magnetic field levels in Section HRXB-4 at locations southwest of the existing Barnum Substation. Figure 11 shows the calculated profile for the same conductor positions in Section HRXB-4, using the transmission-line loading northeast of the existing Barnum Substation.

- 1) beneath the conductors of the repositioned circuits, the highest calculated magnetic field is lower (compared to the existing configuration) because of the higher conductor elevation of the repositioned conductors; and
- 2) at points further away from the north and south circuits, the calculated magnetic field is higher (compared to the existing configuration), since the proposed circuits are shifted laterally, away from the railroad.⁴

Because of these effects can offset one another, the calculated magnetic fields increase, decrease, or remain approximately the same, depending on the configuration of the repositioned circuits and their proximity to the ROW edge.

In Section HRXB-1, the north circuit is rebuilt on the existing ROW on new vertical monopoles. At the north ROW edge, the operation of the Project increases the calculated magnetic field level from approximately 40 mG (pre-construction) to 46 mG (post-construction) under average-load conditions. At the south ROW edge at average load, the calculated magnetic field decreases somewhat, from approximately 50 mG (pre-construction) to 40 mG (post-construction). This decrease is due to the higher conductor elevation in the proposed configuration of Section HRXB-1. The anticipated increase in calculated magnetic fields is approximately the same under peak loading conditions, a 5 mG increase at the north ROW edge and a 9 mG decrease on the south ROW edge.⁵ The calculated electric fields follow a similar trend, increasing from 0.5 kV/m (pre-construction) to 0.7 kV/m (post-construction) at the north ROW edge, and remaining approximately the same (0.6 kV/m) at the south ROW edge.

In Section HRXB-2, both the north and south circuits are rebuilt in a vertical configuration on new monopoles within the existing ROW. At the ROW edges, the increase in calculated

⁴ Because of the shifted centerline, the extremities of the magnetic-field profiles shown in Figures 7-12 increase in the proposed configuration compared to the existing configuration. For average load conditions at the 100 feet north of the ROW, calculated magnetic fields are between 3-5 mG (pre-Project), and increase to levels between 10-16 mG. The calculated magnetic-field levels show a comparable increase (between 3-7 mG) at locations 100 feet south of the ROW at average load.

⁵ Compared to the results for average load, calculated magnetic-field levels for peak-load conditions are lower at the ROW edges for both the existing and proposed configuration. This result is expected since the peak loads provided by UI Transmission Planning (for the filing year 2017) are less than the average loads calculated for the year 2025 (5 years from the in-service date).

magnetic-field levels (due to the lateral shift of their centerlines) is offset by an increase in conductor elevation (which tends to lower the calculated magnetic field). At the north ROW edge, the calculated magnetic field remains nearly constant, approximately 37 mG for average-load conditions and 32-33 mG for peak-load conditions. For both average- and peak-load condition, the calculated magnetic field at the south ROW edge decreases somewhat (by 5-6 mG) with operation of the Project. Operation of the Project is anticipated to increase the ROW-edge electric field, from approximately 0.4 kV/m (pre-construction) to 0.6 kV/m (post-construction).

Section HRXB-4 has a configuration similar to Section HRXB-2, but the centerlines of existing and proposed circuits are aligned closer to the north side of the existing ROW. As a result, the increase in calculated magnetic-field levels (due to the lateral shift of the circuits) is more pronounced at the south ROW edge. At the north ROW edge, the calculated magnetic field remains nearly constant, approximately 42-44 mG for average-load conditions and 37-39 mG for peak-load conditions. For average-load conditions, the calculated magnetic field at the south ROW edge increases from approximately 5-6 mG (pre-construction) to 16-17 mG (post-construction). The anticipated increase in calculated magnetic fields (10 mG) is approximately the same at the south ROW edge under peak-loading conditions. Operation of the Project is anticipated to increase the electric field at the north ROW edge, from approximately 0.4 kV/m (pre-construction) to 0.6 kV/m (post-construction). At the south ROW edge—more the 80 feet from the centerlines of existing and proposed circuits—the calculated electric field is quite low, falling below 0.1 kV/m for the existing and proposed cases.

In Section HRXB-5, the existing circuits are rebuilt off of the raised railroad bed on proposed structures north and south of the existing ROW and so evaluation of the magnetic-field level at the ROW edge does elucidate the project-related changes far from the structures where people are more likely to be present. The following discussion therefore focusses on field levels at 100 feet from the ROW edge. At locations 100 feet north of the existing ROW, the proposed Project is anticipated to increase the calculated magnetic field from approximately 4.6 mG (pre-construction) to 16 mG (post-construction) under average-load conditions. 100 feet south of the existing ROW under average load, the calculated magnetic field increases from 6.4 mG (pre-

construction) to 13 mG (post-construction). The anticipated increase in calculated magnetic fields is approximately the same under peak loading conditions, a 6 mG increase 100 feet north of the existing ROW and 20 mG increase 100 feet south of the existing ROW. The maximum calculated electric field in the proposed position of the circuits is 0.7 kV/m, compared to 0.5 kV/m in the existing configuration.

In Section HRXB-3 (encompassing the Stratford MNR Train Station), the centerline of the repositioned circuits is more closely aligned with their existing centerlines. At the ROW edges, the calculated electric fields remain approximately the same and are below 0.2 kV/m at the ROW edges. The calculated magnetic fields also vary by smaller amounts in this span, increase by 2-4 mG at the ROW edges for average- and peak-load conditions.

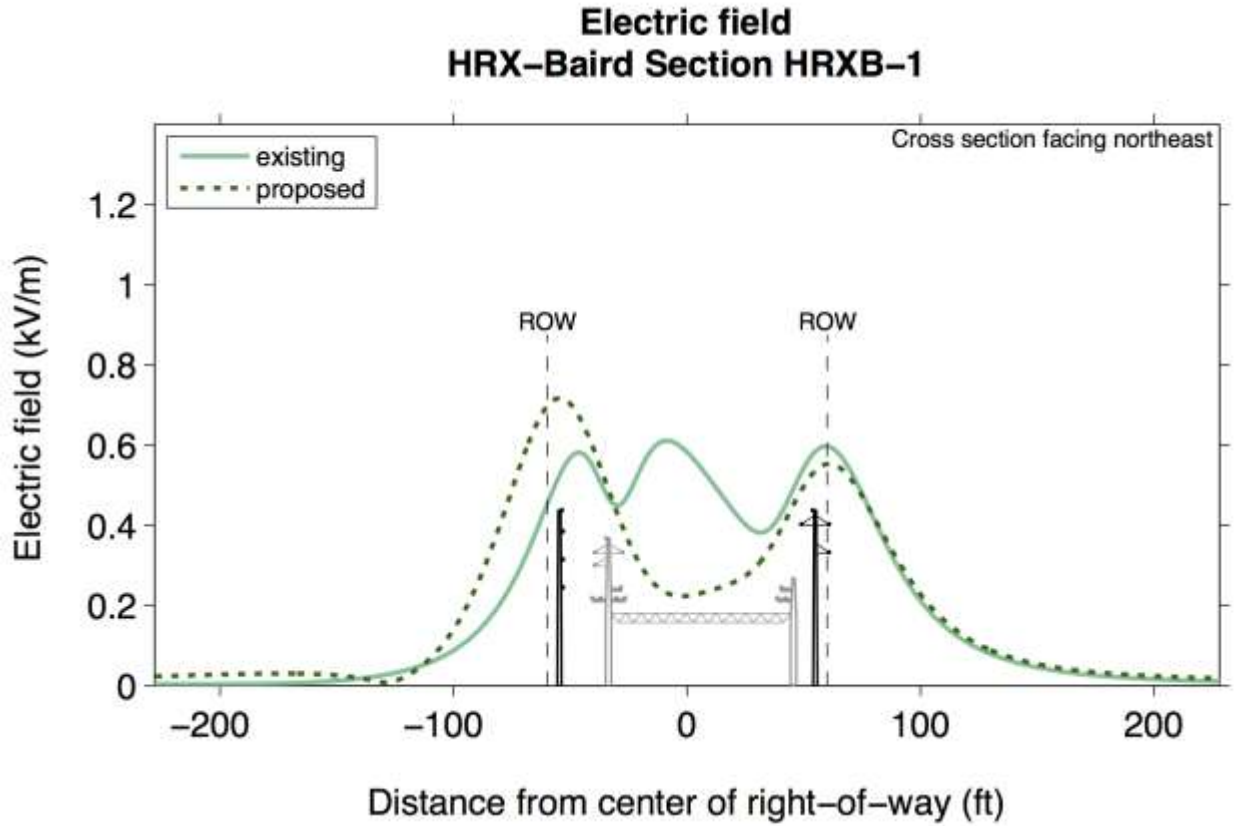


Figure 2. Calculated electric-field profile in section HRXB-1 for existing and proposed configurations, between structures 826 and 828.

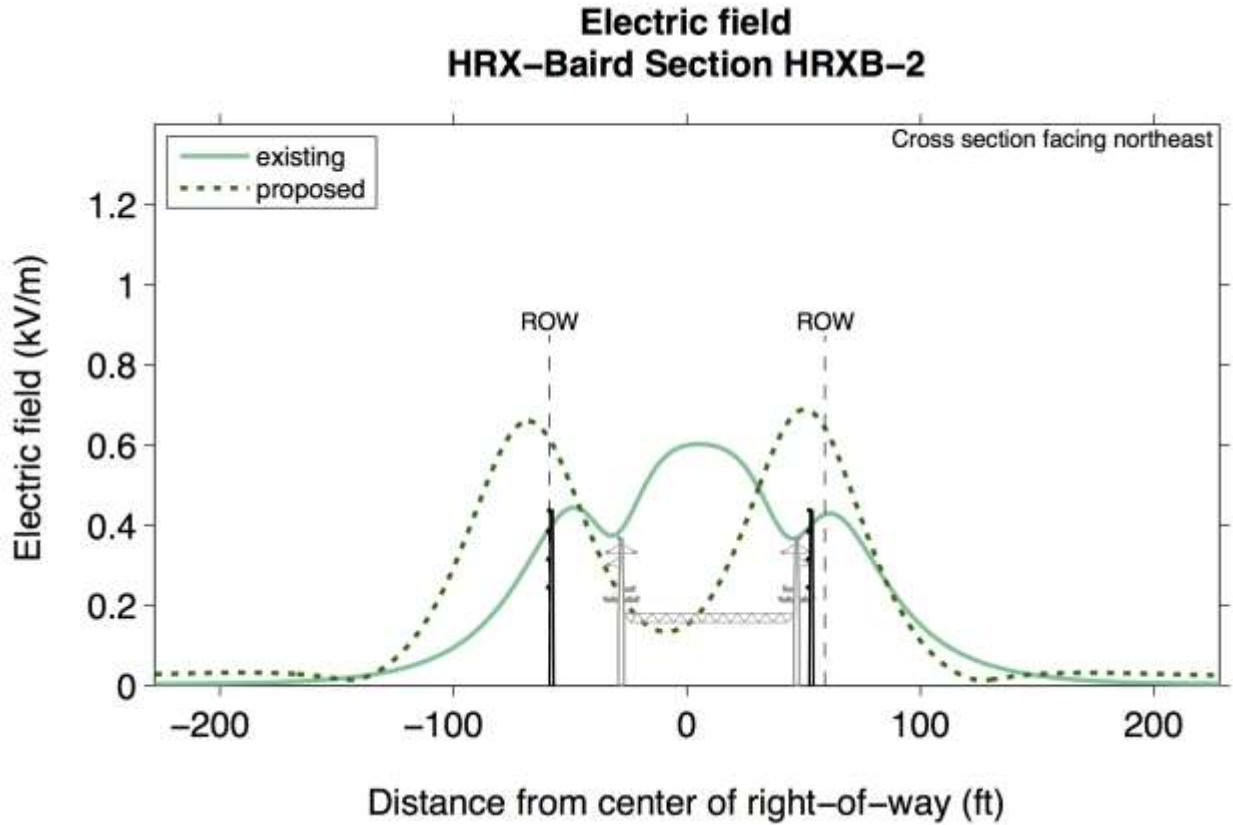


Figure 3. Calculated electric-field profile in section HRXB-2 for existing and proposed configurations, between structures 828 and 840.

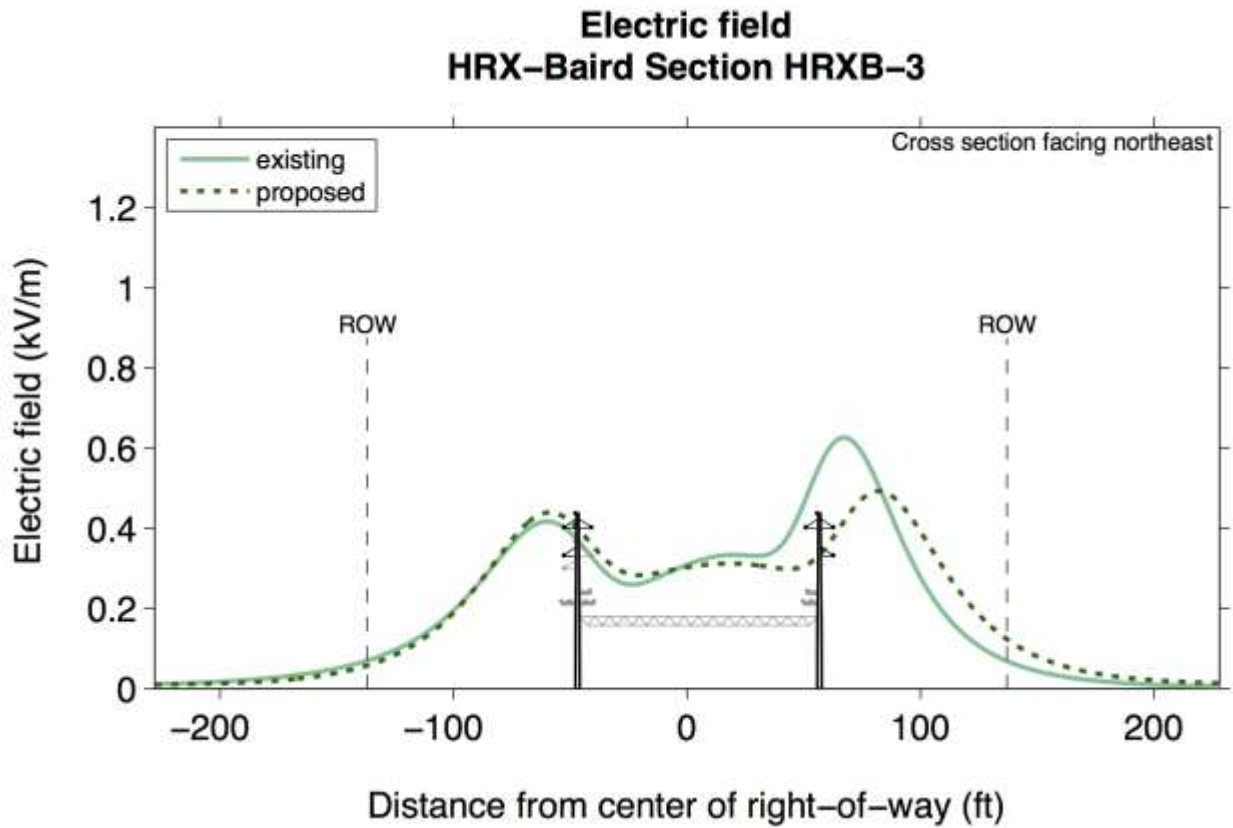


Figure 4. Calculated electric-field profile in section HRXB-3 for existing and proposed configurations, between structures 840 and 841.

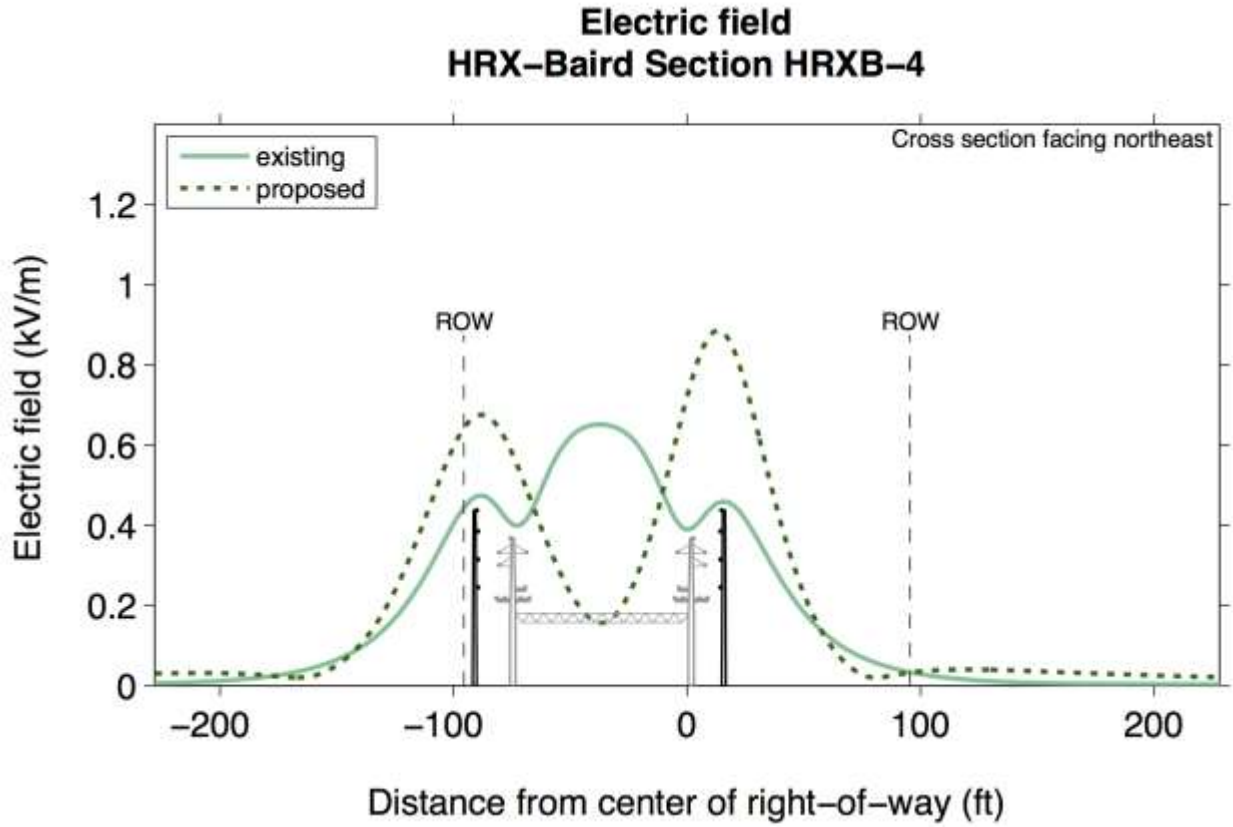


Figure 5. Calculated electric-field profile in section HRXB-4 for existing and proposed configurations, between structures 841 and 853.

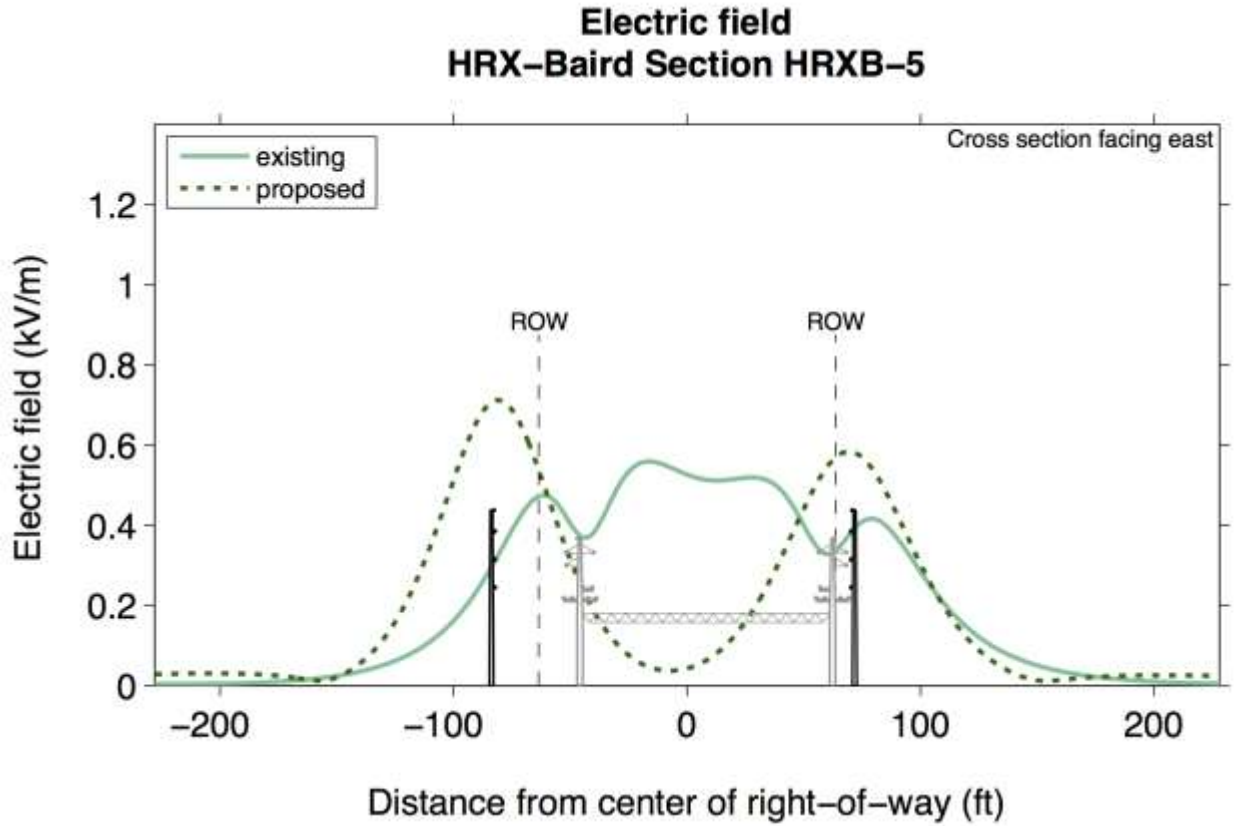


Figure 6. Calculated electric-field profile in section HRXB-6 for existing and proposed configurations, between structures 853 and 860.

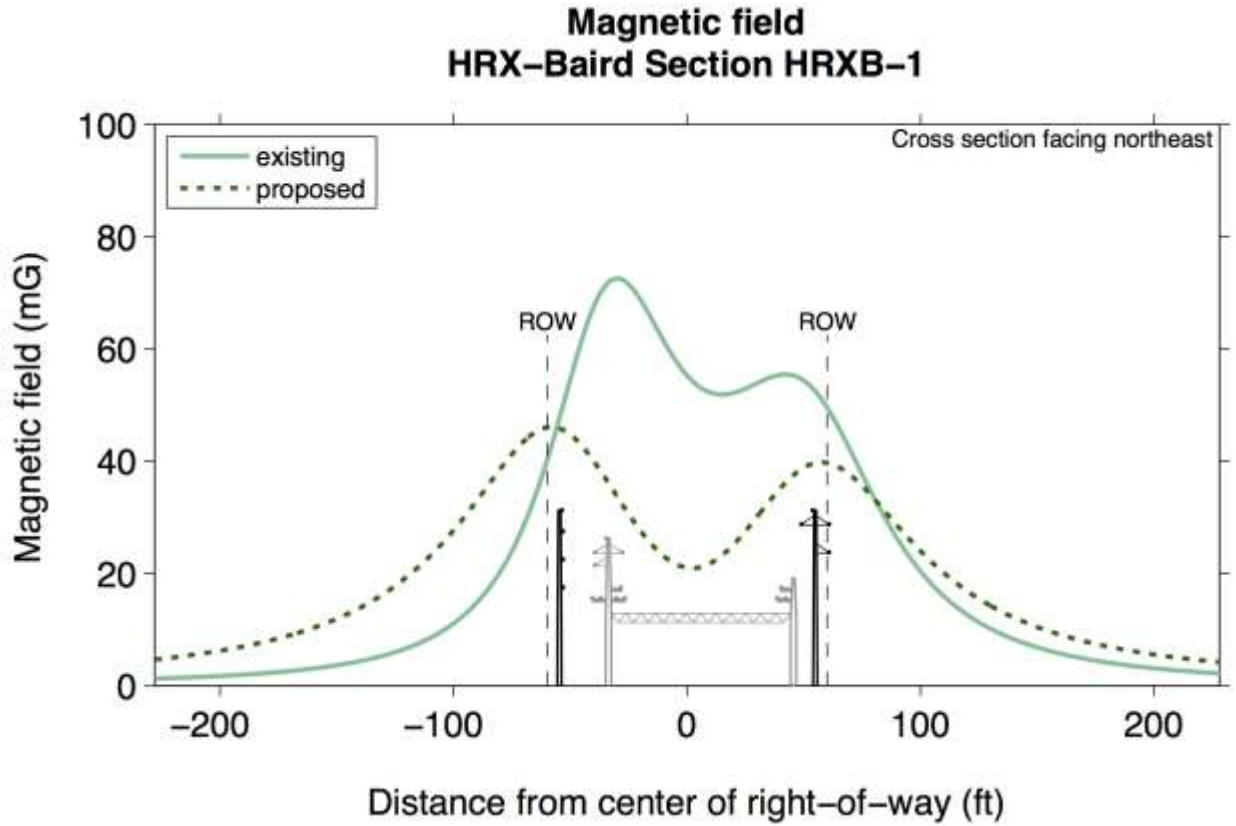


Figure 7. Calculated magnetic-field profile in section HRXB-1 for existing and proposed configurations, average load case, between structures 826 and 828.

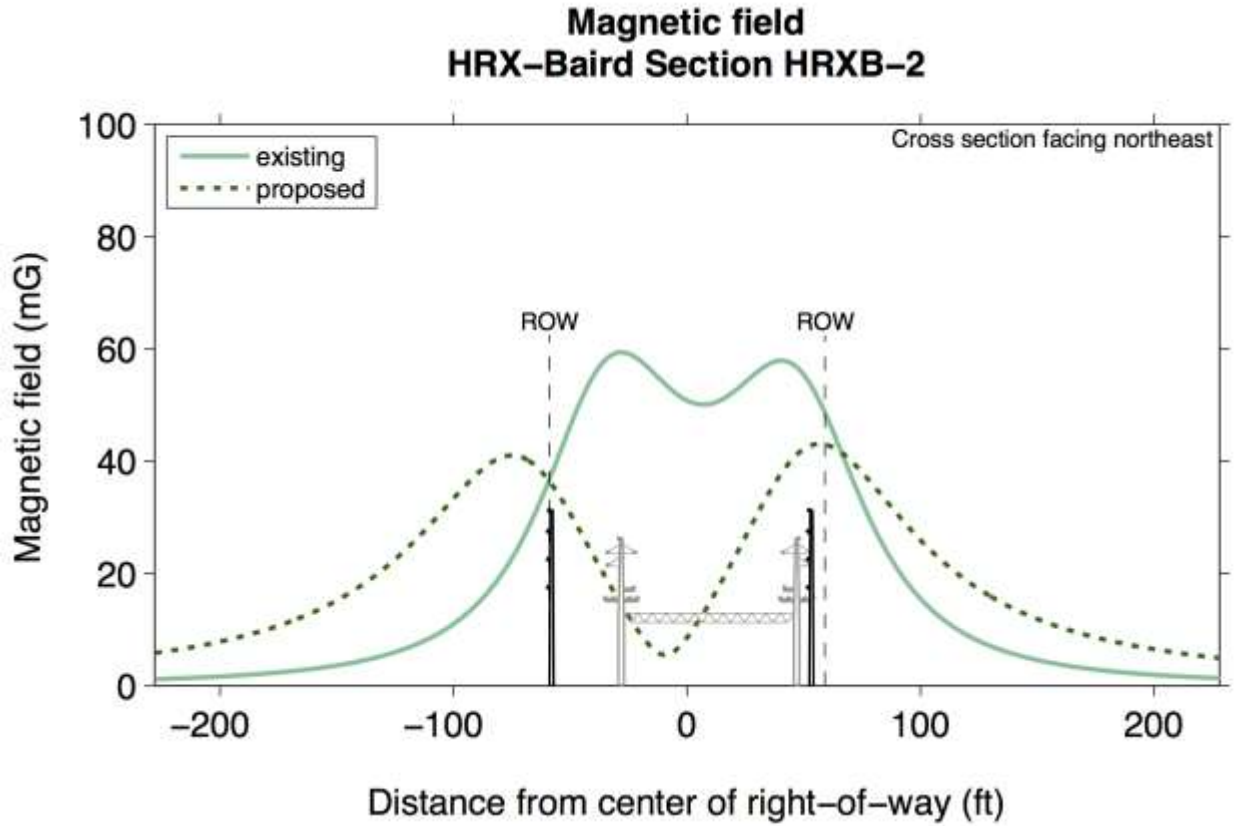


Figure 8. Calculated magnetic-field profile in section HRXB-2 for existing and proposed configurations, average load case, between structures 828 and 840.

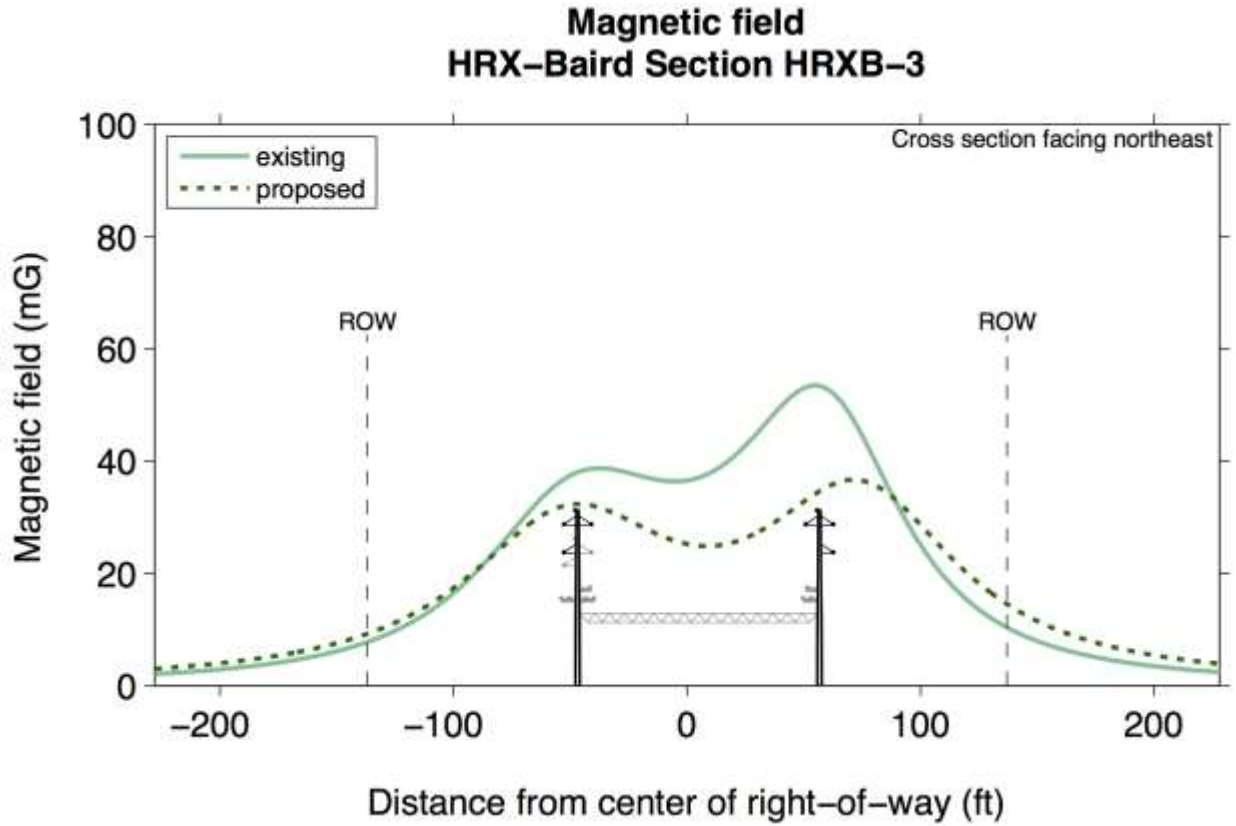


Figure 9. Calculated magnetic-field profile in section HRXB-3 for existing and proposed configurations, average load case, between structures 840 and 841.

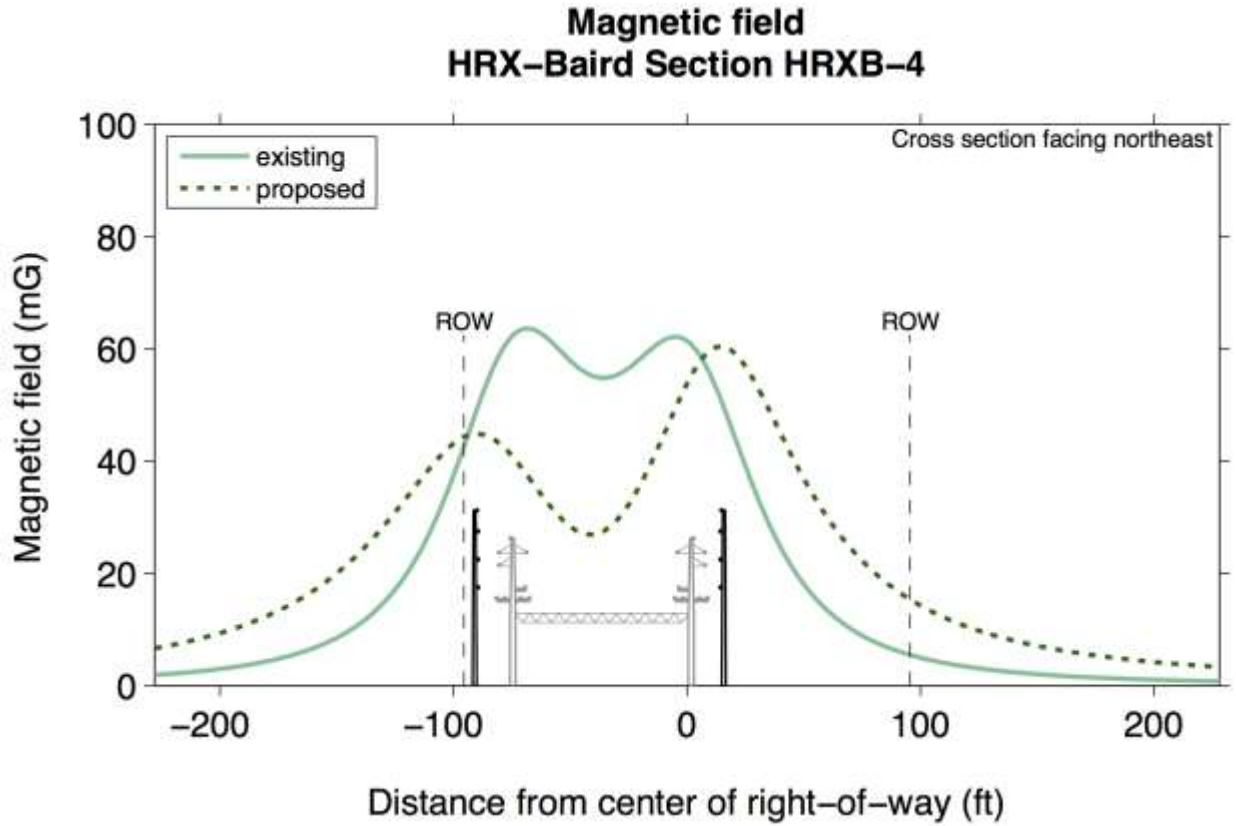


Figure 10. Calculated magnetic-field profile in section HRXB-4 for existing and proposed configurations, average load case, between structures 841 and 846 (southwest of the Barnum Substation).

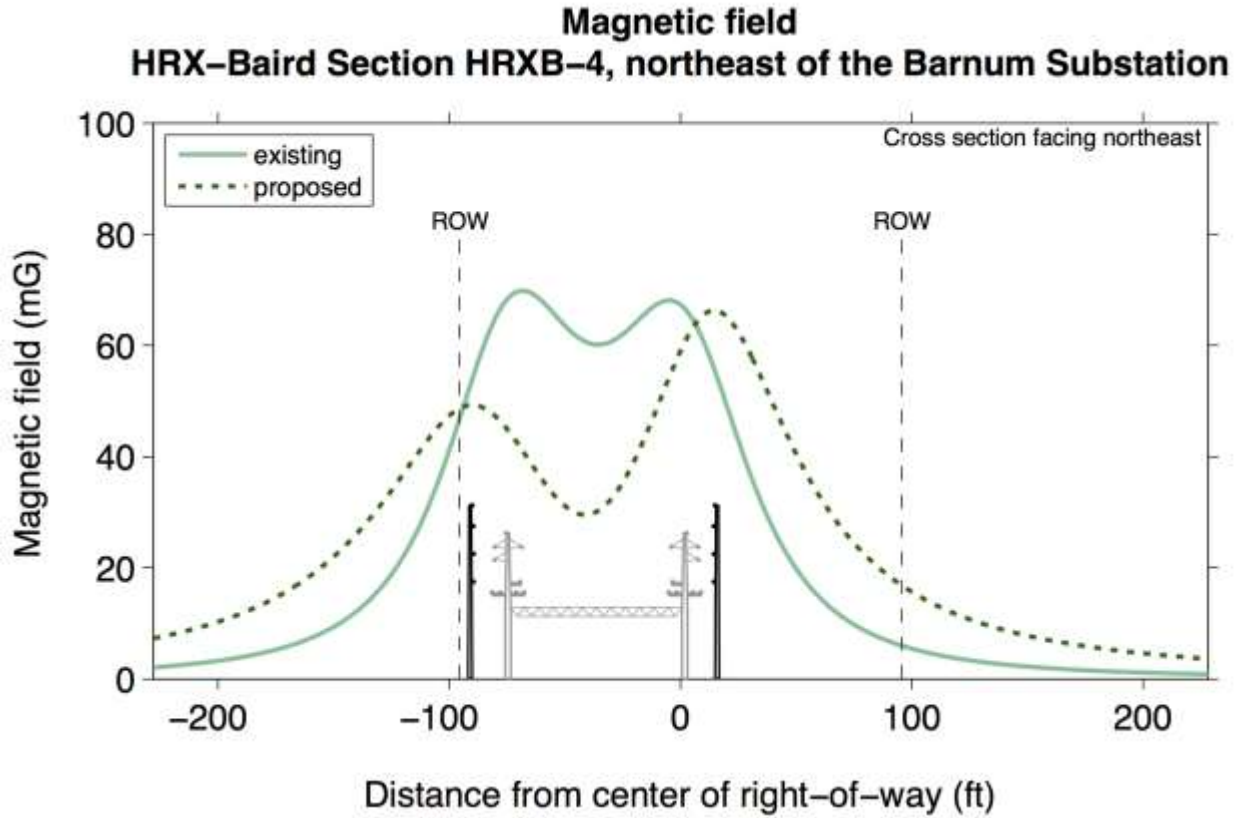


Figure 11. Calculated magnetic-field profile in section HRXB-4 for existing and proposed configurations, average load case, between structures 847 and 853 (northeast of the Barnum Substation).

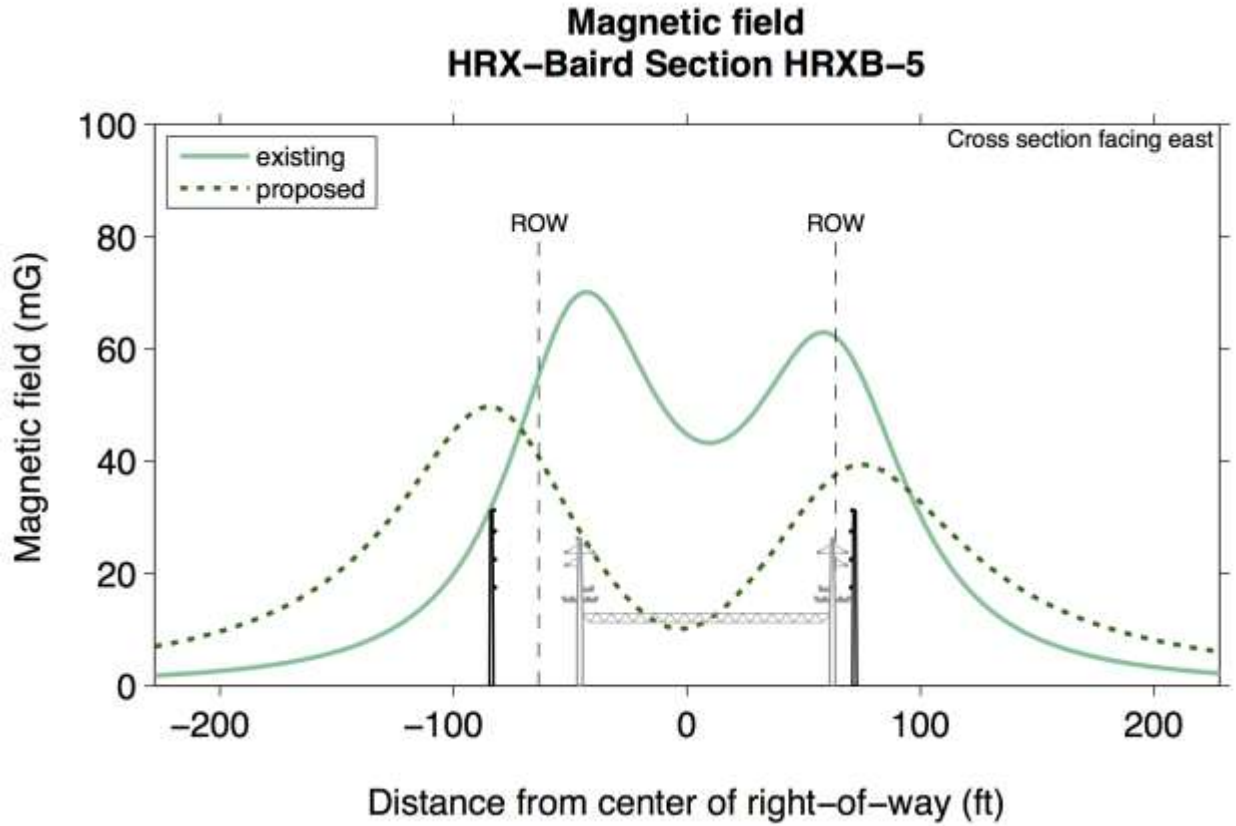


Figure 12. Calculated magnetic-field profile in section HRXB-5 for existing and proposed configurations, average load case, between structures 853 and 860.

Table 3 Calculated electric-field levels

Section	Configuration	Electric Field (kV/m)				
		100 feet north of -ROW edge	North edge of ROW	Max on profile	South edge of ROW	100 feet south of +ROW edge
HRXB-1	Existing	0.01	0.45	0.61	0.60	0.04
	Proposed	0.03	0.70	0.72	0.55	0.04
HRXB-2	Existing	0.01	0.39	0.60	0.43	0.02
	Proposed	0.02	0.62	0.69	0.64	0.03
HRXB-3	Existing	0.01	0.07	0.63	0.07	0.01
	Proposed	0.01	0.06	0.49	0.12	0.01
HRXB-4	Existing	0.01	0.44	0.65	0.03	<0.01
	Proposed	0.03	0.64	0.89	0.03	0.03
HRXB-5	Existing	0.01	0.47	0.56	0.33	0.03
	Proposed	0.02	0.55	0.71	0.57	0.02

Table 4 Calculated magnetic-field levels, average-load case

Section	Configuration	Magnetic Field (mG)				
		100 feet north of -ROW edge	North edge of ROW	Max on profile	South edge of ROW	100 feet south of +ROW edge
HRXB-1	Existing	3.1	40.1	72.5	49.6	5.7
	Proposed	10.3	46.0	46.1	39.7	9.1
HRXB-2	Existing	3.1	36.7	59.4	48.7	3.8
	Proposed	13.3	36.5	43.1	43.0	10.5
HRXB-3	Existing	1.9	7.8	53.5	10.4	2.2
	Proposed	2.7	9.2	36.7	14.6	3.5
HRXB-4	Existing	3.2	42.1	63.6	5.5	1.1
	Proposed	9.9	44.2	60.4	15.5	4.4
HRXB-4 (north of Barnum)	Existing	3.5	46.2	69.8	6.1	1.2
	Proposed	10.8	48.6	66.3	17.0	4.8
HRXB-5	Existing	4.7	54.7	70.1	62.3	6.4
	Proposed	16.0	41.1	49.7	37.4	12.9

Table 5 Calculated magnetic-field levels, peak-load case

Section	Configuration	Magnetic Field (mG)				
		100 feet north of -ROW edge	North edge of ROW	Max on profile	South edge of ROW	100 feet south of +ROW edge
HRXB-1	Existing	2.7	35.6	64.5	44.1	5.1
	Proposed	9.1	40.8	40.9	35.3	8.0
HRXB-2	Existing	2.7	32.6	52.8	43.3	3.4
	Proposed	11.8	32.3	38.3	38.2	9.3
HRXB-3	Existing	1.7	6.9	47.5	9.2	1.9
	Proposed	2.4	8.2	32.6	12.9	3.1

Section	Configuration	Magnetic Field (mG)				
		100 feet north of -ROW edge	North edge of ROW	Max on profile	South edge of ROW	100 feet south of +ROW edge
HRXB-4	Existing	2.8	37.4	56.6	4.9	1.0
	Proposed	8.8	39.3	53.7	13.8	3.9
HRXB-4 (north of Barnum)	Existing	3.2	41.7	63.1	5.5	1.1
	Proposed	9.8	43.8	59.7	15.3	4.4
HRXB-5	Existing	4.2	49.4	63.3	56.3	5.8
	Proposed	14.4	37.1	44.9	33.7	11.6

Pre-construction measurements

In order to characterize the EMF prior to operation of the Project, existing conditions were measured on March 9, 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). Both electric and magnetic fields were expressed as the total field computed as the resultant of field vectors measured along vertical, transverse, and longitudinal axes.⁶ The electric field was measured in units of kV/m with a single-axis field sensor and meter manufactured by Enertech Consultants. 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. These instruments meet the Institute of Electrical and Electronics Engineers (IEEE) instrumentation standard for obtaining accurate field measurements at power line frequencies (IEEE Std.1308-1994b). The meters were calibrated by the manufacturer by methods like those described in IEEE Std. 644-1994a.

The locations of point measurements recorded in the vicinity of the project are depicted in Figure 13, overlaid on the project route. EMF readings at these locations are summarized in Table 6. The MNR New Haven Line includes a 12.6-kV, 60-Hz catenary system that powers

⁶ Measurements along the vertical, transverse, and longitudinal axes were recorded as root-mean-square magnitudes. Root mean square refers to the common mathematical method of defining the effective voltage, current, or field of an AC system.

some rolling stock, and magnetic fields in the vicinity of the tracks would be expected to exhibit variation with traction load during periods of train acceleration. The readings in Table 6 represent steady-state EMF readings, which were observed to fluctuate with the passage of east- and west-bound trains.

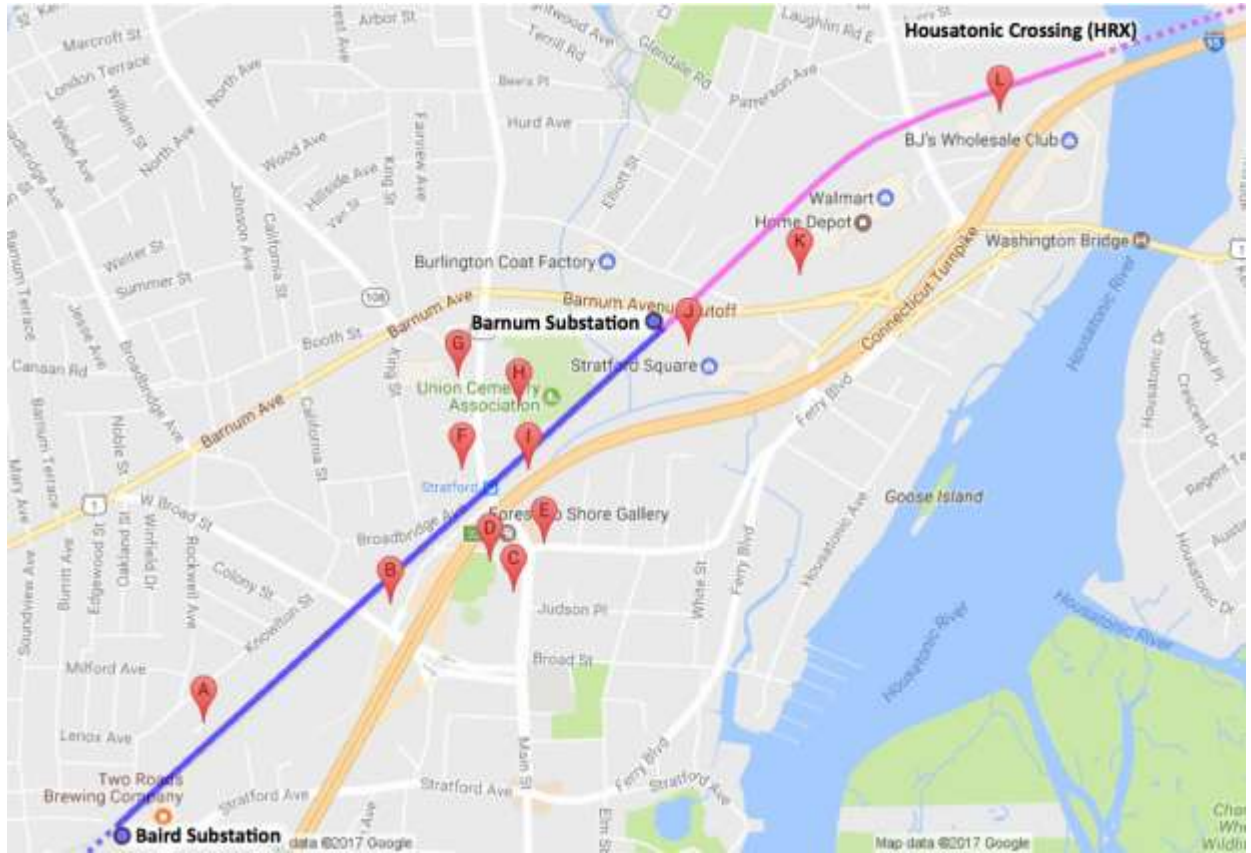


Figure 13. Map of the proposed route between HRX and the Baird Substation, showing measurement locations A-L

Table 6. Measured magnetic fields at measurement locations A-L

Location	Section	Address	Distance from ROW edge (ft)	Measured magnetic field (mG)		
				Min	Mean	Max
A	HRXB-2	Miranda Ln. condominiums	60	0.74	1.10	1.54
B	HRXB-2	Gas Station/Offices 1290 W Broad St	30	1.23	1.52	1.86
C	HRXB-2	Sterling House Comm. Ctr. 2283 Main St	700	0.18	0.44	0.49
D	HRXB-2	1 st Congregational Church 2301 Main St	470	0.11	0.17	0.26
E	HRXB-3	Stratford Board of Ed. 1000 E Broadway	480	0.66	0.75	0.83
F	HRXB-2	Stationhouse Sq. Shops 2505 Main St	120	0.49	0.57	0.72
G	HRXB-3	Stratford High School	920	0.31	0.40	0.43
H	HRXB-4	Union Cemetery	150	0.14	0.33	0.64
I	HRXB-3	Stratford MNR Station	0	2.62	2.84	3.13
J	HRXB-4*	99 Restaurant 411 Barnum Ave. Cutoff	170	0.26	0.51	0.82
K	HRXB-4*	Home Depot 350 Barnum Ave. Cutoff	220	0.11	0.21	0.34
L	HRXB-5	Boardwalk Marina Barnum Ave. Cutoff	120	0.96	1.18	1.42

Figure 14 depicts the measured magnetic field on a span in Section HRXB-2 along the West Broad Street underpass, overlaid on the calculated magnetic-field profile for this section. Figure 15 shows a similar comparison, recorded in the Main Street underpass adjacent to the Stratford MNR Train Station. Figure 17 likewise show an overlay of measured and calculated profiles, with readings recorded along the East Main Street/Route 110 underpass in Section HRXB-5. Along the sidewalks and street passing beneath the Project, the measured magnetic fields are lower than the calculated profile, since the sidewalk and street level is below the Project grade.

Figure 16 depicts the measured magnetic field on a span in Section HRXB-4 along the Longbrook Avenue overpass, overlaid on the calculated magnetic-field profile for this section. Here, the overpass grade is higher than the embed elevation of the existing structures. Since the measurement location is closer to the existing transmission conductors and the conductors of the 12.6-kV MNR catenary system, the measured magnetic field exceeds the calculated profile on the overpass itself. The data show that the un-modeled conductors of the MNR electrical system primarily affect EMF levels beneath the existing structures. For this reason, the modeled EMF profiles provide a conservative bound on project-related changes in EMF beyond the ROW edges, where the elevation is lower.

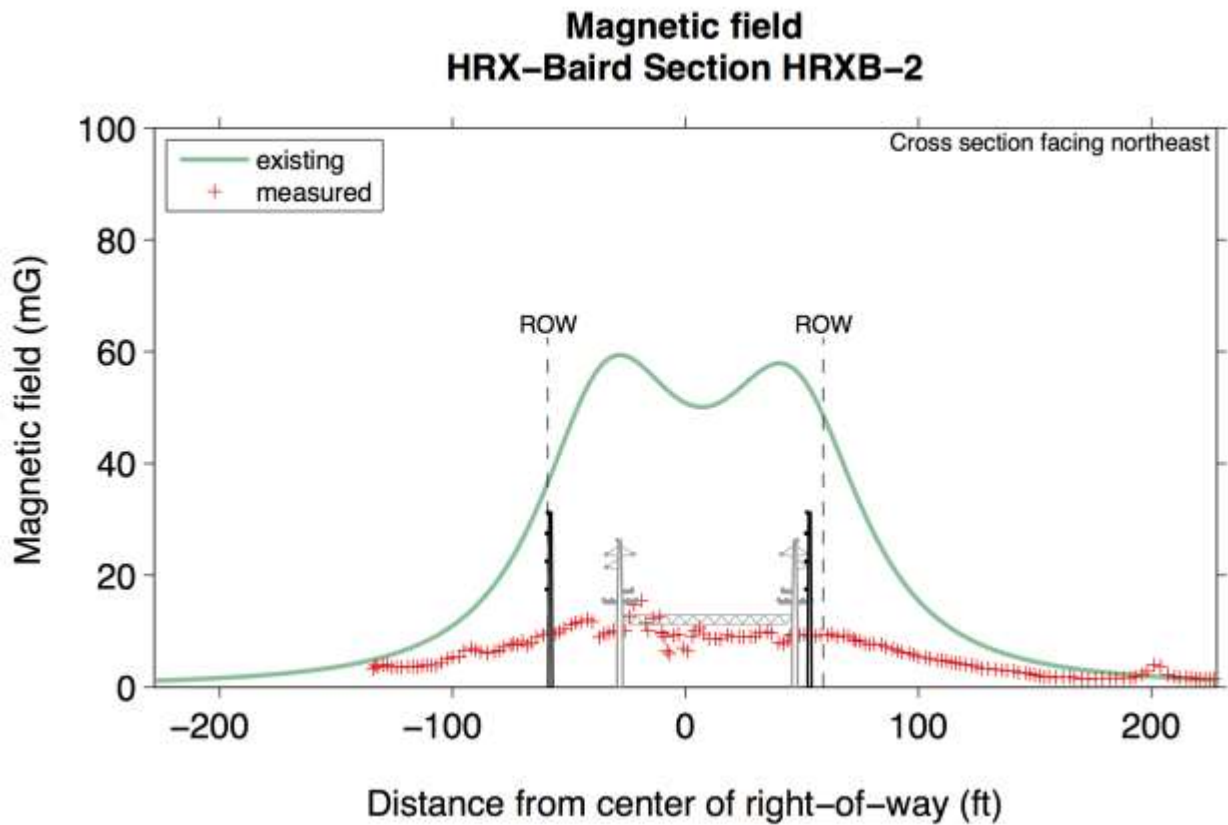


Figure 14. Measured magnetic-field profile of the existing transmission-line configuration between proposed Structures 834 and 835, in section HRXB-2.

The measured profile shows the magnetic field recorded at street level along the West Broad Street underpass.

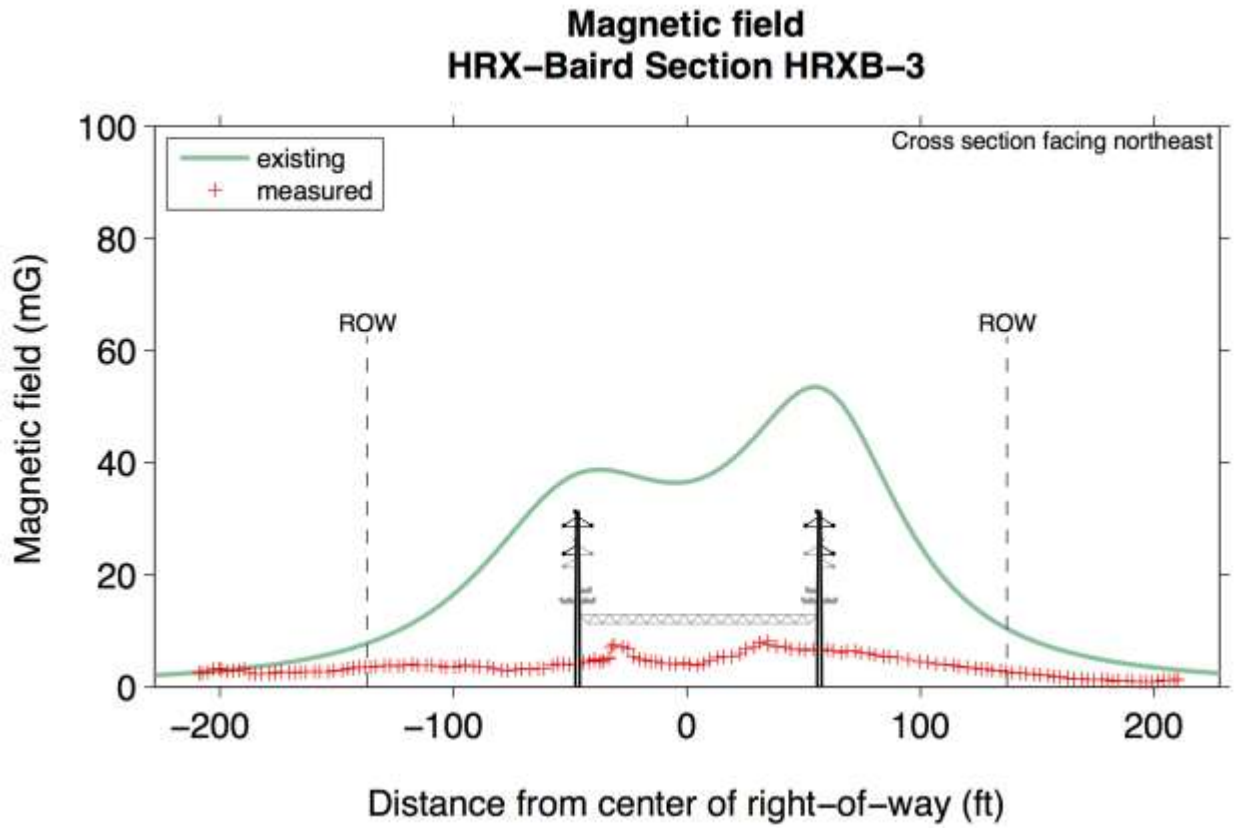


Figure 15. Measured magnetic-field profile of the existing transmission-line configuration in the vicinity of the Stratford MNR Train Station.

The existing profile shows the calculated magnetic field between Structures 840 and 841 in section HRXB-3. The measured magnetic field was recorded at street level along the Main Street underpass between Structures 839 and 840.

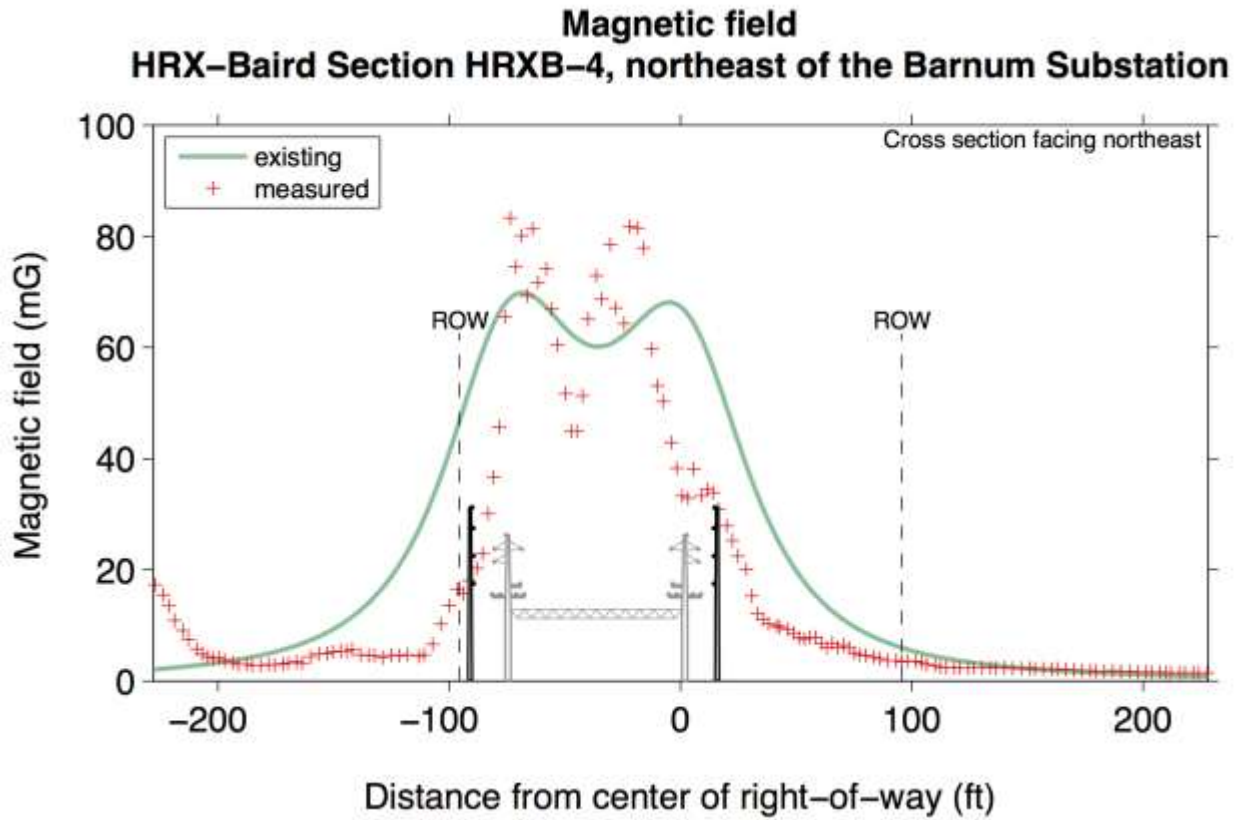


Figure 16. Measured magnetic-field profile of the existing transmission-line configuration between proposed Structures 848 and 849, northeast of the Barnum Substation. The measured profile shows the magnetic field recorded at street level along the Longbrook Avenue overpass.

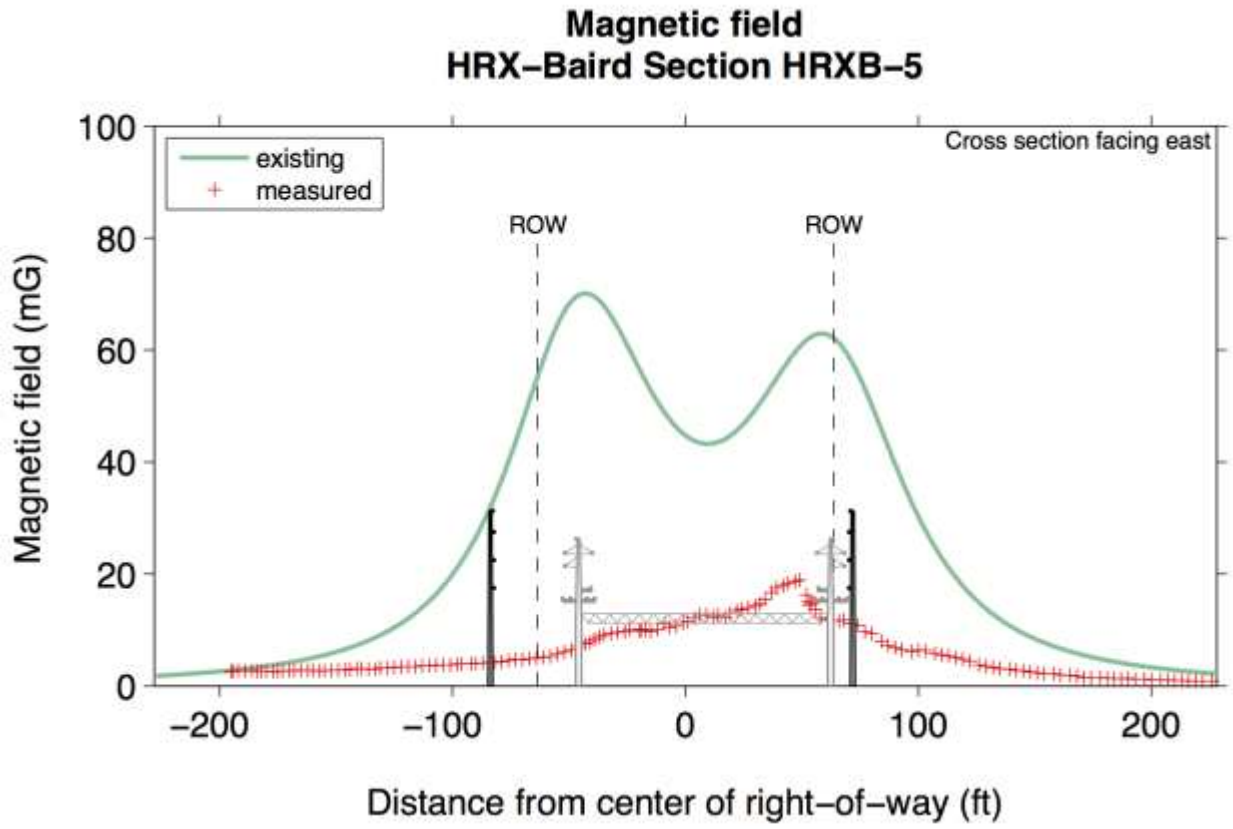


Figure 17. Measured magnetic-field profile of the existing transmission-line configuration between proposed Structures 856 and 857, in section HRXB-5.

The measured profile shows the magnetic field recorded at street level along the East Main Street/Route 110 underpass.

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