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# Electric and Magnetic Field Assessment: The Baird Substation Rebuild Project

# Electric and Magnetic Field Assessment: The Baird Substation Rebuild Project

Prepared for

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# Notice

At the request of The United Illuminating Company (UI), Exponent modeled the electric and magnetic fields associated with the rebuild of the Baird Substation in the Town of Stratford, Connecticut. 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 UI. We cannot verify the correctness of this input data, and rely on the client for the data's accuracy. UI has confirmed to Exponent that the summary of data provided to Exponent contained herein is not subject to Critical Energy Infrastructure Information restrictions. 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.

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 users of this report, and any re-use of this report or its findings, conclusions, or recommendations presented herein other than for permitting of this project 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

The United Illuminating Company (UI) proposes a full rebuild of the Baird Substation (the Project) located at 1770 Stratford Avenue in the Town of Stratford, Connecticut. The proposed site of the new Baird Substation is a 1.5-acre parcel adjacent to 1770 Stratford Avenue, and will include part of the vacant parking lot west of the Two Roads Brewery. Both the existing and proposed sites are south of the existing railroad/transmission line right-of-way (ROW), which includes Metro North Railroad (MNR) tracks and catenary structures of the New Haven Line.

As part of the Project, UI proposes to remove the 115-kV transmission lines on the adjoining ROW, which terminate at the existing Baird Substation and are supported on MNR catenary structures. UI will relocate these circuits to new steel monopole structures on the railroad/transmission line ROW, and interconnect the repositioned circuits to the proposed Baird Substation.

The effect of the Baird Substation rebuild on existing magnetic-field levels was evaluated by modeling magnetic fields for pre- and post-Project conditions. The pre-Project condition includes the 115-kV lines supported on the MNR catenary structures with the existing substation in operation. For pre-Project conditions, equipment loading was calculated for the year 2016, and also for 2023, but without the effect of the proposed substation equipment. Pre-project electric and magnetic fields were also measured around the substation on June 4, 2015.

Modeling of the post-Project conditions assumed line and equipment loadings calculated in the same years as for pre-Project conditions but with (1) the rebuilt substation in operation, (2) the existing Baird Substation de-energized, and (3) the overhead 115-kV lines on the adjacent ROW transferred to new monopole structures. Thus, two load cases were studied, corresponding to 2023 annual average load and 2016 annual peak load for both pre- and post-Project conditions.

Comparing pre- and post-Project conditions, the modeling shows that the calculated magnetic fields are approximately the same *magnitude* but have a different *position*. This similarity arises because the equipment in the new Baird Substation will be similar in topology and dimensions to the equipment in the existing Baird Substation and the loads at the Baird Substation do not change significantly as a result of the rebuild. As a result, calculated magnetic fields are nearly the same before and after operation of the Project, but are shifted eastward with the proposed equipment.

On the western edge of the existing Baird Substation, for instance, the calculated magnetic field is 40 milligauss (mG) at the existing property line under average-load conditions (pre-Project). In the post-Project condition, the calculated magnetic field is approximately 14 mG at this location, since equipment in the rebuilt substation will be relocated approximately 200 feet farther east. On the eastern edge of the Project area, likewise, the calculated magnetic field is 5 mG at the Two Roads Brewery property line under average-load conditions (pre-Project). In the post-Project condition, the calculated magnetic field is approximately 41 mG at this location, again because of the shift in equipment approximately 200 feet to the east. South of the Project area, the differences in the calculated magnetic field pre- and post-Project reflect the new location of underground interconnections to distribution circuits along Stratford Avenue. The distribution loads served in the surrounding community, however, are not anticipated to change as a result of the Baird Substation rebuild.

The modeling shows that at locations near the existing railroad/transmission-line ROW, the calculated magnetic-field levels increase with operation of the Project. This result is due to the repositioning of the overhead 115-kV lines on to new monopole structures, located closer to the edges of the ROW. In the residential area north of the MNR, for instance, the calculated magnetic field is approximately 5 mG at a location 200 feet north of the proposed substation fence under average-load conditions (pre-Project). In the post-Project condition, the calculated magnetic field is approximately 15 mG at this location for the same loading. As noted above, the repositioning of the overhead circuits is a required component of the Project.

Only small electric-field values (below 0.04 kV/m) were measured on properties adjoining the existing Baird Substation. Electric-field levels will not differ appreciably around the proposed Baird Substation since the configuration of equipment and overhead interconnections is similar to pre-Project conditions.

# Introduction

The existing Baird Substation is a 50-year old substation located at 1770 Stratford Avenue in the Town of Stratford, Connecticut. Based on a comprehensive Condition and Needs Assessment, the United Illuminating Company (UI) has determined that the existing equipment at the Baird Substation needs to be replaced. UI prepared a Solution Study that compared an In-Kind Replacement and a Full Rebuild. The Full Rebuild option was determined to be the more reliable and lower-cost alternative due to the risk and complexity of working in and around an energized substation.

UI examined 12 potential sites for the new Baird Substation, and selected the property adjacent to 1770 Stratford Avenue as the preferred location based on reliability, cost, and long-term expansion of the electric grid. In addition, the Baird substation was originally proposed to be situated approximately 110 feet further to the east. This would have positioned the substation fence next to the property line and Two Roads Brewery. However, after discussions with the town of Stratford and the Two Roads Brewery, UI made the decision to shift the substation to the west by 110 feet. The resulting buffer area between the substation fence and the Two Roads Brewery will result in reduced EMF levels at the brewery compared to the original proposed location.

The proposed site of the new Baird Substation is a 1.5-acre parcel adjacent to 1770 Stratford Avenue, south of the existing railroad/transmission line right-of-way (ROW), which includes Metro North Railroad (MNR) tracks and catenary structures of the New Haven Line (Figure 1). As shown in the single-line diagram in Figure 2, four 115-kV circuits terminate at the Baird Substation:

- Two overhead 115-kV circuits, which cross the railroad tracks from the north, designated Line “A” east and Line “A” west; and
- Two overhead 115-kV circuits on the south side of the railroad tracks, designated Line “B” east and Line “B” west.

The topology of the existing Baird Substation and proposed Baird Substation is the same, as depicted in Figure 2. A tie breaker is connected between the terminal buses of Line "A" east and Line "A" west, and transformer "A" is connected to the terminal bus of Line "A" east. Likewise, a tie breaker is connected between the terminal buses of Line "B" east and Line "B" west, with a transformer designated "B" connected to the terminal bus of Line "B" east. Other new equipment to be installed within the proposed substation perimeter includes disconnect switches, surge arrestors, potential transformers, current transformers, and station service transformers. Low-voltage distribution feeders terminate in the switchgear enclosure, and exit the proposed substation underground to the south.

The site is surrounded by commercial areas, with a residential neighborhood located on the north side of the MNR corridor. The nearest proposed equipment is approximately 220 feet from the closest single-family dwelling to the north, approximately 170 feet from the northern substation fence line.

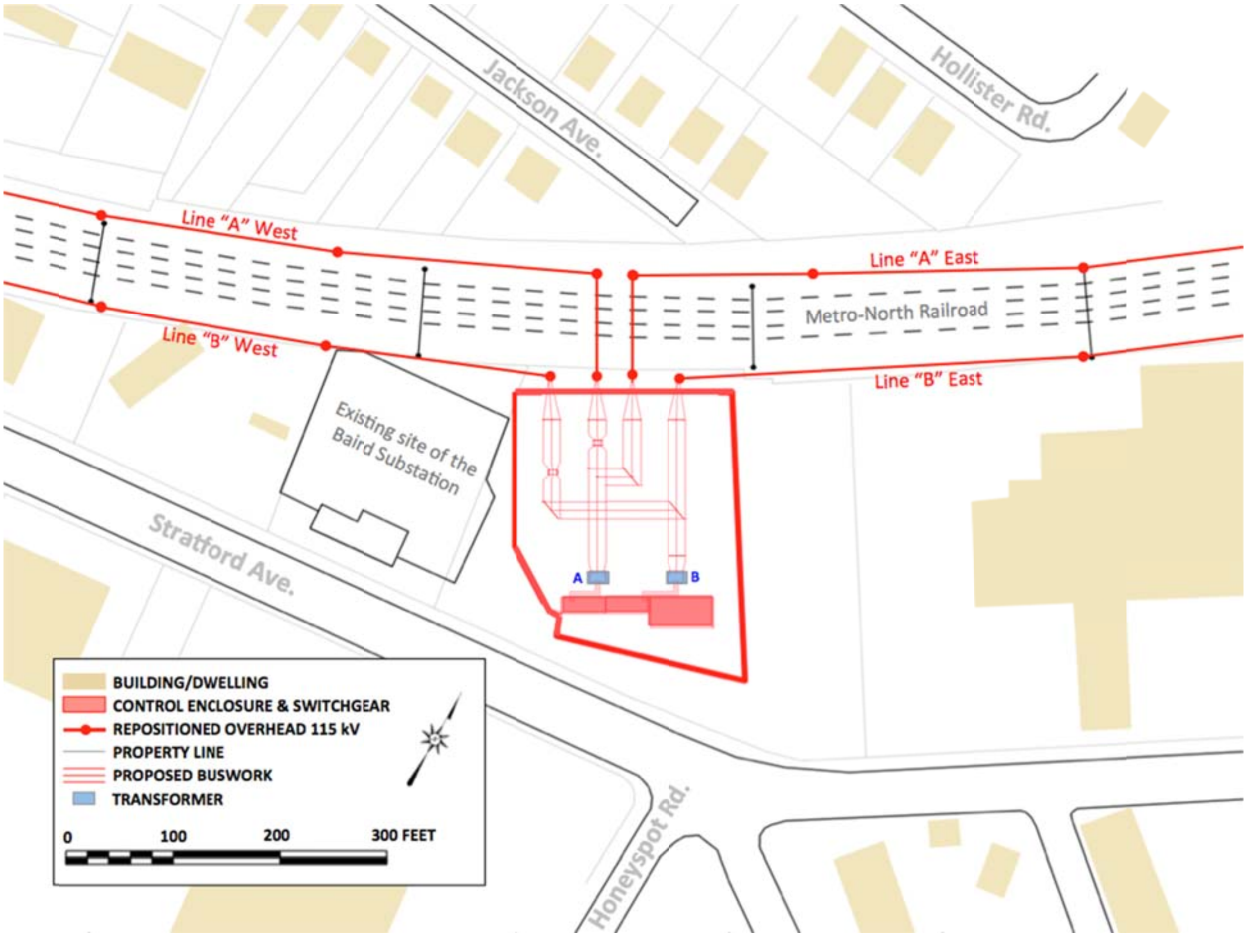


Figure 1. Plan view of the proposed expansion of the Baird Substation. The proposed location of overhead 115-kV circuits on the adjacent ROW is depicted.

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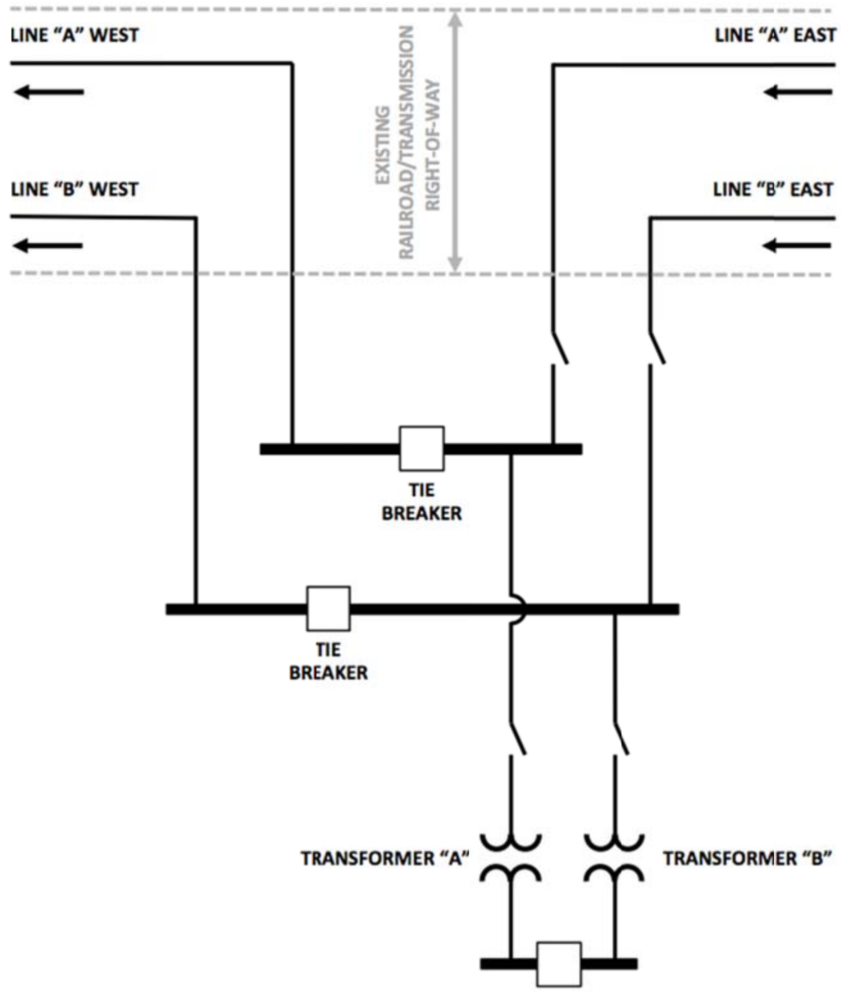


Figure 2. Diagram of the 115-kV transmission system showing overhead lines terminating at the Baird Substation.

The reference direction of current flow on the overhead transmission lines is depicted. Transformer "A" is connected to the terminal bus of Line "A" east, and Transformer "B" is connected to the terminal bus of Line "B" east.

# Technical Background

***Magnetic Fields.*** The current flowing in the conductors of a substation bus-line or an overhead transmission line generates a magnetic field near the conductor. The strength of project-related magnetic fields in this report are expressed as magnetic flux density in units of milligauss (mG), where 1 Gauss (G) = 1,000 mG. In the case of alternating current (AC) transmission lines, these currents (and thus magnetic fields) vary in direction and magnitude with a 60-Hertz (Hz) cycle. Since load currents—expressed in units of amperes (A)—generate magnetic fields around the conductors, measurements or calculations of the magnetic field present a snapshot for the load conditions at only one moment in time. On a given day, throughout a week, or over the course of months and years, the magnetic-field level can change depending upon the patterns of power demand on the bulk transmission system.

***Electric Fields.*** The voltage on the conductors of transmission lines generates an electric field in the space between the conductors and the ground. Many objects are conductive—including fences, shrubbery, and buildings—and thus shield electric fields. Electric fields within the Baird Substation therefore are not calculated since they are likely to be blocked by the substation fence. In addition, the buried distribution lines will not be a source of 60-Hz electric fields above ground, since electric fields are confined by the cables' conductive sheath and armor, as well as blocked by the surrounding soil and duct bank. In this report, electric-field levels are calculated for the transmission lines and are expressed in units of kilovolts per meter (kV/m)—1 kV/m is equal to 1,000 volts per meter (V/m).

Electricity is an integral part of our infrastructure (e.g., transportation systems) and our homes and businesses, and people living in modern communities are therefore surrounded by sources of EMF. Figure 3 depicts typical magnetic-field levels measured in residential and occupational environments, compared to levels measured on or at the edge of transmission line ROWs.

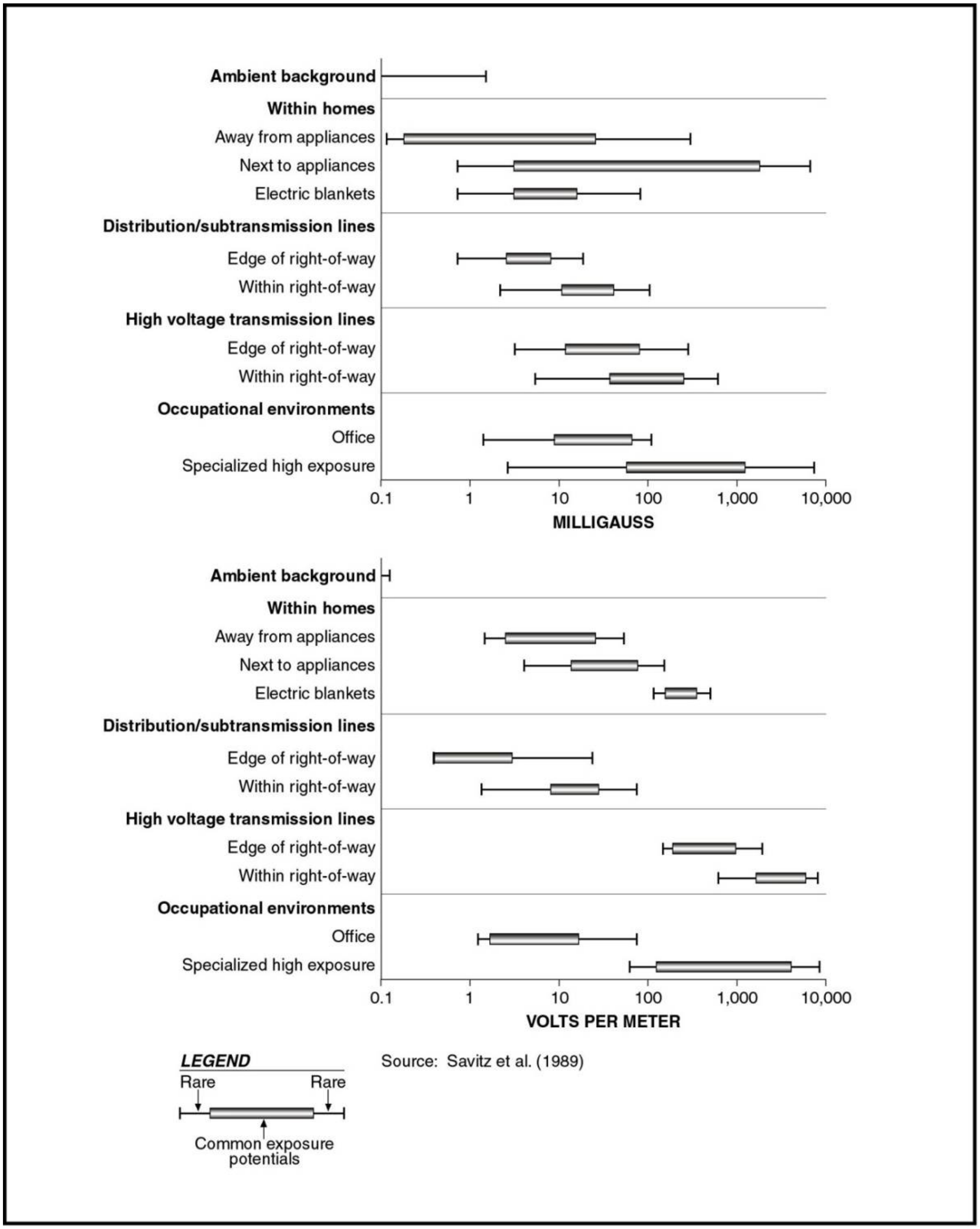


Figure 3. Electric- and magnetic-field levels in the environment.

# Configurations and Layout of Measurement and Modeling Profiles

Measurements of electric- and magnetic-field (EMF) levels from existing sources at the proposed boundaries of the new Baird Substation were taken on June 4, 2015, to assess pre-Project conditions. The results of these measurements are summarized in the following sections. In addition, to compare the pre-Project and post-Project magnetic-field levels, Exponent created a detailed model of both the existing substation and the proposed substation and used the two models to examine magnetic-field levels in the surrounding area.

In addition to calculations of magnetic fields around the property line and fence of the Project, Exponent calculated the magnetic field along eight profiles perpendicular to the existing substation fence (Profiles 1 – 8), directed outward onto adjoining property, and one electric-field profile (Profile 7E) traversing the railroad/transmission line ROW north of the Baird Substation (see Figure 4).

**Profile 1** starts at the existing substation fence on the west side, and proceeds west onto adjoining property.

**Profile 2** runs south from a point 15 feet east of the southwest corner of the existing substation yard.

**Profile 3** runs south from a point 15 feet west of the southeast corner of the existing substation yard.

**Profile 4** begins near the proposed control enclosure and proceeds across Stratford Avenue and obliquely along Honeyspot Road.

**Profile 5** starts at the proposed substation fence near the proposed control enclosure and proceeds east/northeast towards the Two Roads Brewery.

**Profile 6** starts at the proposed substation fence near the proposed terminal structure of Line “B” east, and proceeds east/northeast.

**Profile 7** starts at the proposed substation fence near the proposed terminal structure of Line “B” east, and proceeds in a perpendicular transect across the existing railroad/transmission-line ROW.

**Profile 7E** is the same as Profile 7 for the magnetic field; the electric field of the railroad/transmission line ROW post-Project includes the spans west of Baird Substation.

**Profile 8** begins at the existing substation fence near the proposed terminal structure of Line “B” west, and proceeds in a perpendicular transect across the existing railroad/transmission-line ROW.

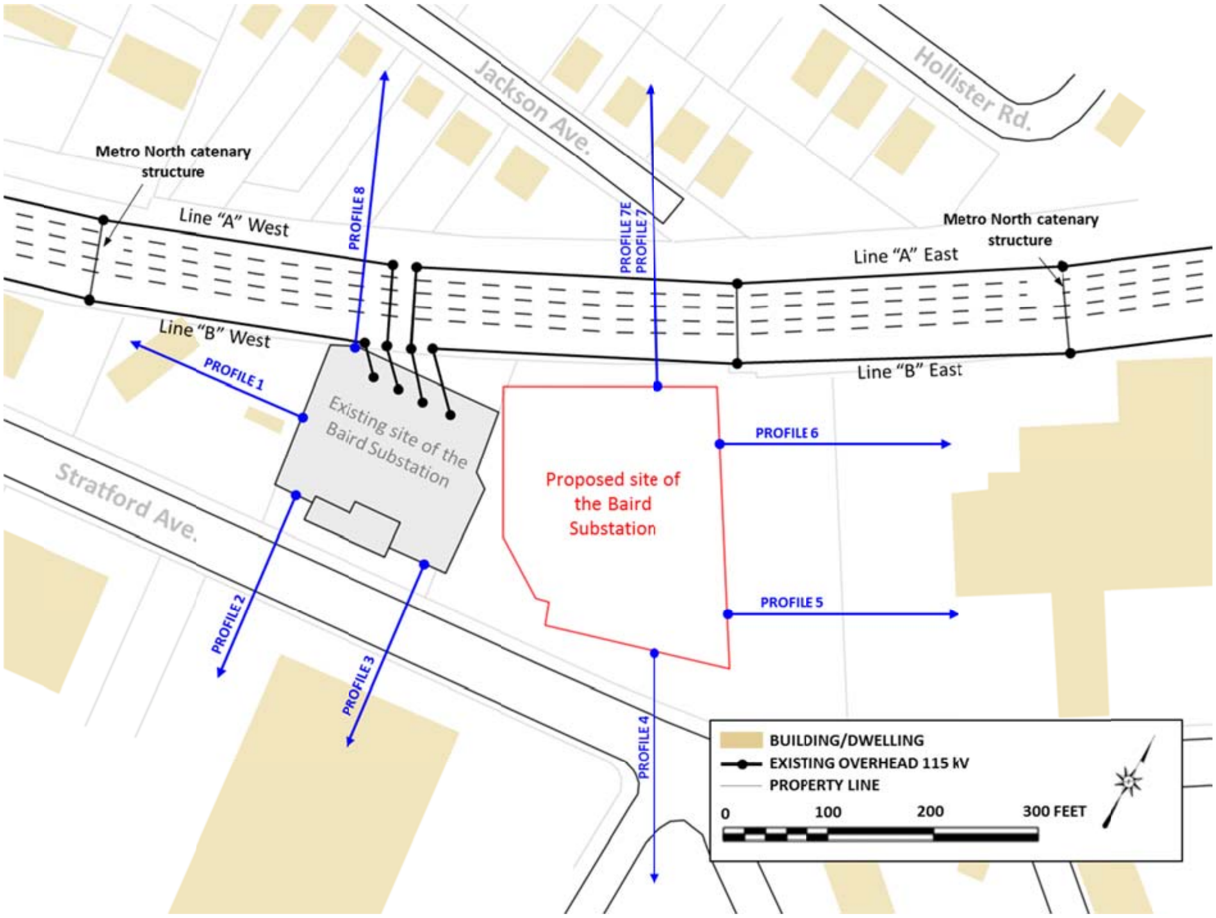


Figure 4. Plan view of the proposed Baird Substation, showing existing and proposed substation yards and the location of calculated profiles.

The existing location of overhead 115-kV circuits on the adjacent ROW also is depicted.

On the ROW adjoining the existing Baird Substation, the overhead 115-kV circuits are mounted on metal support "bonnets" (Figure 5) that are attached to MNR catenary structures. The structures also support the distribution conductors and catenaries of the New Haven Line. In the post-Project condition, Line "A" west and Line "A" east are relocated to new steel monopole structures 5 to 20 feet north of the existing structures. Line "B" west and Line "B" east are repositioned to new steel monopole structures approximately 5 feet to the south of the existing structures. In the rebuilt configuration, both circuits have 12-foot vertical spacing between phase conductors. The red dots in Figure 1 depict the locations of the new monopoles.

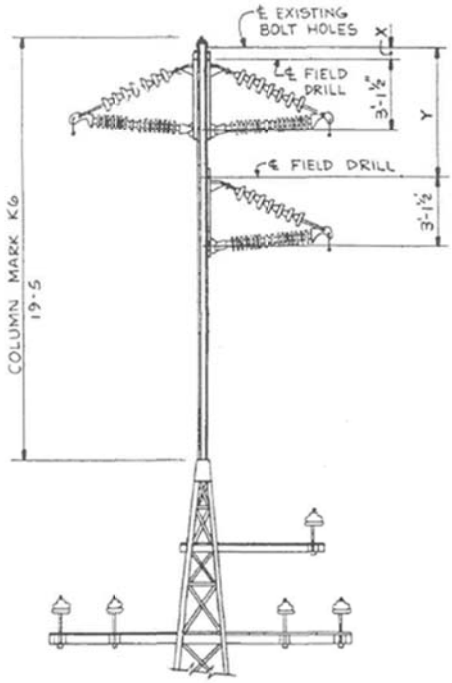


Figure 5. Existing “bonnet” supports for the existing 115-kV circuits interconnecting to the Baird Substation.

# Assessment Criteria

Neither the federal government nor the State of Connecticut has enacted standards for magnetic fields or electric fields from power lines or other sources at power frequencies although the Connecticut Siting Council has developed guidelines for siting new transmission lines as discussed in a subsequent section of this report. Several other states have statutes or guidelines that apply to fields produced by new transmission lines, but these guidelines are not health based. For example, New York and Florida have limits on EMF that were designed to limit fields from new transmission lines to levels characteristic of the fields from existing transmission lines.

More relevant EMF assessment criteria include the exposure limits recommended by scientific organizations. These exposure limits are included in guidelines developed to protect health and safety and are based upon 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.[1]

In a June 2007 Factsheet, the World Health Organization included recommendations that policy makers should adopt international exposure limit guidelines, such as those from ICNIRP or ICES (Table 1), for occupational and public exposure to EMF.[2]

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1 International Committee on Electromagnetic Safety (ICES). IEEE Standard for Safety Levels with Respect to Human Exposure to Electromagnetic Fields 0 to 3 kHz. Piscataway, NJ: IEEE, 2002; International Commission on Non-ionizing Radiation Protection (ICNIRP). Guidelines for limiting exposure to time-varying electric and magnetic fields (1 Hz to 100 kHz). Health Phys 99: 818-836, 2010.

2 World Health Organization (WHO). Fact Sheet No. 322: Electromagnetic Fields and Public Health – Exposure to Extremely Low Frequency Fields. Geneva, Switzerland: World Health Organization, 2007.

**Table 1. ICNIRP and ICES guidelines for EMF exposure at 60-Hz**

| | Exposure (60 Hz) | |
|---|---|---|
| | Electric Field | Magnetic Field |
| **ICNIRP** | | |
| Occupational | 8.3 kV/m | 10 G (10,000 mG) |
| General Public | 4.2 kV/m | 2 G (2,000 mG) |
| **ICES** | | |
| Occupational | 20 kV/m | 27.1 G (27,100 mG) |
| General Public | 5 kV/m* | 9.040 G (9,040 mG) |

*Within power line ROWs, the guideline is 10 kV/m under normal load conditions.

# Methods

## Measurements

In order to characterize EMF levels for the existing configuration of the Baird Substation, fields were measured outside the existing substation fence on June 4, 2015. 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.[3] Both electric fields and magnetic fields were expressed as the total field computed as the resultant of field vectors measured along vertical, transverse, and longitudinal axes.[4] 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.[5] The meters were calibrated by the manufacturer by methods like those described in IEEE Std. 644-2008, "*IEEE Standard Procedures for Measurement of Power Frequency Electric and Magnetic Fields from AC Power Lines*."

Magnetic fields from underground sources were measured along Stratford Avenue and on the southern perimeter of the existing substation near the switchgear and control enclosure, as described in the Results section below.

Electric fields from the substation were not modeled for the proposed configuration because the metallic fence enclosing the substation will effectively block the electric field associated with

[3] Institute of Electrical and Electronics Engineers (IEEE). IEEE Standard Procedures for Measurement of Power Frequency Electric and Magnetic Fields from AC Power Lines (ANSI/IEEE Std. 644-2008). New York: IEEE, 2008.

[4] 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.

[5] Institute of Electrical and Electronics Engineers (IEEE). IEEE Recommended Practice for Instrumentation: Specifications for Magnetic Flux Density and Electric Field Strength Meters – 10 Hz to 3 kHz (IEEE Std. 1308-1994). New York: IEEE, 1994.

the operation of equipment within (as was confirmed by measurements of the existing substation).

## Magnetic-Field Modeling

Exponent modeled magnetic-field levels associated with the existing and proposed configurations of the Baird Substation and the existing 115-kV transmission lines using SUBCALC. SUBCALC, part of the Enertech EMF Workbench Suite, models magnetic fields in and around substation equipment, and accounts for the three-dimensional arrangement of breakers, transformers, reactors, capacitors, buswork, and transmission lines.

Two SUBCALC models were constructed using the substation plan and profile data, and accounting for the elevated grade of the MNR corridor. The inputs to the program include data regarding voltage, current flow, circuit phasing, and conductor configurations, which were provided by UI.

The first SUBCALC model calculated magnetic fields for the existing configuration of the Baird Substation including the breakers, buswork, and transmission-line interconnections (Figure 6). The second SUBCALC model included the proposed breakers, buswork, and transmission-line interconnections of the rebuilt substation in the calculation of magnetic fields (Figure 7). The average-load conditions in 2023 and peak-load conditions in 2016 were used to calculate magnetic fields for both models, as discussed further below. Based on these two models, changes in the calculated magnetic fields associated with the operation of the Project are provided in the Results section.

Along each profile and perimeter, magnetic-field levels were calculated at 1 meter (3.28 feet) above ground as the root-mean-square value of the field in accordance with IEEE Std. C95.3.1-2010 and IEEE Std. 644-2008.[6] Calculated magnetic-field levels are reported as resultant quantities in units of mG.[7]

## Electric-Field Modeling

As described above, electric fields from the substation were not modeled for the proposed configuration because the metallic fence that encloses the substation will effectively block the electric field associated with the operation of equipment within. The same is not true, however, for the transmission lines in the railroad/transmission line ROW, and so electric fields from these lines were modeled using computer algorithms developed by the Bonneville Power Administration, an agency of the U.S. Department of Energy.[8]

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 electric fields associated with the transmission lines were calculated along a profile 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 all transmission-line circuits in calculating electric fields from the transmission lines. These modeling assumptions are made to ensure that the calculated values represent the maximum expected electric-field values for the cases analyzed. Electric-fields were calculated at a height of 1 meter (3.28 feet) above ground and reported as the root-mean-square value of the field in accordance with IEEE Std. C95.3.1-2010 and IEEE Std. 644-2008.

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[6] 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 (IEEE Std. C95.3.1-2010). New York: IEEE, 2010; Institute of Electrical and Electronics Engineers (IEEE). IEEE Standard Procedures for Measurement of Power Frequency Electric and Magnetic Fields from AC Power Lines (ANSI/IEEE Std. 644-2008). New York: IEEE, 2008.

[7] 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.

[8] Bonneville Power Administration (BPA). Corona and Field Effects Computer Program. Portland, OR: Bonneville Power Administration, 1991.

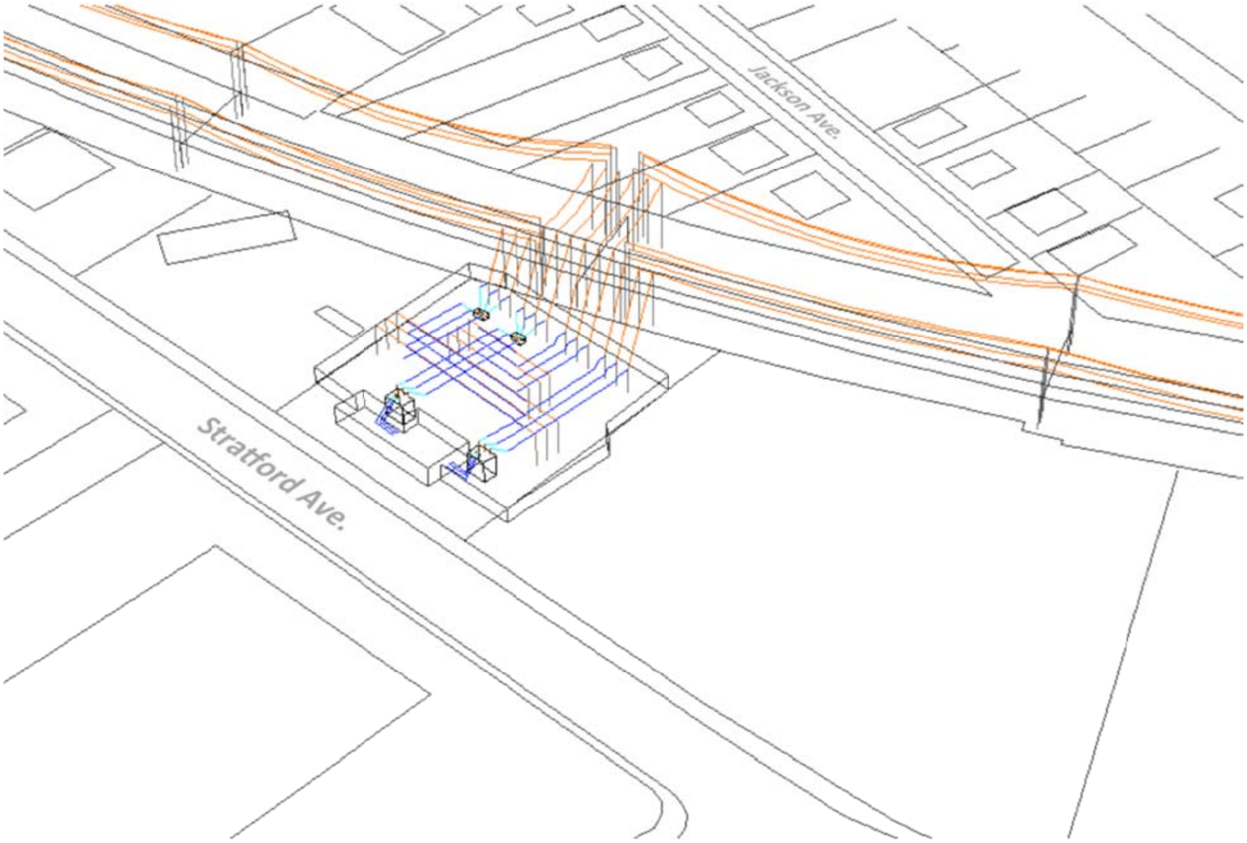


Figure 6. Overview of the three-dimensional SUBCALC model used to calculate magnetic fields for the existing Baird Substation.

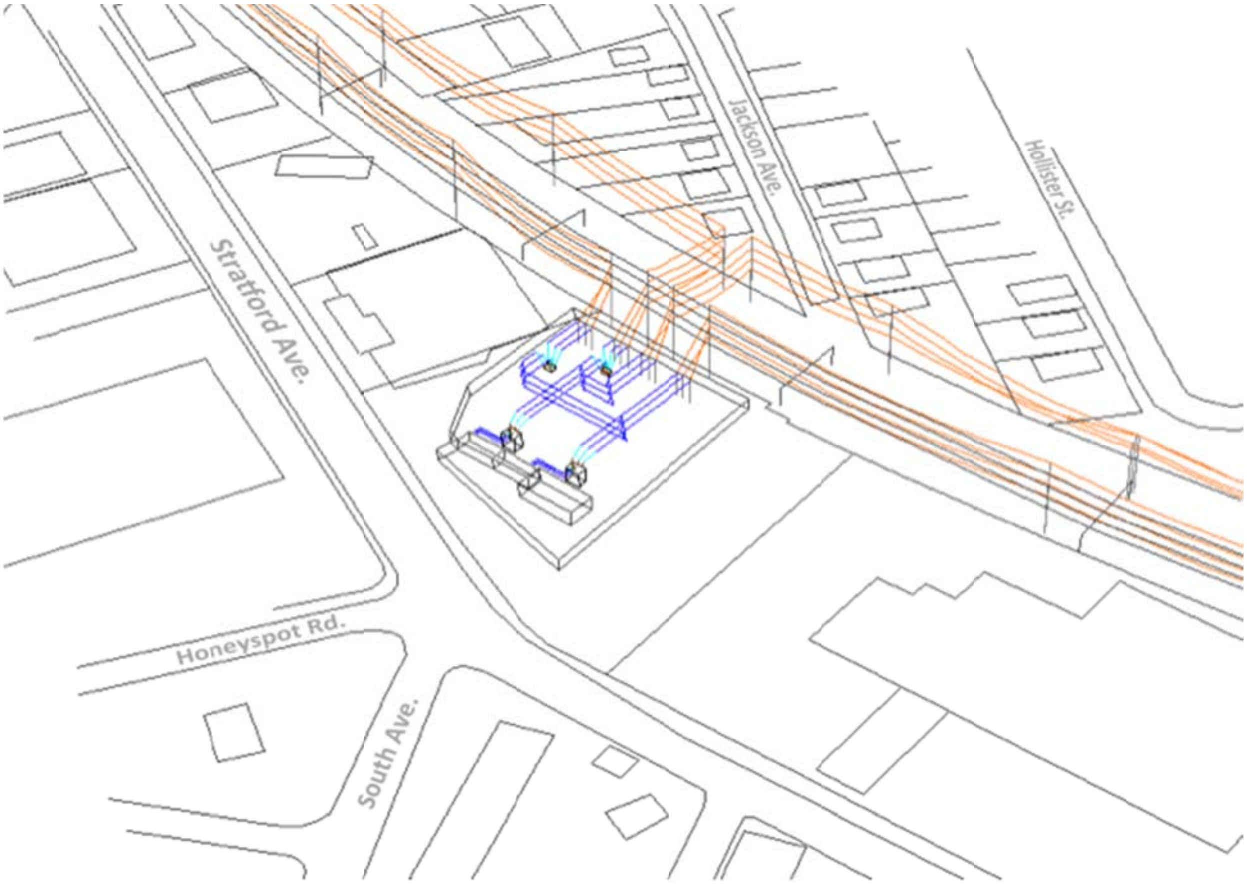


Figure 7. Overview of the three-dimensional SUBCALC model used to calculate magnetic fields for the proposed Baird Substation, including new interconnected 115-kV transmission lines on the adjoining ROW.

## Loading

UI Transmission Planning provided the pre- and post-Project loadings for the 115-kV transmission lines and transformers involved in the Project. UI selected dispatches in such a way to stress the transmission corridor around the project area to cause the maximum current flows on the four transmission lines interconnecting to the Baird Substation. The current flows used for modeling are summarized in a table available from Exponent upon request, consistent with Critical Energy Infrastructure Information restrictions.

UI is required by the Connecticut Siting Council's (CSC) Electric and Magnetic Fields Best Management Practices (BMP) for the Construction of Electric Transmission Lines in Connecticut to provide line loadings for "pre and post project conditions, under: 1) peak load conditions at the time of application filing, and 2) projected seasonal maximum 24-hour average current load on the line anticipated within five years" of operational in service date.[9] As provided by UI Transmission Planning, the term "seasonal maximum 24-hour average load level" was replaced by the term "average daily peak." In this report, "average load" refers to this case.

The project filing date, subsequent peak-load year, planned in-service date, and projected average daily peak-load year are as follows:

- CSC Filing: 3rd quarter of 2015
- Subsequent Peak-Load Year: 2016
- Baird Substation Rebuild In-Service Date: March 2018
- Average Daily Peak-Load Year: 2023

For peak-load analysis, UI modeled the system to reflect the topology of New England's transmission system in the year 2016. In addition, the 2023 study year was modeled to satisfy the CSC requirement for obtaining EMF data for an average-load level within a five-year horizon of the in-service date. In order to determine the scenario with the highest line loadings, generation dispatches were chosen that caused the highest projected flows. The same dispatch was selected for both the average-load and the peak-load cases.

Comparing the average- and peak-load cases in the modeled dispatch, the loading on the overhead 115-kV interconnections into the Baird Substation remain nearly unchanged. In the modeled peak-load case, for instance, load at the Baird Substation increases by approximately 50%. The loading on Line "A" east, however, is less than 3% higher in the peak-load case compared to the average-load case. Likewise, the load on Line "A" west decreases by a small amount (less than 2%) in the modeled peak-load case, compared to the average-load case.

The 115-kV circuit loading is unchanged between pre-Project and post-Project conditions, both for the average-load case and the peak-load case. This result could be reasonably anticipated, since the new Baird Substation is at nearly the same location, has similar equipment, and serves the same load as the existing Baird Substation.

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9 Connecticut Siting Council (CSC). Electric and Magnetic Fields Best Management Practices for the Construction of Transmission Lines in Connecticut (Revised February 20, 2014). New Britain, CT: Connecticut Siting Council, 2014, p. 6.

# Results and Discussion

Calculated magnetic fields for pre-Project and post-Project conditions are depicted in Figure 8 through Figure 18. Summary tables of magnetic-field levels calculated at various distances from the substation fence are provided in Table 2 for the average-load case and in Table 4 for the peak-load case.

## Perimeter Profiles

Figure 8 depicts the calculated magnetic-field level around the perimeter of UI property for average-load conditions in 2023. Both the existing and proposed Baird Substation sites are enclosed in the perimeter path of Figure 8 in order to compare pre-Project and post-Project magnetic fields on adjoining property. The perimeter path begins at the southwest corner of 1770 Stratford Avenue, and proceeds clockwise around UI property back to the starting location. The highest magnetic-field levels for both pre-Project and post-Project profiles are encountered beneath overhead transmission lines and above underground distribution lines. On the north side of the existing Baird Substation, for instance, the highest calculated magnetic field is 130 mG beneath the conductors of Line “A” east. This observation is consistent with IEEE Standard 1127 which notes:

> In 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.[10]

Away from the transmission or distribution lines, especially on the east and south sides of the property, the calculated magnetic-field levels fall below 5 mG. Magnetic-field levels measured on June 4, 2015, are also depicted in Figure 8, and follow the same general trend as the

[10] IEEE Guide for the Design, Construction, and Operation of Electric Power Substations for Community Acceptance and Environmental Compatibility (IEEE Std 1127-2013). New York: IEEE, p. 26.

calculations. Measured magnetic-field levels, which are only shown in Figure 8 at accessible locations, are generally less than calculated values for the pre-Project condition. This relationship shows that the actual loading of the overhead transmission circuits on June 4, 2015, was less than 25% of the loading included in the pre-Project SUBCALC model.

Comparing the pre-Project and post-Project profiles in Figure 8, calculated magnetic-field levels further to the east are higher in the post-Project configuration than in the pre-Project configuration. This result can be reasonably anticipated since the proposed Baird Substation is rebuilt approximately 200 feet to the east of the existing Baird Substation. Likewise, the post-Project magnetic-field levels on the west side of the property-line perimeter are lower than in the pre-Project condition due to the repositioning of equipment. It is also noteworthy that beneath the conductors of the interconnecting transmission lines, the highest magnetic-field level in the post-Project condition is approximately 40% lower than the pre-Project condition for the same loading. This decrease occurs because of the greater conductor heights and mutual cancellation of magnetic fields from the overhead circuits in the post-Project condition.

Figure 9 depicts the calculated magnetic-field level along the same path as Figure 8 for the peak-load case in the year 2016. Comparing the average- and peak-load cases in the modeled dispatch, the loading on the overhead 115-kV interconnections into the Baird Substation remains nearly unchanged, whereas the load served by the Baird Substation increases by approximately 50% in the peak-load case. As a result, Figure 9 shows higher calculated magnetic fields above underground distribution sources along Stratford Avenue compared to Figure 8. Elsewhere along the property line, the calculated magnetic fields in Figure 9 are nearly the same as for the average-load case.

Figure 10 depicts the calculated magnetic-field level around the fence line of the proposed Baird Substation. At the majority of locations, the pre-Project magnetic-field levels are lower than post-Project levels.[11] Figure 10 also shows that, consistent with expectations, the highest post-Project magnetic-field levels are beneath the overhead interconnecting transmission lines. In

[11] This is an expected result since the strength of magnetic fields decrease with distance from sources, and most locations on fence line of the proposed substation (see Figure 7) are closer to equipment and conductors in proposed Baird Substation, and further from sources in the existing Baird Substation (Figure 6).

this case, the highest calculated magnetic-field level is 107 mG beneath the conductors of Line "A" east, where they pass above the fence of the proposed Baird Substation.

## Perpendicular Profiles

Calculated and measured magnetic-field levels along Profiles 1 – 8 are shown in Figure 11 through Figure 18 (*See* Figure 4 for the location of Profiles 1 – 8). Each figure shows pre-Project (noted as existing) and post-Project (noted as proposed) magnetic-field levels calculated for the average-load case. Table 2 summarizes the calculated magnetic-field values in Figure 11 through Figure 18 at various distances from the substation fence. Since the proposed Baird Substation is rebuilt further to the east, calculated magnetic-field levels are generally lower for post-Project conditions than for pre-Project conditions in profiles lying to the west (Profiles 1 – 3 and Profile 8). Conversely, in profiles farther east and nearer to the proposed substation (Profiles 4 – 7), calculated magnetic-field levels are generally higher for post-Project conditions than for pre-Project conditions.

**Profile 1 –** On the western edge of the existing Baird Substation, the calculated magnetic field is 40 mG at the existing property line under average-load conditions (Figure 11). In the post-Project condition, the calculated magnetic field is approximately 14 mG at this location, since equipment in the rebuilt substation is approximately 200 feet farther east. For both pre-Project and post-Project conditions, the calculated magnetic-field levels increase with distance from the existing substation fence because the path of Profile 1 approaches the railroad/transmission-line ROW. At 300 feet from the existing substation fence, for instance, the magnetic-field level is calculated to be approximately 34 mG and 35 mG, respectively, for pre-Project and post-Project conditions.

**Profile 2** – At the southern edge of the existing substation, pre-Project magnetic-field levels (Figure 12) are somewhat higher than post-Project levels. The highest magnetic-field levels for pre-Project and post-Project conditions (at the substation fence) are approximately 18 mG and 5.8 mG, respectively. Within approximately 25 feet of the existing substation fence line, however, both pre-Project and post-Project magnetic-field levels are similar.

**Profile 3** – The pre-Project magnetic-field levels along Profile 3 are significantly higher than post-Project magnetic-field levels within approximately 100 feet of the substation fence (Figure 13). This is due to underground distribution lines, which will be moved as a result of the Project. The highest magnetic-field level for pre-Project and post-Project conditions (at the substation fence) is approximately 36 mG and 5.6 mG, respectively. Additional un-modeled distribution sources, including sources in the control enclosure of the existing Baird Substation, are discernible in the measured magnetic fields along Profile 3.

**Profile 4** – As shown in Figure 14, both pre-Project and post-Project magnetic-field levels along Profile 4 are similar. The slight increase at a distance of approximately 90 feet from the proposed substation fence is due to distribution sources beneath Stratford Avenue. This distribution line is expected to produce similar magnetic-field levels due to the relatively unchanged loading between pre-Project and post-Project conditions. The highest magnetic-field level is less than 6 mG for both pre-Project and post-Project conditions.

**Profile 5** – Magnetic-field levels along Profile 5 are very low (<4 mG) in both pre-Project and post-Project conditions, due to its distance from substation equipment and underground feeders (Figure 15).

**Profile 6** – As shown in Figure 16, post-Project magnetic-field levels along Profile 6 are calculated to increase compared to pre-Project levels due to the shift of the substation eastward. Post-Project magnetic-field levels are highest at the substation fence (approximately 41 mG, compared to approximately 5 mG for pre-Project conditions) and decrease rapidly with distance from the substation. At 185 feet to the east of the fence of the proposed Baird Substation (the minimum distance to the brewery), the calculated magnetic field is 5.5 mG (pre-Project) versus 12.2 mG (post-Project). This increase reflects the calculated magnetic fields associated with the repositioning of Line "B" east, which runs parallel to Profile 6, to new monopole structures on the existing ROW.

**Profile 7** – The path of Profile 7 transects the railroad/transmission line ROW, so calculated magnetic-field levels along this profile generally increase with distance from the substation fence out to a distance of approximately 100 feet (Figure 17). Despite the similar loading level of Line “A” west for pre-Project and post-Project conditions, the calculated magnetic-field level north of the MNR increases due to the repositioning of the overhead circuit. At 170 feet north of the proposed substation fence (the distance to the closest dwelling), the calculated magnetic-field levels are approximately 10.7 mG and 18 mG for pre-Project and post-Project conditions, respectively.

**Profile 7E –** The path is the same as Profile 7 for the magnetic field, but describes the calculated electric field, as noted below.

**Profile 8** – The shift of the substation farther east is calculated to significantly reduce magnetic-field levels within approximately 100 feet of the existing substation fence line (Figure 18). The modeling shows that at locations north of the existing railroad/transmission-line ROW, the calculated magnetic-field levels increase with the operation of the Project. This result is due to the repositioning of the overhead 115-kV lines on to new monopole structures, located closer to the edges of the ROW. In the residential area north of the MNR, for instance, the calculated magnetic field is approximately 5 mG at a location 200 feet north of the proposed substation fence under average-load conditions (pre-Project). In the post-Project condition, the calculated magnetic field is approximately 15 mG at this location for the same loading. Likewise, the calculated magnetic field is approximately 10 mG at the nearest residence on Jackson Avenue under average-load conditions (pre-Project). In the post-Project condition, the calculated magnetic field is approximately 26 mG at this location for the same loading.

As noted above in the discussion of the property line profile (Figure 8 and Figure 9), the loading on the overhead 115-kV interconnections into the Baird Substation remains nearly unchanged between the average-load and peak-load cases. This similarity is also reflected in Table 4, which summarizes the calculated magnetic-field values for the peak-load case in Profiles 1 – 8. Comparing the entries in Table 2 and Table 4, the calculated magnetic-field levels differ by 2 – 3%, reflecting the small changes in loading in Line “A” and Line “B” in the peak-load case.

# Electric Fields

## Modeled Electric Fields

The rebuild of the transmission line interconnection shifts the electric-field peak location slightly farther north and south from existing locations and also increases the peak level somewhat. A graphic profile of the existing and proposed transmission line interconnection along Profile 7E is shown in Figure 19, and values of the electric-field levels at the ROW edge, and 100 feet beyond the ROW edge, are summarized in Table 5. As shown in this table, electric-field levels at the northern ROW edge are calculated to increase to approximately 0.79 kV/m after construction, but at 100 feet beyond the ROW edge, electric-field levels are near background levels and are relatively unchanged from existing conditions (0.03 kV/m).

## Measured Electric Fields

Figure 20 depicts the location of electric-field measurements recorded on June 4, 2015. Measured electric-field values in three orthogonal axes are summarized in Table 5, along with calculated resultant quantities. The highest measured electric field (0.04 kV/m) was recorded beneath the conductors of the existing overhead lines along the northern edge of the substation property. Along the western property edge, the field was measured to be 0.027 kV/m, and along the eastern and southern facing fences, the electric field was below 0.014 kV/m. The results show that even beneath 115-kV transmission lines, the substation fence and nearby vegetation decreased the value of the measured electric field.

# Consistency with Connecticut Siting Council Best Management Practices

Exponent has provided information that fulfills the requests made of Applicants to include information relating to EMF in an Application for a Certificate of Environmental Compatibility and Public Need for an electric substation facility.

The discussion below focusses on the CSC's EMF BMP (CSC, 2014) that pertains to the calculation of magnetic fields. Note, however, that the BMP explicitly applies to transmission lines, not substations. Despite this, Exponent has endeavored to address the spirit of the BMP for transmission lines as interpreted for a substation. The Project does involve relocation of existing transmission line interconnection, but otherwise the EMF from these lines post-Project will be similar to pre-Project conditions.

The models developed for the existing and proposed Baird Substation configurations provided calculations of the magnetic fields at the Baird Substation and from the interconnecting transmission lines based on recommendations in the BMP:

- Peak load conditions at the time of the application filing in 2016 and projected "average daily peak" in 2023;
- Consideration of any already approved changes to the electrical system; and,
- Calculations at a height of 1 meter (3.28 feet) above ground level.

Although no new transmission lines are part of the Project, calculations of EMF from existing lines and the relocated lines were provided because they are an existing adjacent background source of EMF. Despite the differences between the guidance applicable to substations and transmission lines, the principal aspects of this project that are consistent with the BMP applied to transmission lines include:

- There are no adjacent statutory facilities where children might congregate around the Baird Substation; and

- UI selected the location for the relocated Baird Substation no closer to nearby residents so it is consistent with “no-cost/low-cost designs that do not compromise system reliability or worker safety, or environmental and aesthetic project goals.”[12]

[12] Connecticut Siting Council (CSC). Electric and Magnetic Fields Best Management Practices for the Construction of Transmission Lines in Connecticut (Revised February 20, 2014). New Britain, CT: Connecticut Siting Council, 2014, p. 6.

# Conclusions

As shown in the modeling results, the proposed Project will not significantly change magnetic-field levels surrounding the substation. Calculated pre-Project and post-Project magnetic fields are of approximately the same *magnitude* but have a different *location* due to the similar equipment and topography in the existing and proposed Baird Substations as well as the similar loading of the station under pre- and post-Project conditions. As a result, the calculated magnetic fields are nearly the same before and after operation of the Project, but are shifted eastward with the proposed equipment.

As mentioned above, electricity is an integral part of our infrastructure (e.g., transportation systems), as well as our homes and businesses, and people living in modern communities are therefore surrounded by sources of EMF, as noted in Figure 3, which depicts typical magnetic-field levels measured in residential and occupational environments, compared to levels measured on or at the edge of transmission-line ROWs.

While magnetic-field levels decrease with distance from the source, any home, school, or office tends to have a background magnetic-field level as a result of the combined effect of numerous EMF sources. In general, the background magnetic-field level as estimated from the average of measurements throughout a house away from appliances is typically less than 4 mG, while levels can be hundreds of mG in close proximity to appliances. Comparing Figure 3 to the results discussed above, the calculated magnetic-field levels in the vicinity of both the pre-Project and post-Project configurations of the Baird Substation are comparable in magnitude to the magnetic-field levels encountered in the vicinity of typical distribution lines and in homes and workplaces.

Away from where transmission or distribution lines enter or exit the Baird Substation, the calculated magnetic-field levels are approximately 50 mG or less at the property line for both pre-Project and post-Project configurations. In addition, only small electric-field values (below 0.04 kV/m) were measured on properties adjoining the existing Baird Substation. Electric-field levels will not differ appreciably around the proposed Baird Substation, since the configuration of equipment and overhead interconnections is similar to pre-Project conditions. Along the railroad/transmission line ROW, the electric-field level will increase locally around the rebuilt transmission line interconnection, but levels are less than 1 kV/m in all locations and decrease to near pre-Project levels within approximately 100 feet of the ROW edge

Both calculated magnetic-field levels and measured electric-field levels around the perimeter of the Baird Substation are a small fraction of those recommended for the general public by international health-based standards (ICES and ICNIRP) and are comparable to fields that may be found in homes near major appliances.

The EMF assessment was performed in concordance with the CSC's BMP for transmission lines and the Project is consistent with "no-cost/low-cost designs that do not compromise system reliability or worker safety, or environmental and aesthetic project goals" as called for in the BMP.

**Table 2. Summary of calculated magnetic fields (mG) for Profiles 1 – 8 for average load conditions in 2023**

| Profile | Heading | Modeling condition | Distance from proposed substation perimeter (ft) | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | 0 | 100 | 150 | 170 | 200 | 300 |
| 1 | west | Pre-Project | 39.7 | 10.5 | 14.4 | 16.2 | 19.1 | 33.6 |
| | | Post-Project | 14.3 | 21.9 | 25.4 | 26.1 | 26.2 | 35.1 |
| 2 | south | Pre-Project | 17.7 | 2.3 | 1.4 | 1.2 | 0.9 | 0.4 |
| | | Post-Project | 5.8 | 2.6 | 1.8 | 1.6 | 1.4 | 0.8 |
| 3 | south | Pre-Project | 36.1 | 4.8 | 2.3 | 1.8 | 1.3 | 0.5 |
| | | Post-Project | 5.6 | 2.4 | 1.6 | 1.4 | 1.2 | 0.7 |
| 4 | south | Pre-Project | 1.2 | 4.0 | 0.2 | 0.2 | 0.2 | 0.1 |
| | | Post-Project | 5.5 | 3.2 | 0.9 | 0.8 | 0.6 | 0.3 |
| 5 | east | Pre-Project | 1.4 | 1.2 | 1.2 | 1.2 | 1.1 | 1.1 |
| | | Post-Project | 3.8 | 2.6 | 2.6 | 2.6 | 2.6 | 2.7 |
| 6 | east | Pre-Project | 5.0 | 5.4 | 5.5 | 5.5 | 5.4 | 5.0 |
| | | Post-Project | 40.8 | 14.0 | 12.7 | 12.4 | 11.9 | 10.7 |
| 7 | north | Pre-Project | 29.3 | 60.3 | 18.4 | 10.7 | 5.5 | 1.3 |
| | | Post-Project | †64.0 | †90.9 | 31.7 | 18.0 | 9.4 | 2.5 |
| 8 | north | Pre-Project | †137.2 | †30.8 | 12.4 | 8.3 | 4.6 | 1.1 |
| | | Post-Project | 47.8 | 38.0 | 37.0 | 25.9 | 15.2 | 4.2 |

† This location is near 115-kV transmission-line interconnections on the adjoining ROW.

**Table 3. Calculated electric-field for Profile 7E**

| Profile | 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 |
|---|---|---|---|---|---|---|
| 7E | Existing | 0.02 | 0.39 | 0.57 | 0.49 | 0.02 |
| | Proposed | 0.03 | 0.79 | 0.79 | 0.67 | 0.03 |

**Table 4. Summary of calculated magnetic fields (mG) for Profiles 1 – 8 for peak load conditions in 2016**

| Profile | Heading | Modeling condition | Distance from proposed substation perimeter (ft) | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | 0 | 100 | 150 | 170 | 200 | 300 |
| 1 | west | Pre-Project | 40.5 | 10.5 | 14.3 | 16.0 | 18.8 | 33.1 |
| | | Post-Project | 14.1 | 21.7 | 25.1 | 25.7 | 25.9 | 34.6 |
| 2 | south | Pre-Project | 29.5 | 2.2 | 1.4 | 1.1 | 0.9 | 0.4 |
| | | Post-Project | 5.7 | 2.5 | 1.8 | 1.6 | 1.3 | 0.8 |
| 3 | south | Pre-Project | 57.5 | 4.7 | 2.3 | 1.8 | 1.3 | 0.5 |
| | | Post-Project | 5.6 | 2.3 | 1.6 | 1.4 | 1.1 | 0.7 |
| 4 | south | Pre-Project | 1.2 | 6.2 | 0.3 | 0.2 | 0.2 | 0.1 |
| | | Post-Project | 5.2 | 5.2 | 1.0 | 0.8 | 0.6 | 0.3 |
| 5 | east | Pre-Project | 1.4 | 1.2 | 1.2 | 1.2 | 1.2 | 1.1 |
| | | Post-Project | 4.0 | 2.5 | 2.6 | 2.6 | 2.7 | 2.7 |
| 6 | east | Pre-Project | 5.0 | 5.5 | 5.6 | 5.6 | 5.5 | 5.1 |
| | | Post-Project | 41.6 | 14.3 | 13.0 | 12.7 | 12.2 | 10.9 |
| 7 | north | Pre-Project | 30.0 | 61.8 | 18.8 | 10.9 | 5.6 | 1.4 |
| | | Post-Project | †65.0 | †92.9 | 32.5 | 18.4 | 9.5 | 2.5 |
| 8 | north | Pre-Project | †137.0 | †31.1 | 12.6 | 8.4 | 4.7 | 1.1 |
| | | Post-Project | 47.3 | 37.5 | 36.6 | 25.6 | 15.0 | 4.1 |

† This location is near 115-kV transmission-line interconnections on the adjoining ROW.

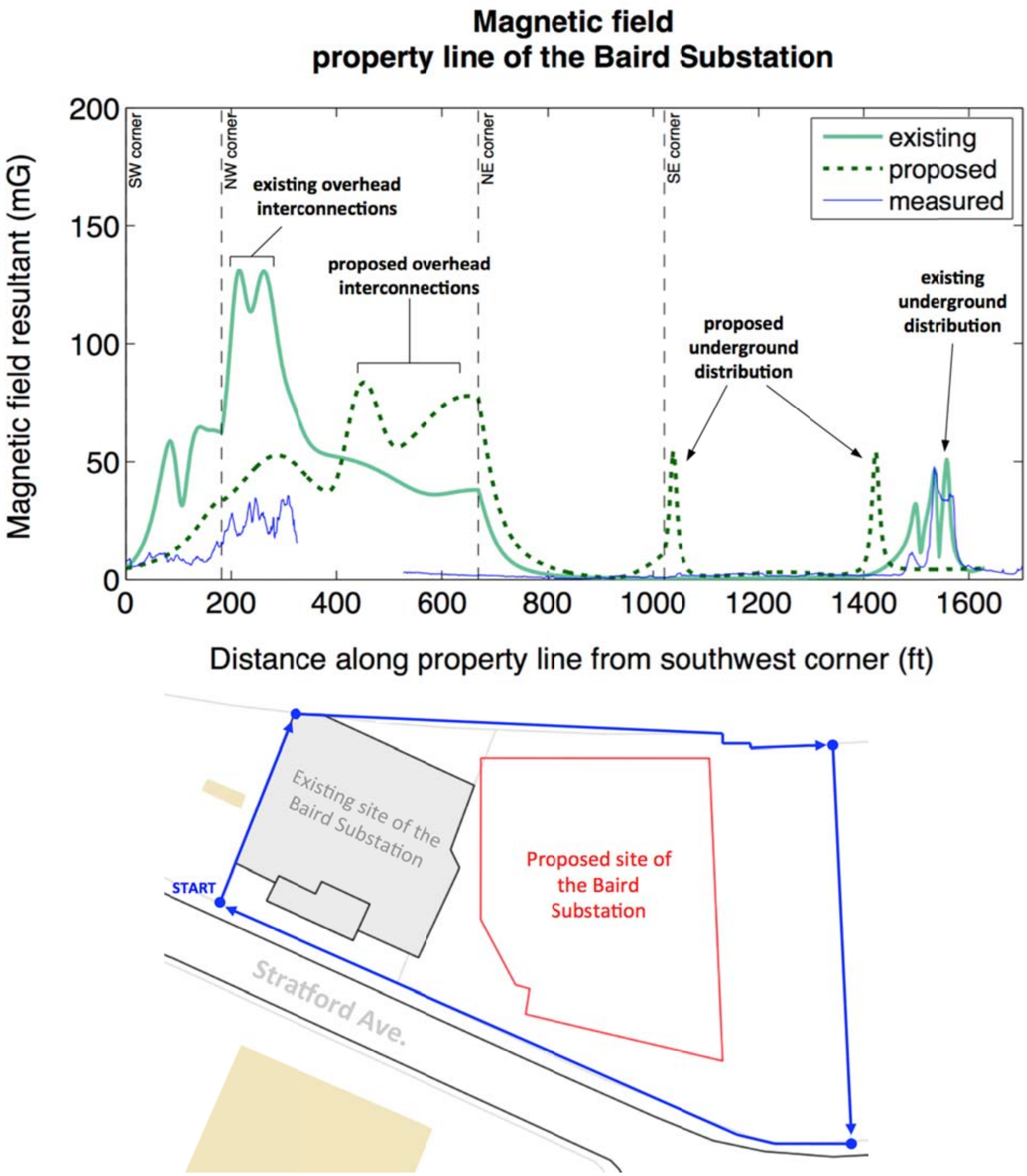


Figure 8. Measured and calculated magnetic-field profiles around the property line enclosing the combined pre-Project and post-Project Baird Substation sites for average-load conditions in the year 2023.

The profile begins at the southwest corner of the substation, and proceeds clockwise along the west, north, east, and south sides of the yard.

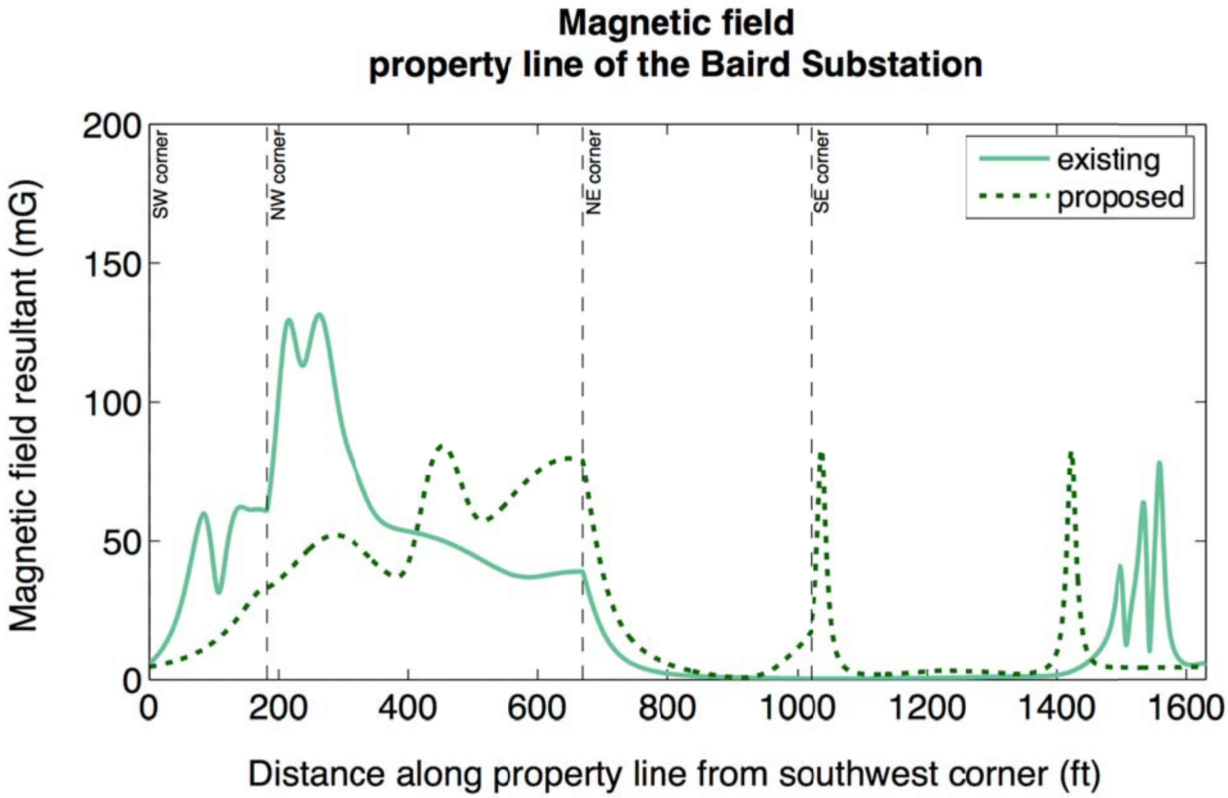


Figure 9. Calculated magnetic-field profiles around the property line enclosing the combined existing and proposed Baird Substation sites for peak-load conditions in the year 2016.

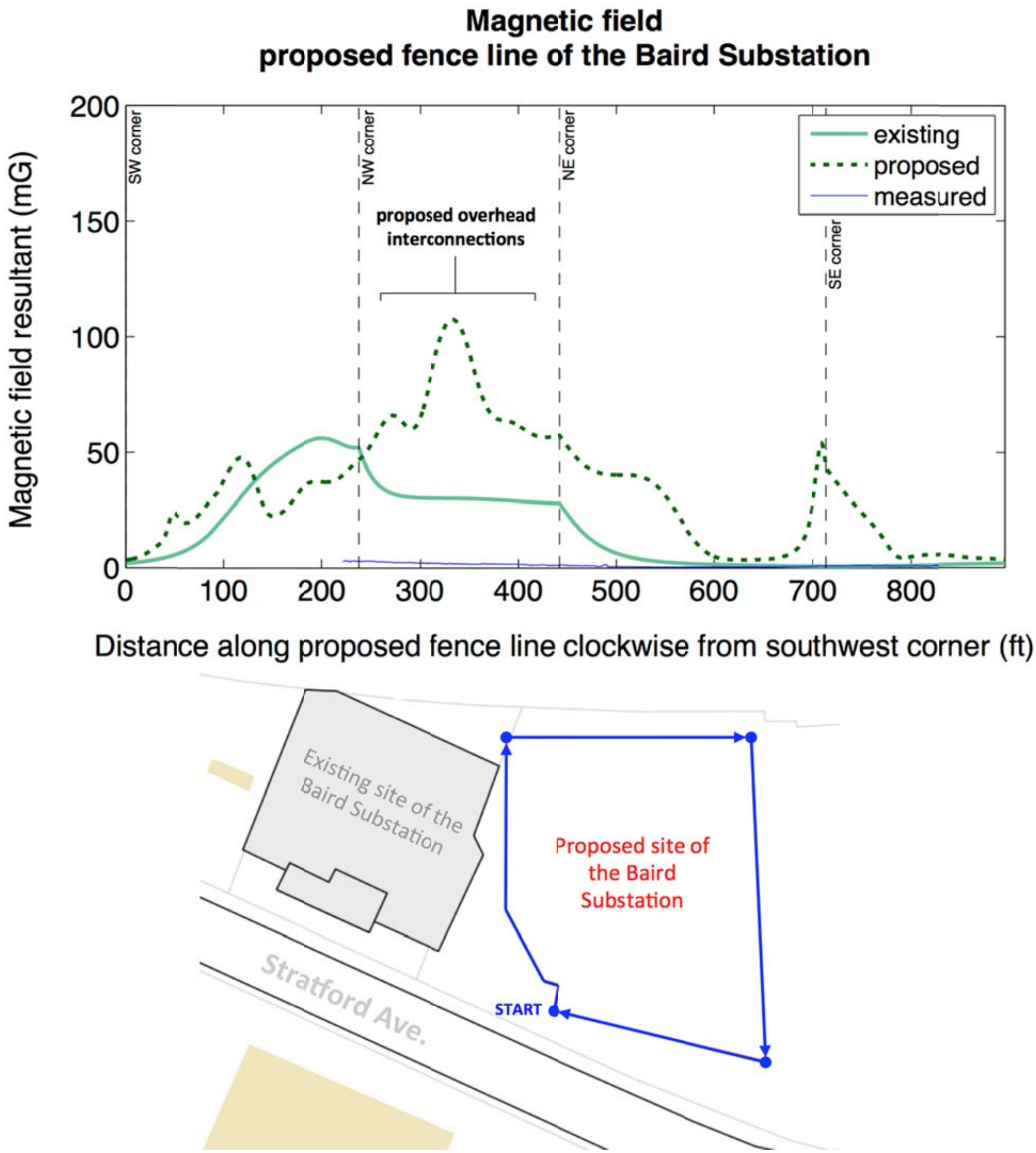


Figure 10. Calculated magnetic-field profiles around proposed fence line of the Baird Substation for average-load conditions in the year 2023.

The profile begins at the southwest corner of the substation, and proceeds clockwise along the fence line. The highest calculated magnetic fields are beneath the conductors of the overhead circuits where they pass above the proposed perimeter of the substation.

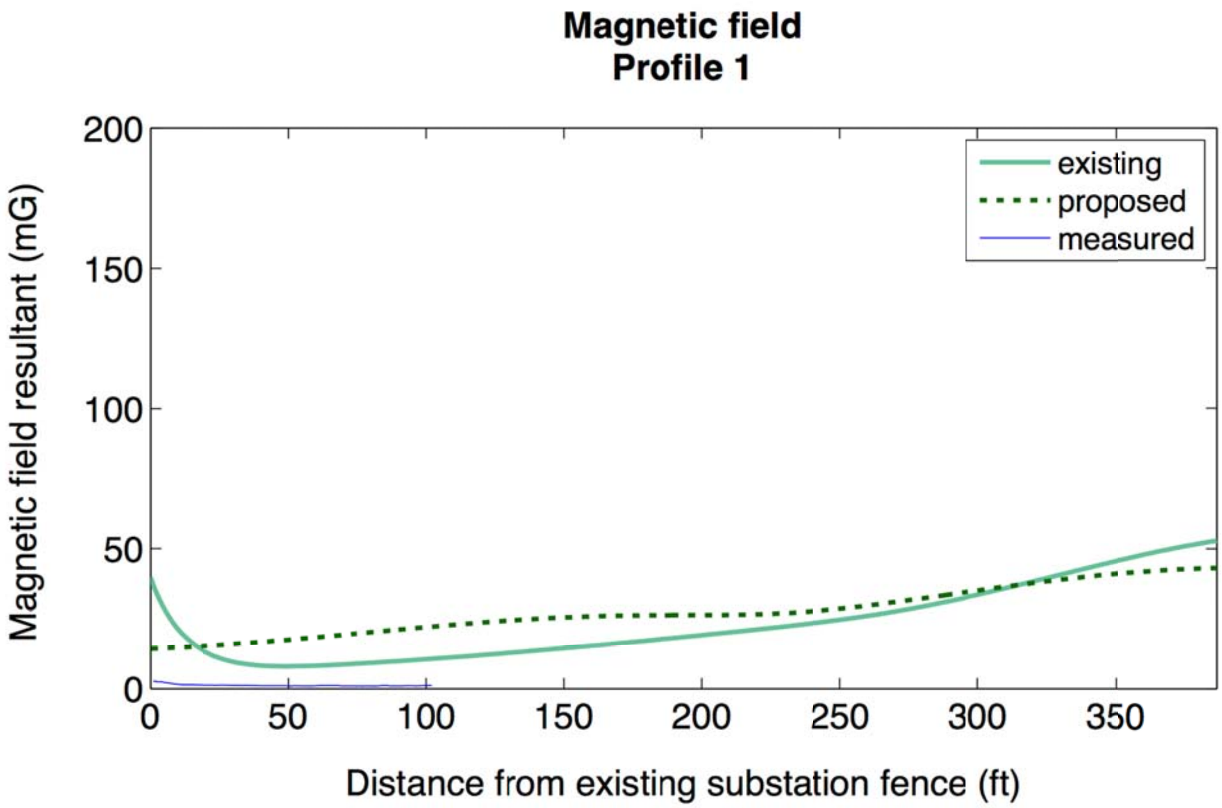


Figure 11. Calculated and measured magnetic-field levels along Profile 1.

The calculated magnetic-field levels are for existing and proposed configurations of the Baird Substation under average-load conditions in 2023. Measured magnetic fields reflect existing substation and loading on June 30, 2015.

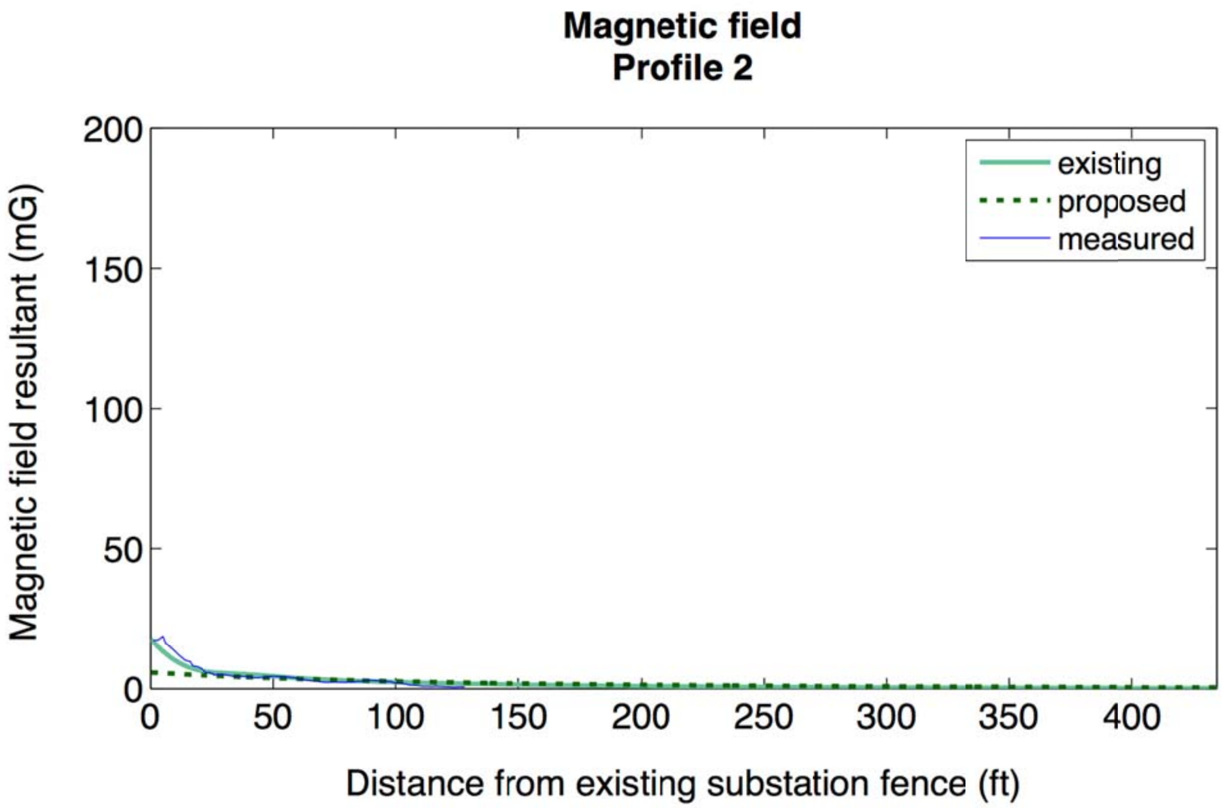


Figure 12. Calculated and measured magnetic-field levels along Profile 2.

The calculated magnetic-field levels are for existing and proposed configurations of the Baird Substation under average-load conditions in 2023. Measured magnetic fields reflect existing substation and loading on June 30, 2015.

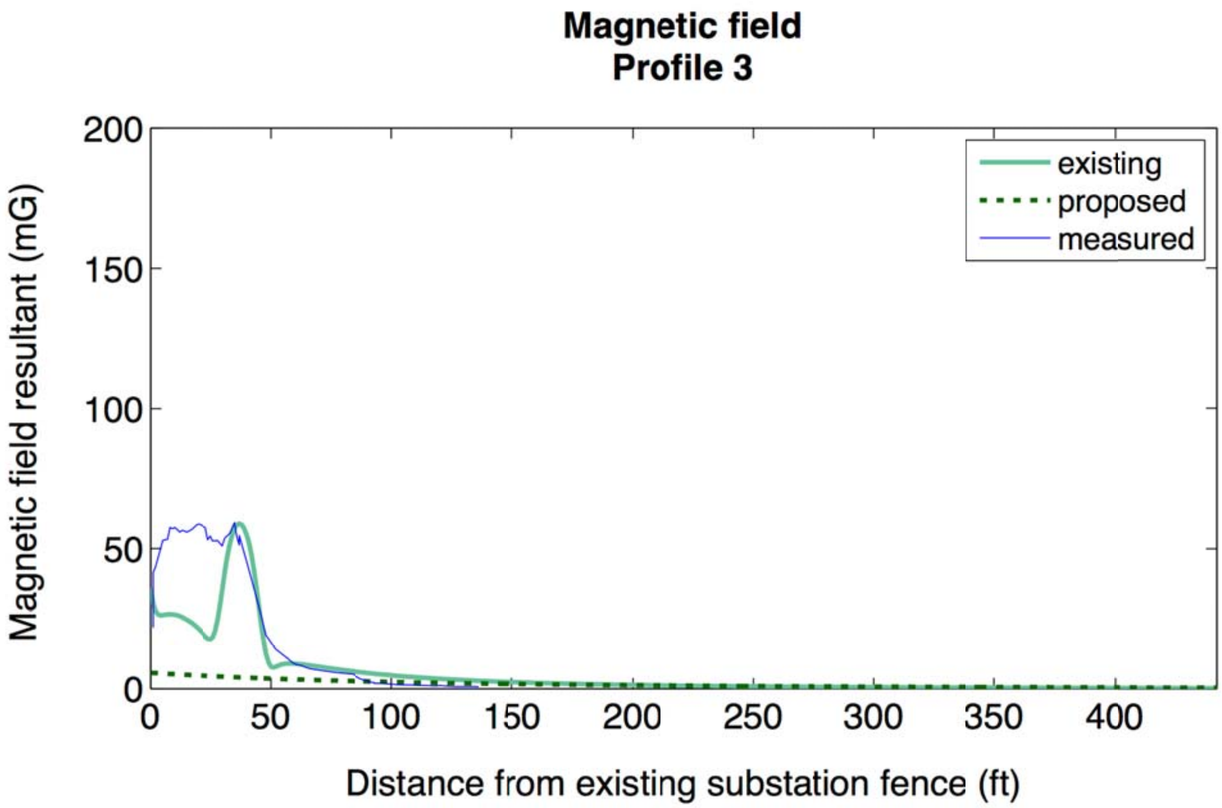


Figure 13. Calculated and measured magnetic-field levels along Profile 3.

The calculated magnetic-field levels are for existing and proposed configurations of the Baird Substation under average-load conditions in 2023. Measured magnetic fields reflect existing substation and loading on June 30, 2015.

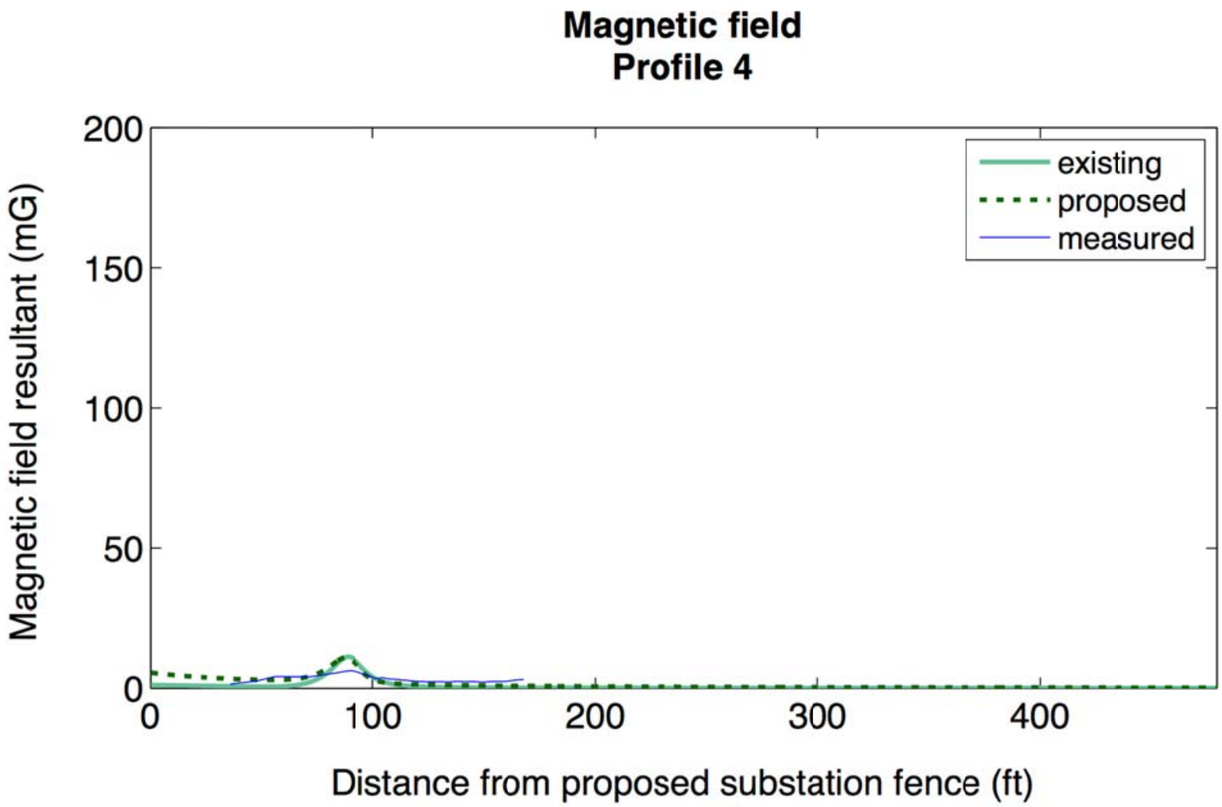


Figure 14. Calculated and measured magnetic-field levels along Profile 4.

The calculated magnetic-field levels are for existing and proposed configurations of the Baird Substation under average-load conditions in 2023. Measured magnetic fields reflect existing substation and loading on June 30, 2015.

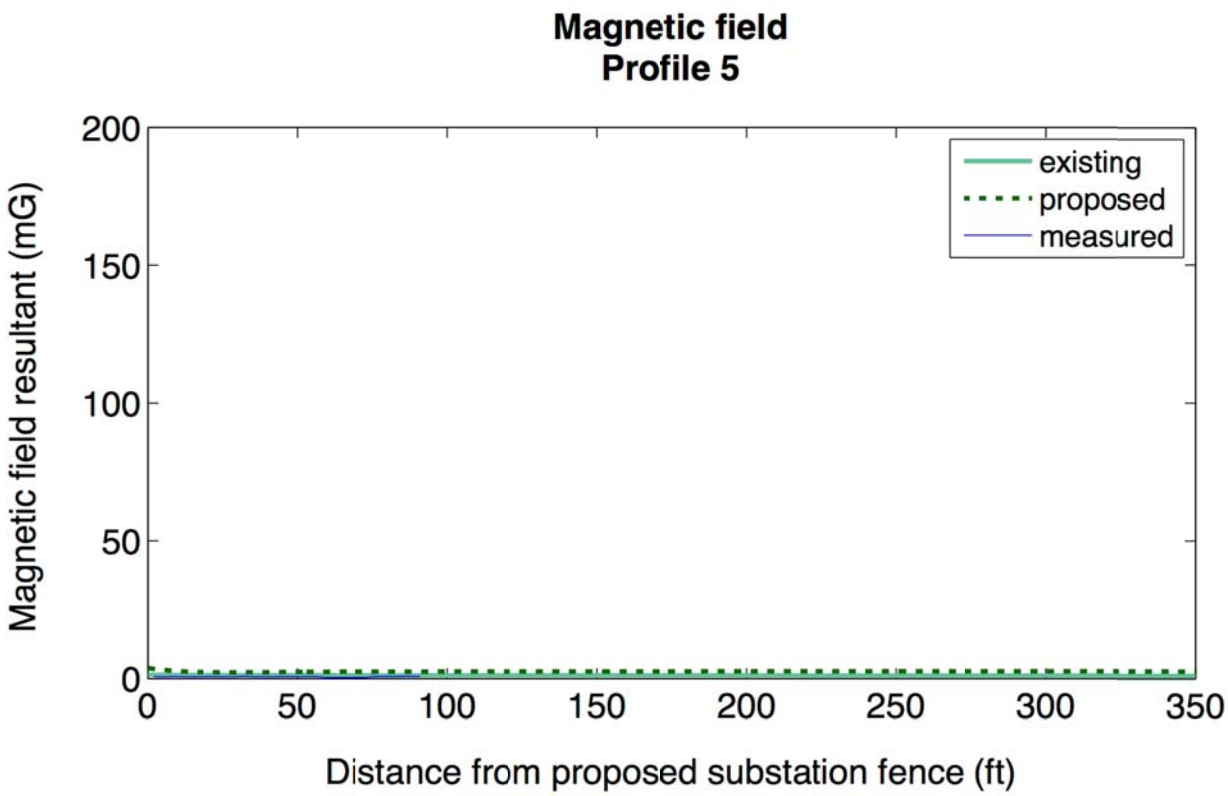


Figure 15. Calculated and measured magnetic-field levels along Profile 5.

The calculated magnetic-field levels are for existing and proposed configurations of the Baird Substation under average-load conditions in 2023. Measured magnetic fields reflect existing substation and loading on June 30, 2015.

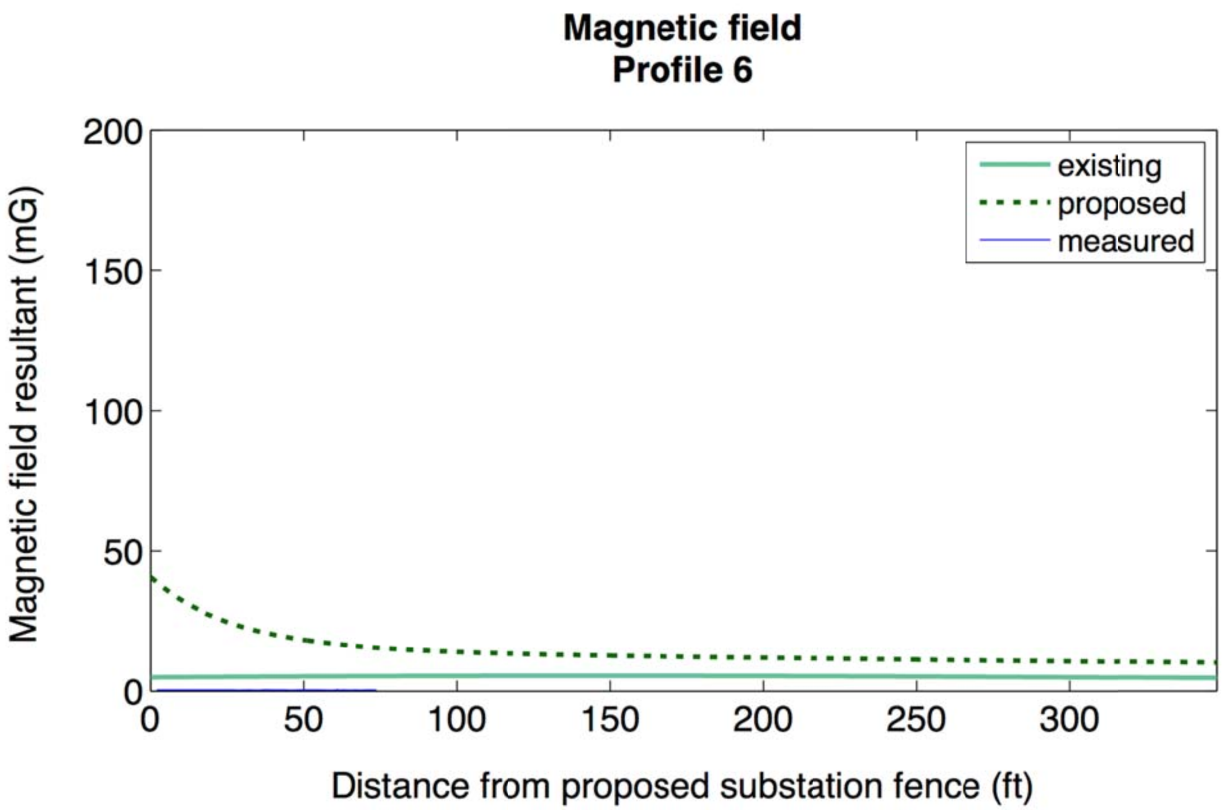


Figure 16. Calculated and measured magnetic-field levels along Profile 6.

The calculated magnetic-field levels are for existing and proposed configurations of the Baird Substation under average-load conditions in 2023. Measured magnetic fields reflect existing substation and loading on June 30, 2015.

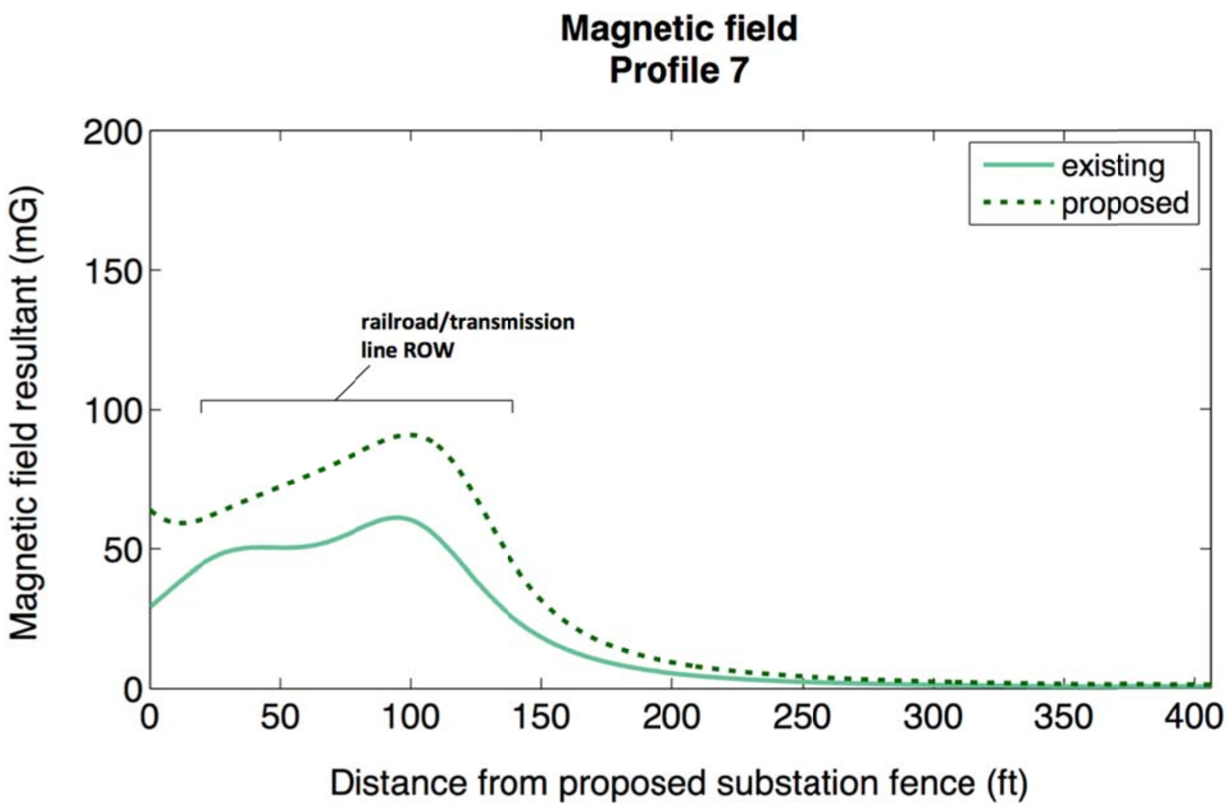


Figure 17. Calculated and measured magnetic-field levels along Profile 7.

The calculated magnetic-field levels are for existing and proposed configurations of the Baird Substation under average-load conditions in 2023. Measured magnetic fields reflect existing substation and loading on June 30, 2015.

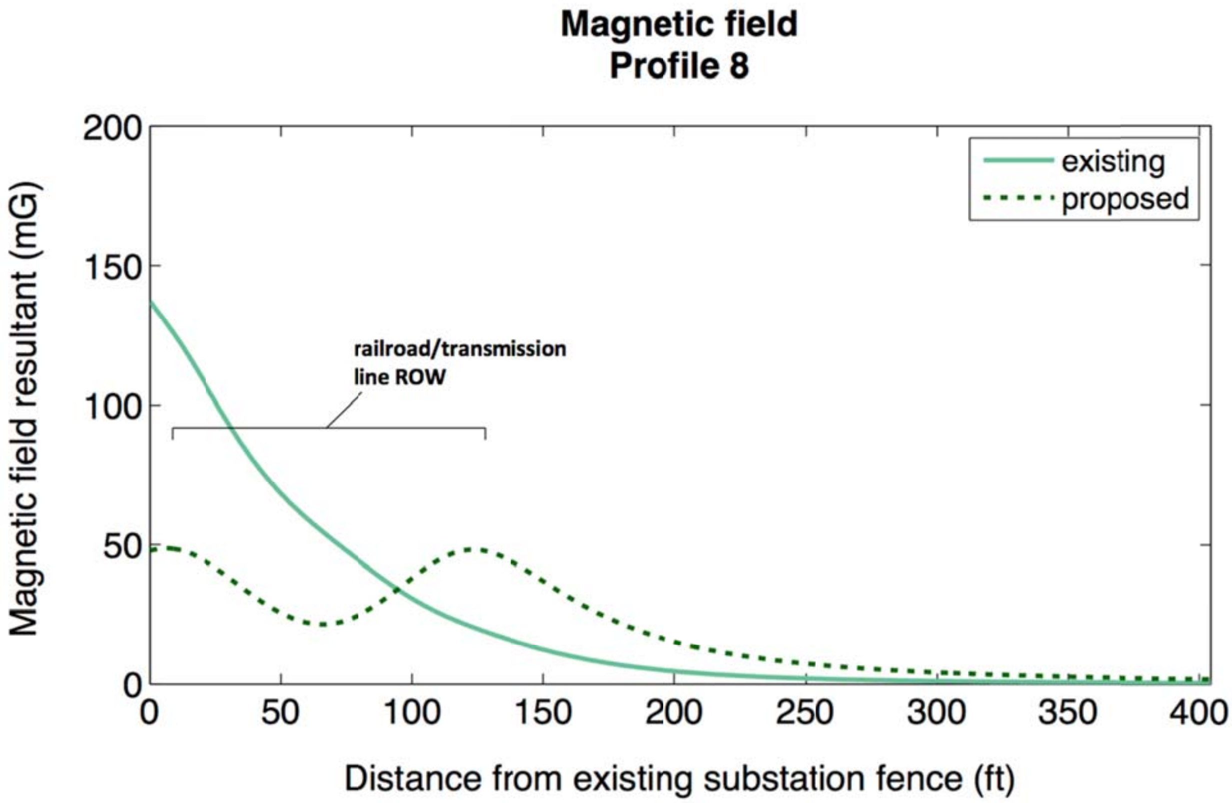


Figure 18. Calculated and measured magnetic-field levels along Profile 8.

The calculated magnetic-field levels are for existing and proposed configurations of the Baird Substation under average-load conditions in 2023. Measured magnetic fields reflect existing substation and loading on June 30, 2015.

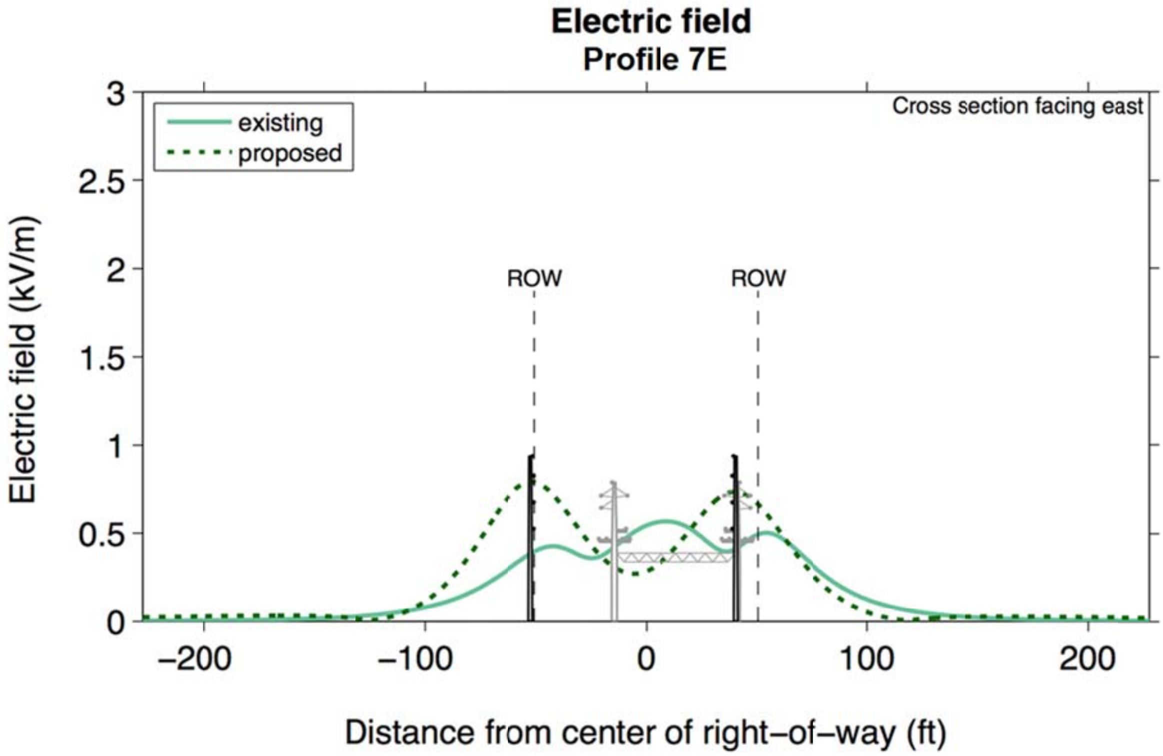


Figure 19. Calculated electric-field for Profile 7E for existing and proposed configurations.

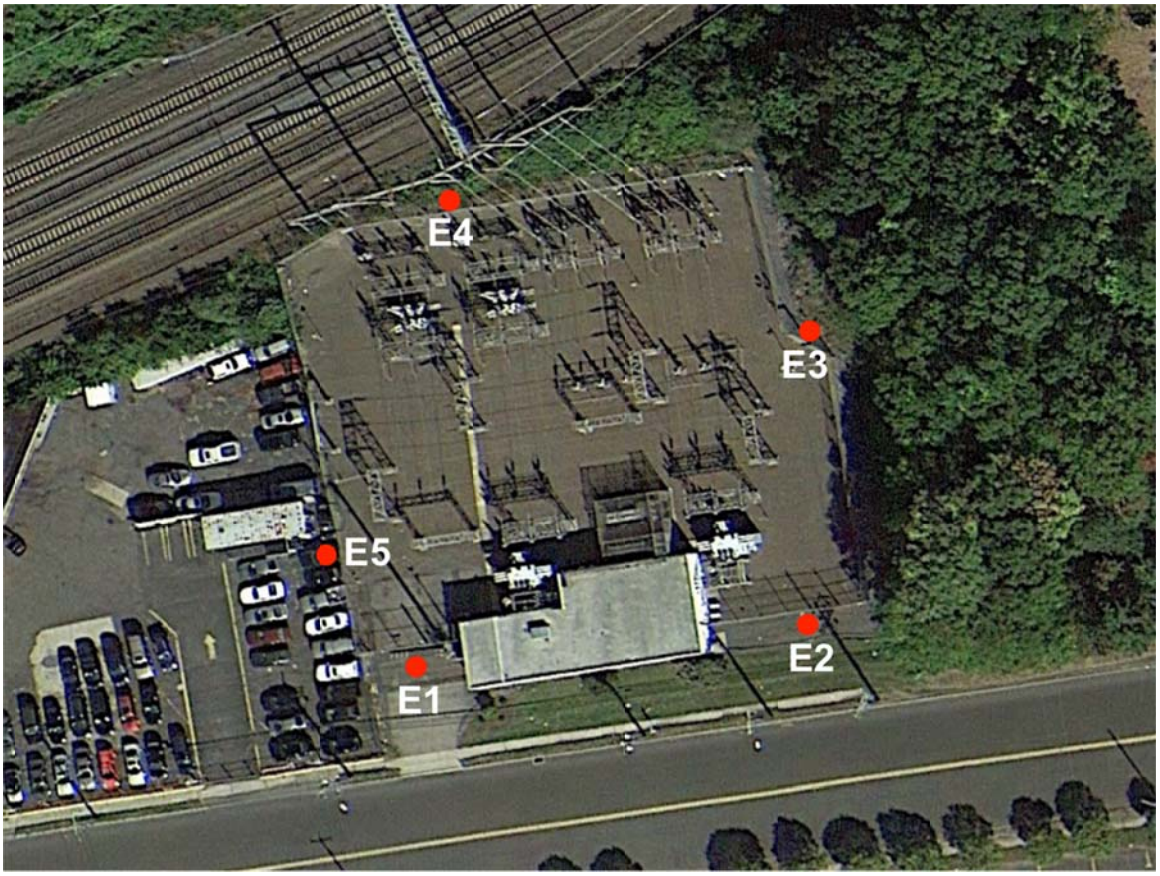


Figure 20. Locations of electric field-measurements.

**Table 5. Summary of measured electric fields**

| Location (Figure 20) | Electric field (kV/m) Vertical | North-South | East-West | Resultant |
|---|---|---|---|---|
| E1 | 0.005 | 0.000 | 0.000 | 0.005 |
| E2 | 0.010 | 0.005 | 0.000 | 0.011 |
| E3 | 0.010 | 0.010 | 0.000 | 0.014 |
| E4 | 0.037 | 0.010 | 0.010 | 0.040 |
| E5 | 0.026 | 0.005 | 0.005 | 0.027 |