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Via Electronic Mail and U.S. Mail

October 22, 2018

New Hampshire Site Evaluation Committee
Ms. Pamela Monroe, Administrator
21 South Fruit Street, Suite 10
Concord, NH 03301

New Hampshire Public Utilities Commission
Randall S. Knepper, P.E.,
Director, Safety Division
21 South Fruit Street, Suite 10
Concord, NH 03301

Re: SEC Docket No. 2015-05: Public Service Company of New Hampshire d/b/a Eversource Energy ("PSNH") and New England Power Company d/b/a National Grid ("NEP"): Joint Application for a Certificate of Site and Facility for the Merrimack Valley Reliability Project – Post-Construction Measurements of Electric and Magnetic Field Levels

Dear Ms. Monroe and Mr. Knepper:

Enclosed for filing in the above-captioned docket, please find the Joint Applicants' Post-Construction Measurements of Electric and Magnetic Field Levels and related appendices.

Please do not hesitate to contact me with any questions.

Sincerely,

Adam Dumville

Adam M. Dumville

cc: SEC Distribution List
Mr. Paul Kasper, NH PUC

Electrical Engineering and
Computer Science Practice

Exponent®

Eversource / National Grid Merrimack Valley Reliability Project

Post-Construction Measurements of Electric and Magnetic Field Levels

Exponent®

Eversource / National Grid Merrimack Valley Reliability Project

Post-Construction Measurements of Electric and Magnetic Field Levels

Prepared for

New Hampshire Site Evaluation Committee
New Hampshire Department of Environmental Services
29 Hazen Drive
Concord, NH 03302

On behalf of

Public Service of New Hampshire
PSNH Energy Park
780 N Commercial Street
Manchester, NH 03101

and

National Grid
40 Sylvan Road
Waltham, MA 02451

Prepared by

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17000 Science Drive, Suite 200
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October 18, 2018

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Acronyms and Abbreviations

EMF	Electric and magnetic fields
Eversource	Eversource Energy
IEEE	Institute of Electrical and Electronics Engineers
kV	Kilovolt
kV/m	Kilovolts per meter
MVRP	Merrimack Valley Reliability Project
mG	Milligauss
NHSEC	New Hampshire Site Evaluation Committee
PUC	Public Utilities Commission
ROW	Right-of-way
The Application	New Hampshire Site Evaluation Committee Docket No. 2015-05

Limitations

At the request of the Public Service Company of New Hampshire, d/b/a Eversource Energy (Eversource), and the New England Power Company, d/b/a National Grid, Exponent measured and modeled the levels of electric and magnetic fields associated with the existing and new transmission lines along the route of the Merrimack Valley Reliability Project (MVRP or the Project) in New Hampshire. 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 the clients. National Grid and Eversource have confirmed to Exponent that the data provided to Exponent and summary contained herein is not subject to Critical Energy Infrastructure Information restrictions. We cannot verify the correctness of this data and rely on the clients for the data's accuracy. Although Exponent has exercised usual and customary care in the conduct of this analysis, the responsibility for the design and operation of the Project remains fully with the clients.

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 outside of the New Hampshire Public Utilities Commission's or New Hampshire Site Evaluation Committee's review of the MVRP, and any re-use of this report or its findings, conclusions, or recommendations presented herein are at the sole risk of the user. The opinions and comments formulated during this assessment are based on observations and information available at the time of the investigation. No guarantee or warranty as to future life or performance of any reviewed condition is expressed or implied.

Executive Summary

The Merrimack Valley Reliability Project (MVRP or Project) constructed a new 345-kilovolt transmission line (designated the 3124 line) for approximately 24.4 miles from the Tewksbury 22A Substation in Tewksbury, Massachusetts, to the Scobie Pond Substation in Londonderry, New Hampshire.

The application for this Project was submitted July 21, 2015, in New Hampshire Site Evaluation Committee (NHSEC) Docket No. 2015-05 (the Application), and was approved with conditions in its Decision and Order granting a Certificate of Site and Facility on October 4, 2016. On November 29, 2016, the NHSEC amended the Order and Certificate of Site and Facility to clarify a condition for pre- and post-construction measurements of electric and magnetic fields (EMF). A pre-construction EMF measurement report was submitted on March 27, 2017.[1] To comply with the condition for post-construction EMF measurements in the amended Order and Certificate of Site and Facility, Exponent measured EMF levels from the existing, reconstructed, and new lines under conditions as near as possible to conditions assumed in the original modeling.

The location of measurements was jointly evaluated by National Grid and Eversource in consultation with the New Hampshire Public Utilities Commission (PUC). As described in a letter sent from the PUC to the NHSEC, dated December 2, 2016, EMF test sites were selected in each of the 10 cross sections of the proposed line specified in Tables A-1 and A-2, in Appendix AG, Attachment A, of the Application.[2] The PUC further requested EMF measurements at six road crossings of the right-of-way (ROW). Measurements of post-construction EMF levels were performed at the same sites as pre-construction EMF measurements (including PUC-specified road crossings).

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[1] Exponent, Inc. Eversource/National Grid Merrimack Valley Reliability Project: Pre-Construction Measurements of Electric and Magnetic Field Levels. Prepared for the New Hampshire Department of Environmental Services, on behalf of Public Service of New Hampshire and National Grid. Exponent, Inc., March 27, 2017.

[2] Exponent, Inc. Eversource/National Grid Merrimack Valley Reliability Project: Electric Field, Magnetic Field, Audible Noise, and Radio Noise Modeling in New Hampshire. Prepared for the New Hampshire Department of Environmental Services, on behalf of Public Service of New Hampshire and National Grid. Exponent, Inc., June 16, 2015.

For each of the 10 cross-section measurement sites, Exponent measured EMF levels and calculated EMF levels based on the site-specific line configuration and time-specific loading on the lines (the As-Measured Model) for direct comparison to measured values. Consistent with the NHSEC order, Exponent performed separate calculations that adjusted the line height and loading of the As-Measured Model to predict EMF levels expected during peak-loading conditions (As-Measured − Adjusted for Peak Model).

The results of these analyses demonstrate that measurements of the EMF levels at the specified sites were similar to or lower than the calculated EMF levels. These results also confirm the accuracy and applicability of the modeling approach used to estimate EMF levels presented in the Application. Furthermore, when adjusted to peak loading, the EMF levels (As-Measured – Adjusted for Peak Model) are similar to, or lower than, the EMF levels calculated at peak line loadings in the Application, with differences at a few sites, due to conductor height, terrain variations, and other measurement conditions.

Both measured and calculated EMF levels at all locations are far below health-based standards and guidelines developed by the International Commission on Non-Ionizing Radiation Protection and the International Committee for Electromagnetic Safety and were found to be below levels that would cause exceedance of Basic Restrictions on public exposure discussed in the Application.[3] In addition, the demonstrated agreement between modeling and measurements confirms the reasonableness of the input data used for modeling EMF from existing transmission lines and accuracy of the modeling approach followed in the Application.

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3 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: 818-36, 2010; 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; Reaffirmed 2007.

Introduction

The Merrimack Valley Reliability Project (MVRP or Project) constructed a new 345-kilovolt (kV) transmission line (designated the 3124 line) for approximately 24.4 miles from the Tewksbury 22A Substation in Tewksbury, Massachusetts, to the Scobie Pond Substation in Londonderry, New Hampshire. For approximately 18 miles, the line passes through Londonderry, Hudson, Windham, and Pelham in New Hampshire, and for 6.5 miles it passes through Dracut, Andover, and Tewksbury in Massachusetts. Of the 18 miles in New Hampshire, Eversource constructed 10 miles of the line through Londonderry and Hudson, and National Grid constructed 8 miles of the line through Hudson, Windham, and Pelham.

The application for this Project was submitted on July 21, 2015, in New Hampshire Site Evaluation Committee (NHSEC) Docket No. 2015-05 (the Application) and was approved with conditions in its Decision and Order granting a Certificate of Site and Facility on October 4, 2016. On November 29, 2016, the NHSEC amended the Order and Certificate of Site and Facility to clarify a condition for pre-construction measurements of electric and magnetic fields (EMF). The amended order reads:

> … the Applicant, in consultation with the PUC's Safety Division, shall measure actual electric and magnetic field levels along the Project ROW [right-of-way] in the locations and at the distances as near as possible to those identified in Tables A-1 and A-2 in the Application, Appendix AG, Attachment A, both before and after the Project is placed into service. If peak or near-peak conditions do not occur before elements of the Project are placed into service, Pre-Project measurements should be presented in both raw form and adjusted to reflect a peak loading condition and other conditions represented in Table A-1 and A-2 at each measurement location. Pre-project [*sic*] measurements shall be taken before any existing lines are moved and under conditions as near as possible to conditions assumed in the original modeling shown in the Tables A-1 and A-2. Post construction measurements will be taken during the summer peak loading season and a similar procedure will be used, if necessary, in acknowledgement that the Applicant cannot know in advance when peak loading will occur and that the days planned for measurements may occur when line loadings are below the forecasted peak loading.

The Joint Applicants and the New Hampshire Public Utilities Commission (PUC) together identified cross sections as described in a letter dated December 2, 2016, from the PUC to the NHSEC. The letter provides as follows:

> The Safety Division of the New Hampshire Public Utilities Commission is writing to acknowledge that the Joint Certificate Holders, in consultation with our Staff, have selected representative primary and alternate EMF test sites in each of the ten cross sections of the proposed line 3134 [*sic*] that are specified in Tables A-1 and A-2 in the Application, Appendix AG.

These 10 measurement sites (4 in National Grid service territory and 6 in Eversource service territory) were selected as representative of the ROW configurations identified in Tables A-1 and A-2, in Appendix AG, Attachment A, of the Application. During these consultations, the PUC further requested EMF measurements be performed at six road crossings of the right of way (ROW).[4]

To comply with the condition for pre-construction EMF measurements in the amended Order and Certificate of Site and Facility, Exponent measured EMF levels from the existing lines at each of the 16 sites in January 2017, before these lines were moved and under conditions as near as possible to conditions assumed in the original modeling (shown in the Tables A-1 and A-2 of the Application). A report describing the results of these measurements was submitted on March 24, 2017.[5] In December, 2017 the MVRP transmission line was energized. To comply with the condition for post-construction EMF measurements, Exponent measured EMF levels in July 2018 from the lines after all construction had been completed at each of the 16 sites.

The measurement methods and protocol for post-construction measurements were outlined in the memorandum *"Measurements of Electric and Magnetic Fields"* sent on June 18, 2018, to the PUC and NHSEC. A copy is attached in Appendix G. At each of the 10 selected cross sections, Exponent recorded the conductor position and height of all transmission line

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4 The request for measurements of the road crossings was sent in an email from Mr. Robert Wyatt of the PUC to Ms. Pamela Monroe of the NHSEC on December 1, 2016. This email was subsequently forwarded by Ms. Monroe to Mr. Adam Dumville, also on December 1, 2016.

5 Exponent, Inc. Eversource/National Grid Merrimack Valley Reliability Project: Pre-Construction Measurements of Electric and Magnetic Field Levels. Prepared for the New Hampshire Department of Environmental Services, on behalf of Public Service of New Hampshire and National Grid. Exponent, Inc., March 27, 2017.

conductors and used these data (as well as recorded transmission line loading provided by National Grid and Eversource) to develop an As-Measured Model with which to calculate EMF levels to compare to measured values. Additionally, to comply with the NHSEC Order, Exponent adjusted these site-specific models of the as-measured conditions to account for changes in conductor height and loading for peak-loading conditions (As-Measured – Adjusted for Peak Model).

The scope of the measurements taken at the six road crossing sites specified by the PUC was more limited than the detailed measurements and calculations performed at the representative 10 sites along the route. Measurements of EMF levels were taken at the PUC-specified road crossings, but no modeling was performed.

A. Cross Section Measurement Sites

The goal of the measurements performed at the 10 representative sites on the Project route was to compare the measured EMF levels to those identified in Tables A-1 and A-2 in the Application. This report addresses this goal by summarizing the work performed as follows:

1. A comparison between the EMF measurements taken after completion of all construction activities and EMF values calculated from an As-Measured Model developed using actual line conditions at the time these measurements were taken (tabular summary in Appendix A, and a graphical summary in Appendix B).

2. A comparison between the EMF levels calculated from the As-Measured – Adjusted for Peak Model and modeled EMF levels submitted in the Application for peak-loading conditions (tabular summary in Appendix A, graphical summary in Appendix B).

3. Aerial maps with annotations reflecting the specific locations of EMF measurements (Appendix C).

4. Loadings of transmission lines (as well as measured conductor heights) at the time of measurements (Appendix D, Table D-1).

B. Road Crossing Measurements

The sites of road crossing measurements were selected by the PUC. Road crossings are often not suitable for performing detailed measurements and modeling of EMF levels due to road traffic, line geometry in relation to the road, and other EMF sources along the road. Due to these factors, measurements of electric and magnetic fields were performed and summarized somewhat differently and consisted of:

1. Aerial maps with annotations summarizing the EMF levels recorded beneath transmission line conductors and separate graphical figures showing all recorded EMF levels (Appendix E).

2. Loading of transmission lines at the time of measurements (Appendix D, Table D-2).

EMF Measurement and Calculation Methods

Measurement Methods

The methods employed for taking post-construction measurements were identical to those used for pre-construction measurements and are described in the protocol *"Measurements of Electric and Magnetic Fields,"* which was sent to both the NHSEC and the PUC for review and comment on June 18, 2018. The description below is based on the procedures described in this protocol.

Measurement Setup

At each measurement site, Exponent engineers photographed the conditions of the ROW and transmission lines and laid a long measuring tape on the ground beneath the lines to identify the horizontal location of the overhead line conductors. The vertical height of each conductor was measured and recorded using an acoustic, line-height sensor (SupaRule T30).[6,7] Where a measurement transect other than perpendicular was required, the angle of the transect to the transmission lines was noted and measurement distances were adjusted accordingly.

Measurements

Exponent engineers measured both electric fields and magnetic fields as the total field computed as the resultant of field vectors measured along vertical, transverse, and longitudinal axes.[8] The magnetic field was measured in units of milligauss (mG) by orthogonally-mounted sensing coils whose output was recorded by a digital meter (EMDEX II) and attached to a survey wheel to simultaneously measure magnetic-field magnitude distance. The electric field was measured in units of kilovolts per meter (kV/m) with a single-axis sensor accessory for the EMDEX II

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6 The heights of some shield wires were above the range of the line-height sensor. The heights of these shieldwires were estimated using the as-measured phase conductor heights and design drawings.

7 An As-Measured Model was not performed at road crossing locations specified by the PUC and so no line-height measurements were performed at these locations.

8 Measurements along the vertical, transverse, and longitudinal axes were recorded as root-mean-square magnitude, which refers to the common mathematical method of defining the effective voltage, current, or field of an alternating-current system.

meter.[9] The single-axis sensor was aligned sequentially along vertical, transverse, and longitudinal axes to capture the value of the electric-field vector along each axis.

Magnetic-field measurements were recorded at intervals of approximately 1 to 3 feet using the measurement system of the EMDEX II and survey wheel, while electric-field measurements were performed at 5- to 50-foot intervals with a minimum of five measurement locations performed in the immediate vicinity of each transmission line in accordance with IEEE Standard 644-1994-R2008.[10]

In addition, at each measurement site, an additional magnetic-field meter (EMDEX LITE) was placed at ground level beneath the center conductor of one of the transmission lines and set to continuously record fluctuations in the magnetic field that were due to changes in current flow on the lines above. The data from this sensor were used to evaluate if there was a large change in loading during the time that measurements were taken. The time and date of the field measurements were noted so that the loading on each of the lines at the time of field measurements could be matched.

These instruments meet the IEEE instrumentation standard for obtaining accurate field measurements at power line frequencies (IEEE Std.1308-1994).[11] All meters and measurement accessories were calibrated by EMDEX, LLC, using methods like those described in IEEE Std. 644-1994 (R2008). In addition, a Kestrel 4000 weather meter was used to record temperature, relative humidity, barometric pressure, and wind speed for reference. The calibration certificates for each piece of equipment are included in Appendix F.

[9] Measurement equipment was manufactured by Enertech Consultants, Cupertino, California.

[10] Institute of Electrical and Electronics Engineers (IEEE). IEEE Standard Procedures for Measurement of Power Frequency Electric and Magnetic Fields from Alternating Current Power Lines (IEEE Std. 644-1994, Reaffirmed 2008). New York: IEEE, 1994/2008. At locations far from the transmission lines, the distance between successive electric-field measurements was larger (approximately 25 to 50 feet). Nearer to the transmission lines, the distance between successive measurement locations was smaller (approximately 5 to 10 feet).

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

Daily Pre-Measurement Calibration Procedure

The EMDEX II and EMDEX LITE were calibrated on July 5, 2018, approximately three weeks before the scheduled measurement trip. The certificates of calibration are included in Appendix F. In addition, to monitor the EMDEX II calibration throughout the week-long measurement trip, the calibration was checked each morning with a portable calibration coil. Throughout the weeklong measurement trip, the maximum change in any calibration measurement was less than 2% indicating that the EMDEX II maintained calibration throughout the measurement trip.

Modeling Methods

At each measurement site, Exponent used the recorded conductor position and height of each transmission line obtained during measurements, as well as voltage and loading information provided by National Grid and Eversource, to develop an As-Measured Model to represent the operation of the lines at the site. This As-Measured Model also included information from the Application, such as the phasing configuration, conductor type, and conductor bundle spacing of each line.

In addition to the As-Measured Model, Exponent also developed a model representative of the measurement site, but adjusted it to peak line loadings (As-Measured – Adjusted for Peak Model). This adjustment was made by using the peak loading information provided in the Application and by lowering the measured height of the conductors above ground (due to increased sag in the lines) by the amount appropriate for each line at peak loading.

The EMF levels for models were calculated using computer algorithms developed by the Bonneville Power Administration, which also were used for the modeling of EMF levels in the Application.[12] The inputs to the program include data regarding voltage, current flow, phasing, and conductor positions measured on-site at each location.

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

In the model, simplifying assumptions were made to make the calculations more tractable for a large number of transmission line conductors and to yield conservative values (i.e., higher than what might be measured). Each conductor was modeled as infinite in length at a fixed height above a flat earth (also assumed infinite in extent) and was assumed to be parallel to all other conductors. All real-world conditions encountered in the measurements obviously were not included in this simplified model. The assumptions used in the modeling are designed to generally overestimate the actual values. Measured values, however, are expected to differ slightly from modeling due to induced currents on the transmission line shieldwires (which are not accounted for in the model) as well as due to terrain irregularities.

Measurement Locations

The measurement sites were divided into two segments based upon whether the sites were in National Grid or Eversource service territories. As with the pre-construction measurements, PUC and SEC staff observed measurements at selected sites.

The location of the measurement sites were the same for both pre-construction and post-construction measurements. All measurement sites, including the PUC road crossings, are shown in Figure 1 (National Grid service territory) and Figure 2 (Eversource service territory). The 10 sites representative of the configurations presented in Tables A-1 and A-2 of the Application were selected to encompass as many of the following characteristics as possible to provide the best comparison with idealized models constructed for calculations:

1. Free of infrastructure (e.g., distribution lines, water or sewer pipes, gas or oil pipelines) or sources of EMF (e.g., other overhead lines or underground distribution lines; nearby equipment) that can alter or affect measured EMF levels;
2. Flat, level surface beneath the transmission lines that is away from transmission line structures (ideally near the mid-span of lines);
3. Free of underbrush, trees, or other conductive objects; and
4. Provide a measurement transect perpendicular to the transmission line conductors.[13]

The selection of each site went through a multi-stage process, beginning with review of aerial photographs, to select potential locations. An in-person visit to each site followed to evaluate other factors not discernable from aerial photographs such as terrain roughness, variation, and the nature and density of brush. If the initially-selected site was found to be deficient in one aspect or another additional sites were investigated. In many (but not all) cases the cross sections of shorter extent (e.g., XS-13 through XS-15) resulted in measurement sites with greater deficiencies (Sites 8 through 10) in large part because there were not many potential options on those shorter sections and so sub-optimal options were necessarily selected.

[13] No calculations or comparison to previously-calculated values were intended to be made at the six road crossing sites. Therefore, these criteria were not evaluated by Exponent for the road crossing sites.

A summary of all measurement sites is provided in Table 1.[14] With the exception of Site 2 in XS-8c, in which a single-phase local distribution circuit was present, no other visible sources of EMF were apparent.[15] All measurement sites had tall trees located along both ROW edges, which generally reduced electric-field levels within approximately 50 feet of either ROW edge.[16]

The discussion below provides a more detailed description of the cross sections and addresses the extent to which each measurement site met (or did not meet) the above criteria.

Table 1. EMF measurement site location and date

Site	Cross Section #	Pre-Construction Measurement Date	Post-Construction Measurement Date	Municipality	Monitoring Location
1	XS-8b	1/12/2017	7/27/2018	Pelham	East of Old Lawrence Road
2	XS-8c	1/16/2017	7/27/2018	Pelham	Off Tina Avenue
3	XS-8d	1/13/2017	7/24/2018	Windham	Along Winter Street
4	XS-9	1/13/2017	7/29/2018	Hudson	Southeast of Griffin Road
5	XS-10	1/25/2017	7/27/2018	Londonderry	South of Dan Hill Road
6	XS-11	1/27/2017	7/30/2018	Londonderry	North of Wiley Hill Road
7	XS-12	1/20/2017	7/28/2018	Londonderry	Off Davis Drive
8	XS-13	1/19/2017	7/29/2018	Londonderry	Along Bancroft Road
9	XS-14	1/20/2017	7/28/2018	Londonderry	Off Snow Flake Lane
10	XS-15	1/19/2017	7/30/2018	Londonderry	Along Londonderry Rail Trail
PUC 1	XS-8b	1/12/2017	7/24/2018	Pelham	Dutton Road
PUC 2	XS-8d	1/13/2017	7/25/2018	Pelham	Shelly Drive
PUC 3	XS-8d	1/13/2017	7/29/2018	Windham	Glance Road
PUC 4	XS-10	1/17/2017	7/27/2018	Hudson	David Drive
PUC 5	XS-11	1/17/2017	7/25/2018	Londonderry	Wiley Hill Road
PUC 6	XS-11	1/25/2017	7/28/2018	Londonderry	Mayflower Drive

[14] An extension of Table 1 is included in Appendix B, Table B-1, including site evaluation criteria with a numerical ranking from 1 (poor) to 3 (good) for each site.

[15] Although not an external source of EMF, the measurement path at Site 10 in XS-15 was relatively near to a turn in the ROW, which affects calculated levels and reduces the similarity of the measurement path to the idealized model assumed for calculations.

[16] Note that for the modeling performed in the Application, conductors were conservatively modeled at midspan clearance (minimum distance above ground) and the ROW was treated as being entirely free of brush or trees so there was no shielding (reduction) of electric fields.

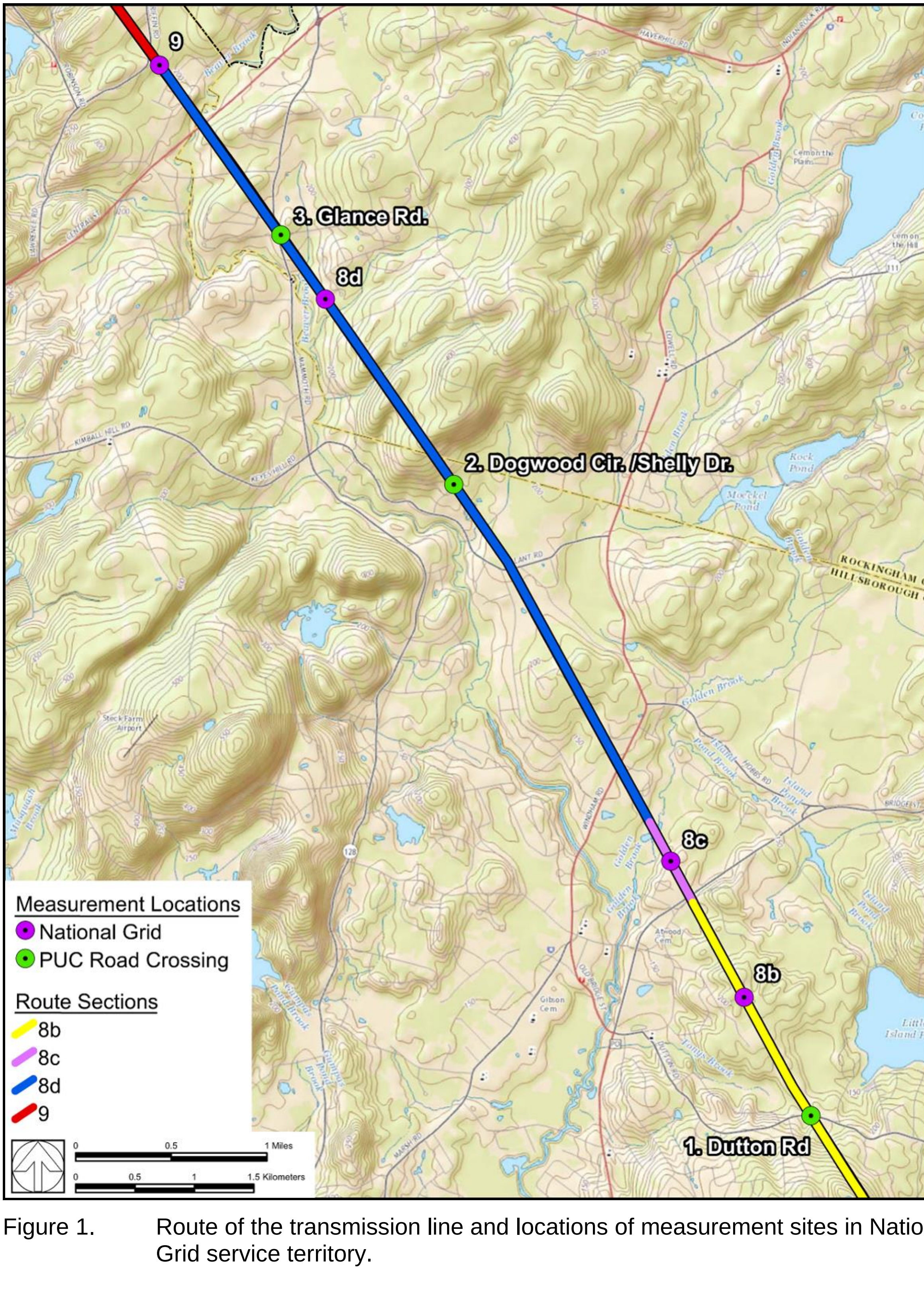


Figure 1. Route of the transmission line and locations of measurement sites in National Grid service territory.

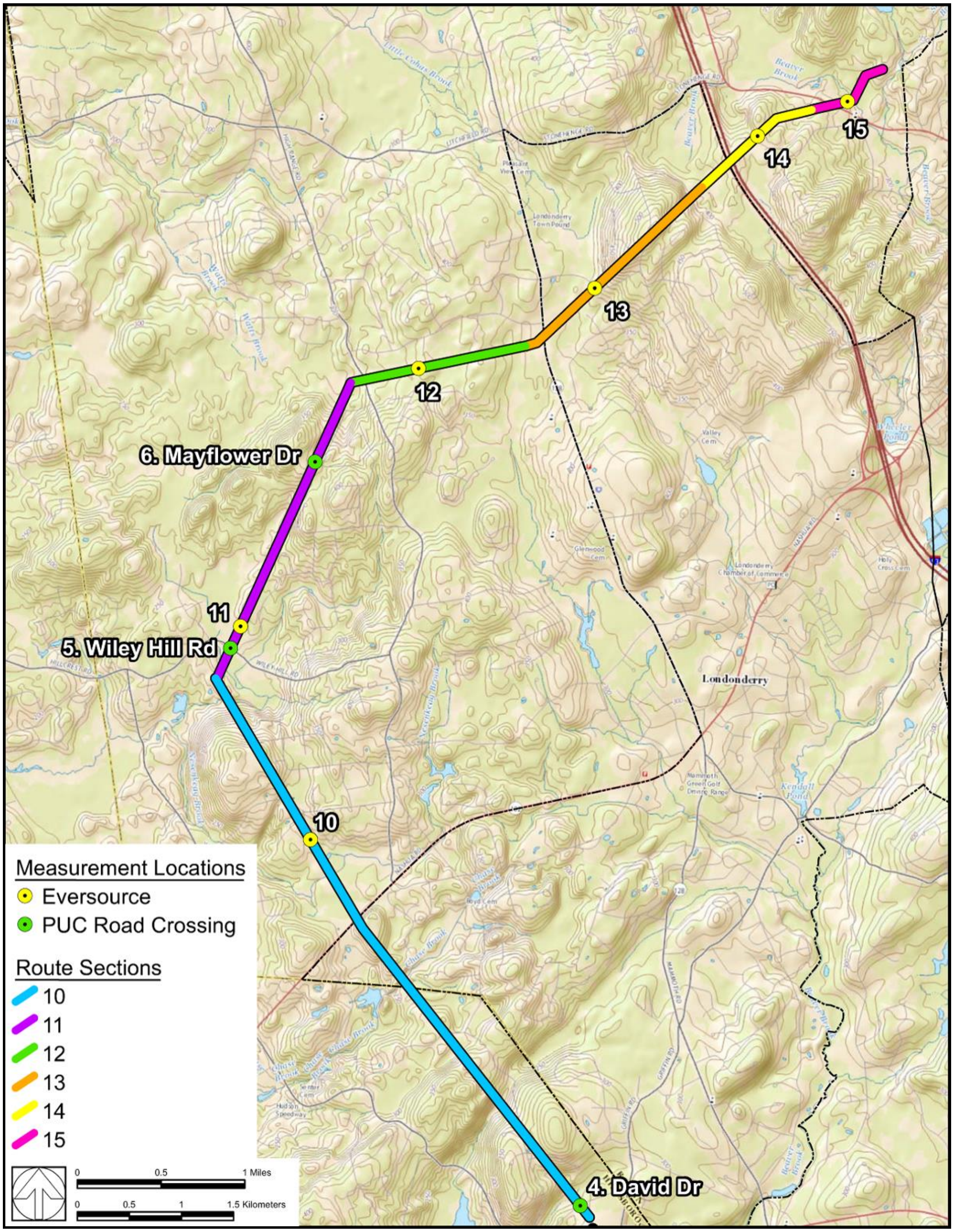


Figure 2. Route of the transmission line and locations of measurement sites in Eversource service territory.

Measurement Site 1 is located in cross section XS-8b where the ROW width is 350 feet. The post-construction measurements were taken on a portion of the ROW east of Old Lawrence Road, in Pelham. In XS-8b, two 230- kV transmission lines (O-215 and N-214) are constructed on lattice structures 83.5 feet from the west and east ROW edges, respectively. The MVRP line (3124) is constructed on H-frame structures at the center of the ROW and the 115-kV transmission line (Y-151), which was previously at the center of the ROW, was rebuilt on delta structures 28.5 feet from the western ROW edge. The terrain varied somewhat (less than approximately 4 to 5 feet) across the width of the ROW at the location of measurements but did not slope significantly from one side to the other, and the measurement transect was located near the midspan of the transmission lines. Furthermore, National Grid cleared the ROW at this location resulting in a measurement path relatively clear of brush. This brush clearing not only made measurements possible, but it made the site more closely resemble the conditions assumed for modeling in the Application. Post-construction measurements were taken on July 27, 2018.

Measurement Site 2 is located at the end of Tina Avenue in Pelham in a portion of cross section XS-8c. In XS-8c, the physical configurations of all transmission lines are identical to that in XS-8b, but the loading of the Y-151 transmission line is different. The terrain along this measurement site is very flat and smooth since the measurement path is along a dirt road. A Y-151 structure was located on top of a hill approximately 50 feet to the south of the measurement path. A single-phase local distribution line crossed the ROW and the measurement path near the inner phase of the N-214 transmission line. The measurement path was aligned approximately 15 degrees from perpendicular to the transmission lines. Post-construction measurements were taken on July 27, 2018.

Measurement Site 3 is located on the north side of Winter Street in Windham in a portion of cross section XS-8d. The physical configuration of the 3124, N-214, and O-215 transmission lines in XS-8d is identical to that of XS-8b and XS-8c. This section was modeled separately in the Application because the phase of the previous configuration of the Y-151 line differed from XS-8b and XS-8c. The proposed configuration (and projected loading) of XS-8d is identical to that of XS-8c. Winter Street slopes downward significantly from east to west along this path, but the terrain is very smooth on the shoulder of Winter Street where measurements were taken. The nearest structures of the O-215 and Y-151 lines were located approximately 75 feet from the measurement path on the other side (i.e., the south side) of Winter Street. Post-construction measurements were taken on July 24, 2018.

Measurement Site 4 is located southeast of Griffin Road in Hudson in a portion of cross section XS-9. On this portion of the ROW, the physical configurations of the 3124, N-214, and O-215 lines are identical to that of XS-8d, and the Y-151 line leaves the ROW, so is not present. The terrain varied somewhat (less than approximately 2 to 3 feet) across most of the ROW with a larger dip (approximately 6 feet) near the northeastern ROW edge (past the N-214 line), but did not slope significantly from one side to the other. In addition, a stone wall (approximately 2- to 3-feet high) crossed the measurement path near the inside conductor of the N-214 line, and the measurement transect was located quite close (approximately 30 feet south) to the nearest 3124structure. Post-construction measurements were taken on July 29, 2018.

Measurement Site 5 is located south of Dan Hill Road in Londonderry in cross section XS-10 on a portion of the ROW approximately 567-feet wide. This ROW contains transmission lines O-215, 451/452 (a direct current transmission line), N-214, 326, and 3124, respectively from west to east. The terrain at this location was quite rough, and varied slightly over most of the ROW. Beyond the 326 line, the terrain sloped downward significantly to the ROW edge. Post-construction measurements were taken on July 27, 2018.

Measurement Site 6 is located on a portion of cross section XS-11, north of Wiley Hill Road in Londonderry. XS-11 is a 460-foot wide ROW with transmission lines 380, 326, 3124, Z119, X116, respectively from west to east. The terrain along this path was very rough with a bog beneath the conductors of the 380 line and dense underbrush on the east side. Traversing the bog with the survey wheel required the use of multiple 2 by 6 pieces of lumber. Even through Eversource cleared the ROW, the remaining small brush stalks increased the roughness of the terrain. Post-construction measurements were taken on July 30, 2018.

Measurement Site 7 is located on a portion of cross section XS-12, off Davis Drive in Londonderry. This 635-foot wide ROW has transmission lines 380, 326, 3124, S188, X116, and Z119, respectively from west to east. The terrain at this location is quite rough, with multiple small hills, ditches, berms, and trails crossing the path. There is a small slope downwards from west to east across the ROW and while Eversource cleared a path along the

ROW, the resulting mulch and remaining small brush stalks increased the roughness of the terrain. In addition, there was tall brush immediately outside the cleared area. Post-construction measurements were taken in July 28, 2018.

Measurement Site 8 is located on a portion of cross section XS-13 along the south side of Bancroft Road in Londonderry. The transmission lines located on this portion of the row include 380, 326, 3124, R187, X116, and Z119, along with distribution line 365, respectively from west to east. The terrain on this ROW slopes significantly up from west to east. Although the portion of the measurement path on the road was quite smooth, the area off the road was quite rough with large rocks, stumps, dirt berms, and other obstacles. Post-construction measurements were taken on July 29, 2018.

Measurement Site 9 is located in cross section XS-14 off Snow Flake Lane in Londonderry. Similar to XS-13, this 535-foot wide ROW has transmission lines 380, 326, 3124, R187, X116, and Z119, respectively from west to east. The terrain along this measurement path varies significantly with multiple hills and valleys of 10 feet or more, and some portions with more gradual slopes. This cross section has the densest underbrush and number of hills, so despite ROW clearing by Eversource, multiple berms and tall brush remain outside the immediate measurement path. Post-construction measurements were taken on July 28, 2018.

Measurement Site 10 is located in cross section XS-15 along Londonderry Rail Trail in Londonderry. This 535-foot wide ROW is similar to that in XS-14 with transmission lines 380, 326, 3124, R187, X116, and Z119, respectively from north to south across the ROW, as well as a double-circuit distribution pole near the southern ROW edge. The terrain along this portion of the route (much on the Londonderry Rail Trail) is smooth without significant slopes. The Londonderry Rail Trail does not travel perpendicular across the ROW and so the measurements were made at an angle to the ROW (distance corrected in post-processing). The clearing of brush from the ROW was effective in clearing a measurement path, but some hills and brush outside the measurement path remained. This measurement path was performed relatively near to a set of angle towers (approximately 200 feet east), which may also have had some effect on the results since the assumption of infinite parallel conductors in the idealized model is not applicable at this location. Post-construction measurements were taken on July 30, 2018.

Results

EMF measurements were performed on portions of the route on July 24 to 25 and on July 27 to 30, 2018. The following section presents a summary of the measurement results at each location, as well as a comparison with calculations in the Application at peak loading. Despite taking measurements in the middle of peak loading season (consistent with the NHSEC Order), peak-loading conditions were not present during the time of measurements and so the electric and magnetic field measurements have therefore been summarized both in raw form, as well as adjusted to levels that would be produced by peak-loading conditions had they occurred during the measurement period.

A direct comparison of the modeling provided in the Application to the measured and modeled levels from these analyses is provided in tabular form in Appendix A. EMF measurement results at each site are presented graphically in Appendix B and the locations of measurements are shown in annotated aerial photographs in Appendix C.

Comparison of Measured and Calculated Magnetic-Field Levels

To confirm the accuracy of modeling methods, Exponent compared the measured magnetic-field values with the values calculated from the As-Measured Model at each site. These comparisons use the same software algorithms used in the original Application, but in this case, the model accounts for transmission-line conductor heights at the time measurements were taken, and the magnetic fields are calculated from recorded line currents provided by National Grid and Eversource.

As described in the previous section detailing the measurement locations and conditions of measurements, it was rarely possible to identify a single location that encompassed all of the desirable characteristics of a measurement site, and so the results below reflect the deviations between modeled and measured levels expected when comparing calculations from an idealized model with measurements from a real-world transmission line ROW.

These factors include:

1. Differences between actual conductor heights above ground at measurement sites and the typical minimum conductor heights that were assumed for calculations;

2. Differences between the estimated power flows on each line assumed for magnetic-field calculations and actual power flows recorded at the time measurements were taken;

3. Differences in the roughness or slope of the terrain; and

4. For electric-field measurements, the presence of conductive objects such as trees, brush, transmission-line structures, berms, or hills on the ROW.

Example Comparison: Site 3, XS-8d

One example (Site 3 in cross section XS-8d) is presented below in Figure 3 for reference and discussion while the results for the remaining sites are presented in Appendix B. This site was previously discussed in pre-construction measurements and so is presented again for consistency.

Figure 3 shows magnetic-field levels (left side) and electric-field levels (right side) separately. Actual measurement values are shown by a series of ‘+’ markers while the As-Measured Model is superimposed with a solid dark blue line. Magnetic-field measurements were taken every 1 to 3 feet using a survey wheel in conjunction with the magnetic-field meter. The ‘+’ markers sometimes appear as a thick, jagged line due to the close spacing of the measurements locations.

In contrast, electric-field measurements were performed at individual measurement locations separated by approximately 5 to 30 feet (with closer spacing near the transmission lines and at greater spacing on more distant portions of the ROW) and so generally appear as discrete ‘+’ symbols indicating the measured value.

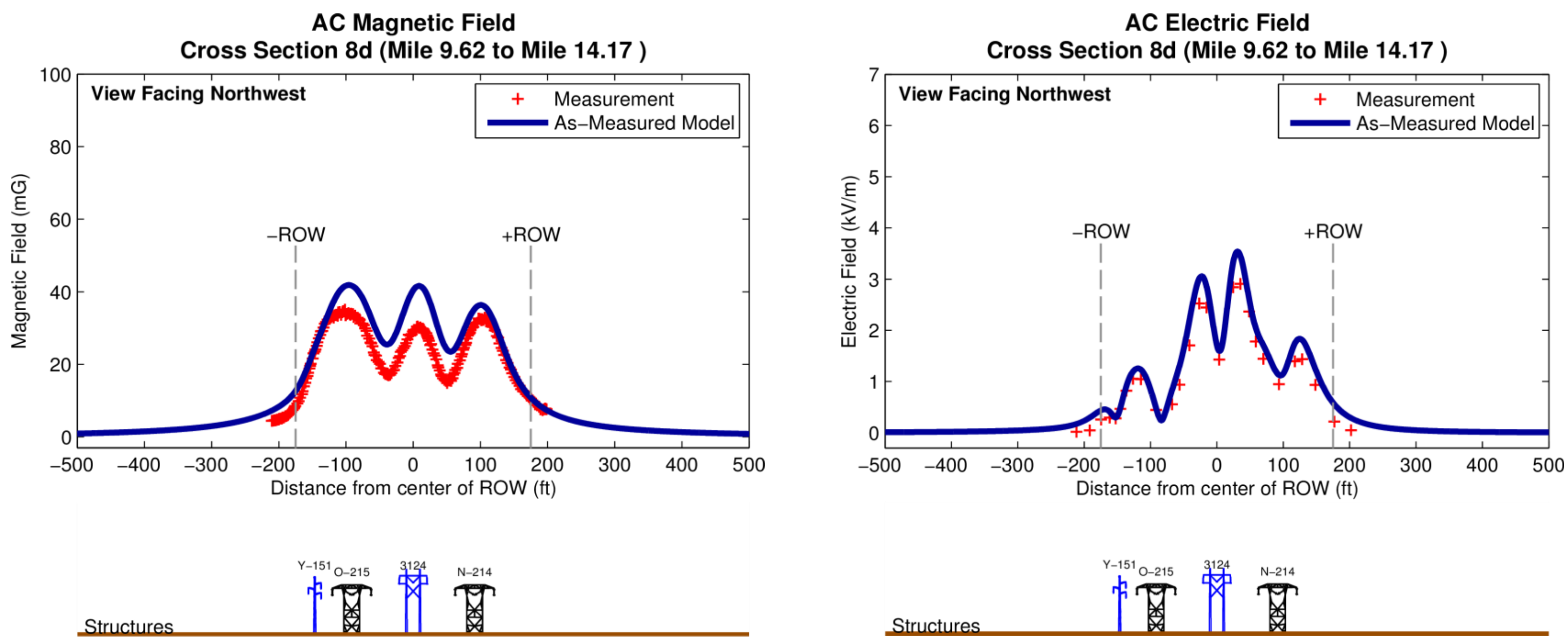


Figure 3. Comparison of measurements at Site 3 (XS-8d) with calculations from the As-Measured Model.

Magnetic-field levels (left graph) and electric field levels (right graph) are shown.

The agreement between the calculated- and measured-field profiles at this location was evaluated by calculating the mean deviation between the measured and calculated magnetic-field values, which was approximately 20% for the magnetic field, with the measured being lower than the calculated magnetic-field levels. This deviation would have been smaller if the modeled values had not been based on conservative assumptions that tend to overestimate the expected field values. The deviation between measured and modeled electric fields is somewhat larger (a mean deviation of 26%), but this also is expected because of the presence of the N-214 structure near the measurement path, as well as the tall trees, particularly at the eastern ROW edge, which reduce the electric field. These figures also serve to demonstrate the conservative nature of the modeling approach with the results showing that the measured EMF levels are consistently similar to, or lower than, the modeled levels.

Other Sites

The degree of match between measurements and modeling at other locations depended on the characteristics of the measurement site and the extent to which each site meets (or does not meet) the selection criteria discussed above. Measurement Sites 2, 4, 5, and 7 (XS-8c, XS-9, XS-10, and XS-12) all had a mean deviation between measurements and modeling of approximately 10% or less. Measurement Sites 1, 8 and 9 (XS-8d, XS-13, and XS-14) had a mean deviation between measurements and modeling of approximately 14 to 16% and Measurement Sites 3 and 6 (XS-8d and XS-11) had a mean deviation of approximately 20 to 21%.[17]

[17] The agreement between post-construction magnetic-field measurements and modeling is overall better than pre-construction comparisons. Pre-construction modeling matched measurements to within 12% at three sites, to within 14 to 22% at five other sites, and was higher at the remaining two sites.

Magnetic-field levels near the ROW edge

In addition to comparing the EMF levels across the ROW, it also is useful to compare the modeled and measured magnetic-field levels at the edges of the ROW. Since it was not always possible to take measurements precisely at the ROW edges due to limited brush and tree clearing or other obstacles, the comparison below uses the measurement that was made closest to the ROW edge and compares that value to the as-built model of the field levels at that same measurement location (often not precisely at the ROW edge).[18] This comparison is shown in a bar graph (Figure 4) in which the measured field level closest to the ROW edge is shown in a blue bar and the modeled field level at the same measurement point closest to the ROW edge is shown by a red bar. Using XS-8d as an example and comparing to Figure 3, it can be seen that on the '–' ROW edge, the measured magnetic-field level of 8.5 mG is lower than the modeled level of 13 mG at the same location. Likewise, on the '+' ROW edge, the measured magnetic-field level of 10 mG is slightly lower than the modeled level of 11 mG.

Comparisons of EMF levels at the edges of the ROW in other sections shows a similar trend, with the measured field level generally similar to or lower than the modeled level. There are a couple of exceptions—for example, the measured magnetic-field level at the '+' ROW edge of Site 8 and Site 10 (XS-13 and XS-15) where one or more distribution line at the ROW edge contributed to measured magnetic fields slightly higher than the modeled levels at these locations. The ROW-edge electric-field levels also are shown, but generally provide less information because the trees ubiquitous at the ROW edges significantly attenuated the electric field at these locations.

Figure 4 also shows that although there are some small deviations between measured and calculated magnetic-field values at a few of the sites, the calculated values are generally higher than the measured EMF levels at the edges of the ROW.

[18] The results presented in Figure 4 therefore differ slightly from those presented in Tables A-1 and A-2 in Appendix A

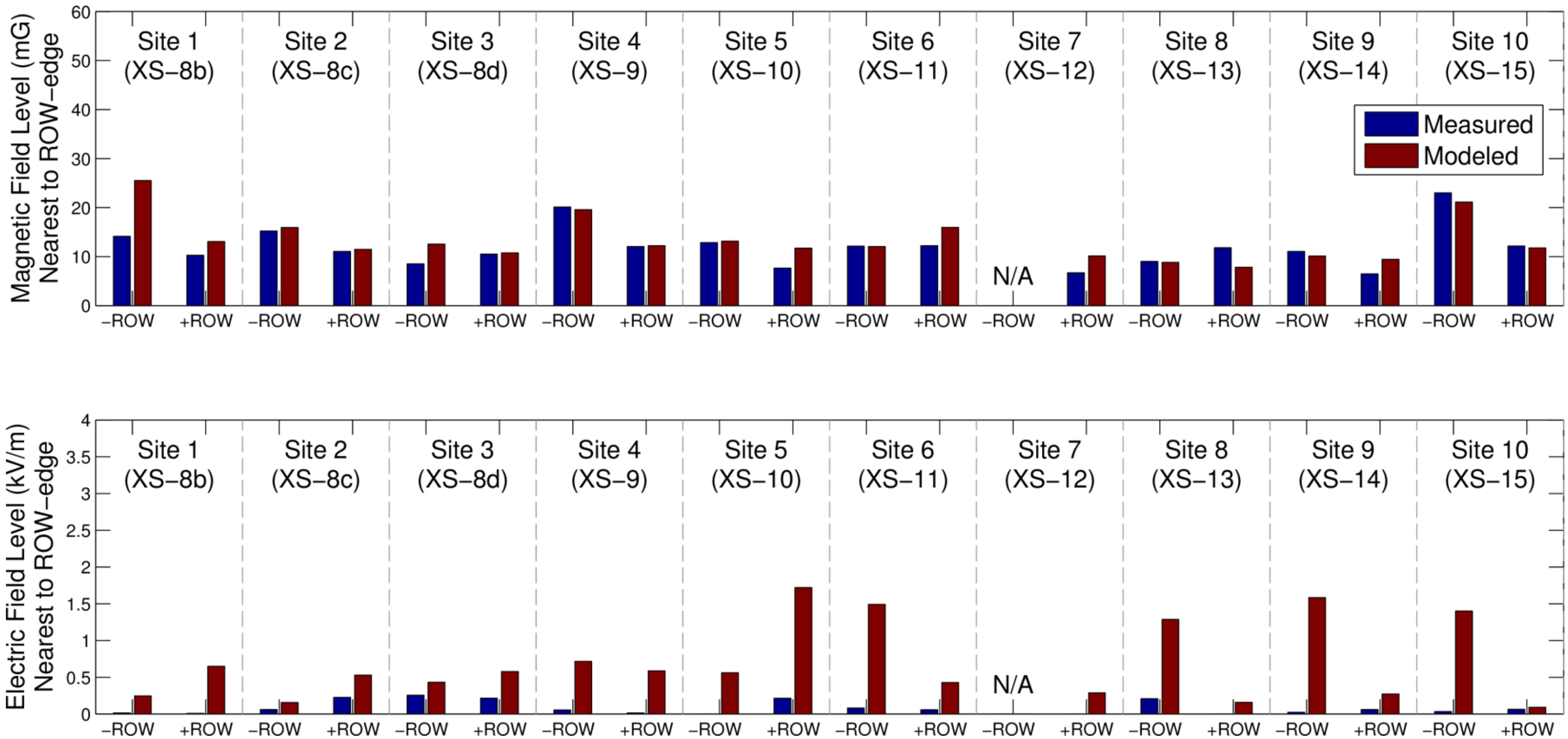


Figure 4. Comparison of measured and modeled EMF levels near the ROW edges.

Agreement between Calculated EMF Levels in the Application to EMF Levels Adjusted for Peak-Loading and Site-Specific Conditions

The calculated EMF levels associated with each of the 10 segments of the project route were provided in the Application for both average- and peak-loading conditions. Direct comparisons of post-construction measurements of magnetic-field levels with calculations in the Application are complicated by differences in power flows on the lines between these periods; however, general comparisons can be made. Comparisons of the measured EMF levels to those presented in the Application are provided in Appendix B where both the As-Measured Model, and the model adjusted for peak loading are presented along with the results from the Application (for peak loading). Each of these models is superimposed on the same graph as measurements for easy visual comparison (Appendix B, with a tabular summary provided in Appendix A) and results indicate that:

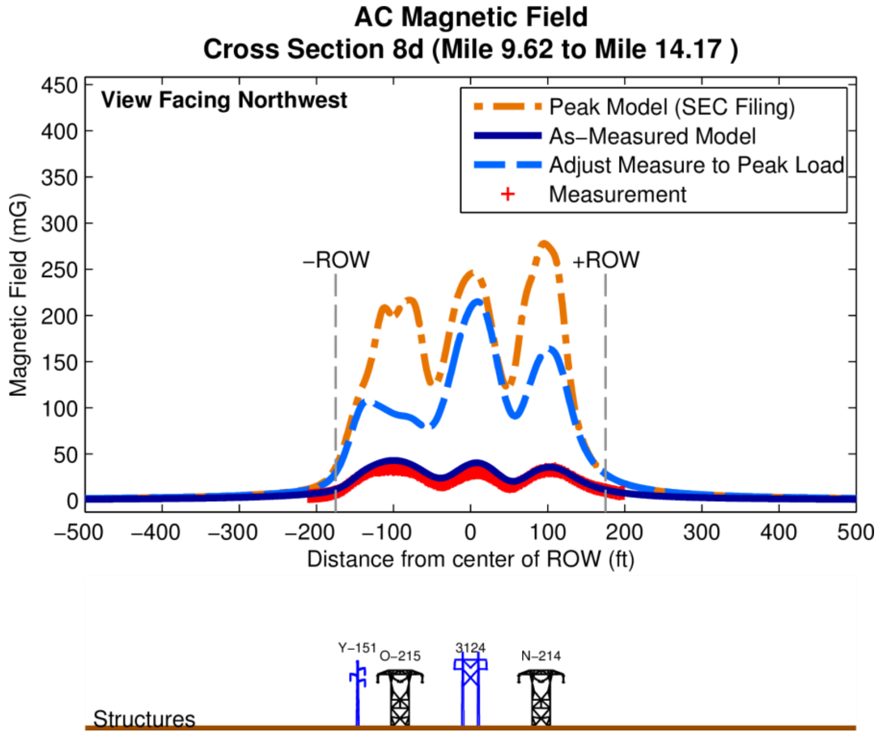
1. Measured electric fields are similar to or lower than values presented in the Application;
2. Measured magnetic fields adjusted to peak loading are similar to or lower than magnetic fields at peak-loading presented in the Application;
3. Measured magnetic fields are generally similar to or lower than calculated magnetic fields at average loading presented in the Application; and
4. Measured fields are lower than calculated magnetic fields primarily because as-measured conductors are generally higher above ground than assumed in the models used to calculate EMF in the Application.

Example Comparison: Site 3, XS-8d

The same example (Site 3 in cross section XS-8d) is presented below in Figure 5, but with results added for the As-Measured – Adjusted Model and the modeling results presented in the Application for pre-construction peak loading—the Peak Model (Appendix AG). Similar results for the remaining sites are presented in Appendix B. In addition to the measured values and the as-measured modeling levels presented in Figure 3, Figure 5 also shows both the field levels for the post-construction, peak-loading scenario evaluated in the Application (dash-dot orange line) as well as the As-Measured Model adjusted for peak loading (shown in the dashed blue line).

As shown in Figure 5, both measured EMF levels as well as EMF levels adjusted for peak loading are lower than the peak-loading levels calculated in the Application. Since the assumed loading for the model adjusted to peak loading is the same as the peak loading in the Application, the difference between the two models is due to the greater heights of the conductors above ground at the measurement sites (approximately 31, 40, 38, and 47 feet for the Y-151, N-214, 3124, and O-215 lines, respectively) than was conservatively assumed in the Application (approximately 31, 32, 35, and 32 feet for the Y-151, N-214, 3124, and O-215 lines, respectively).

Table 2 shows a direct comparison between the measurement and modeling analysis performed in this report, with results from Table A-1 and A-2 in Appendix AG, Attachment A, of the Application. For both electric- and magnetic-field measurements, the table entries “Post-Project AAL [annual average loading]” and “Post-Project annual peak (2023)” correspond to the modeling values previously submitted to the NHSEC. The remaining scenarios: “Measured Field [DATE],” “Modeled Field (for measured line height and load on [DATE]),” and “Modeled Field (for line height and load adjusted to peak conditions)” correspond to values obtained as part of this work. This new work is highlighted in bold for emphasis, both in Table 2 below as well as in Tables A-1 and A-2 of Appendix A of this report. As can be seen from Table 2, the measured EMF levels at the time and date of these measurements were not only below the Post-Project annual peak (2023) loading conditions, but also generally below the annual average-loading conditions. Magnetic-field levels at the ROW edge from the “Modeled Field (for line height and load adjusted to peak conditions)” (28 to 30 mG) are slightly lower than ROW-edge magnetic-field levels previously submitted to the NHSEC for peak loading (28 to 38 mG).



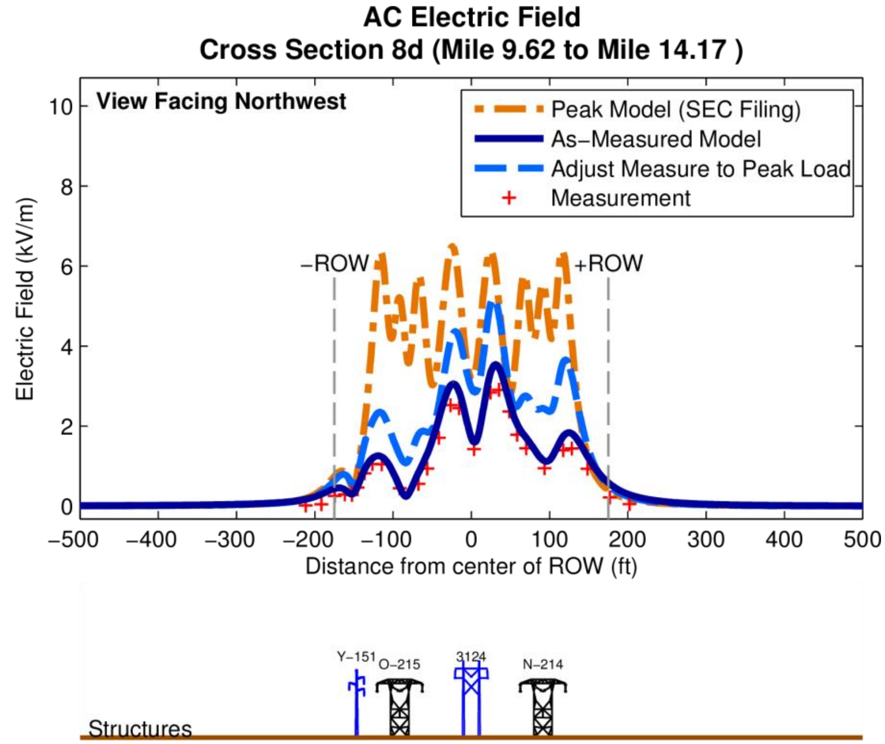


Figure 5. Comparison of measurements at Site 3 (XS-8d) with calculations from the As-Measured Model, the As-Measured – Adjusted to Peak Model, and the calculations (at annual peak loading) provided in the Application.

Magnetic-field levels (left graph) and electric-field levels (right graph) are shown.

Other Sections

Results at other cross sections also show similar trends to those presented here with EMF levels generally similar to, or lower than, those presented in the Application. A graphical summary of the ROW-edge EMF levels is shown in Figure 6 (the figure on the left shows magnetic-field levels and the right side shows electric-field levels). The ROW-edge values reported in the Application[19] are shown on the horizontal axis ("Application Model") and the ROW-edge values calculated in the model adjusted for peak-loading are shown on the vertical axis ("Adjusted Model") with circles representing the –ROW and triangles representing the +ROW. Values above the gray dashed line show where the measured field levels are higher in the Adjusted Model than in the values obtained in the Application Model. Conversely, values below the gray dashed line show locations where the measured values in the Adjusted Model were lower at that site than those in the Application Model.

The results shown in Figure 6 indicate that modeled magnetic-field levels (adjusted to peak conditions) are the same or less than those submitted in the Application. At the –ROW edge of Site 10 (XS-15) the modeled magnetic-field level (adjusted to peak conditions) is slightly greater than that calculated in the Application but the difference is *de minimus* – 1 mG. Modeled electric-field levels (adjusted to peak conditions) are generally similar to those submitted in the application with all small variations within the range of -0.5 to +0.3 kV/m. Complete tables containing similar comparisons for all measured cross sections are presented in Appendix A, Tables A-1 and A-2, with similar graphical comparisons provided in Appendix B.

[19] Some modeling results for cross sections XS-8b and XS-8c were corrected in Supplement Number 2 to Application in which Appendix AG was revised December 23, 2015. The values in Table A-1 and A-2 reflect these corrected values.

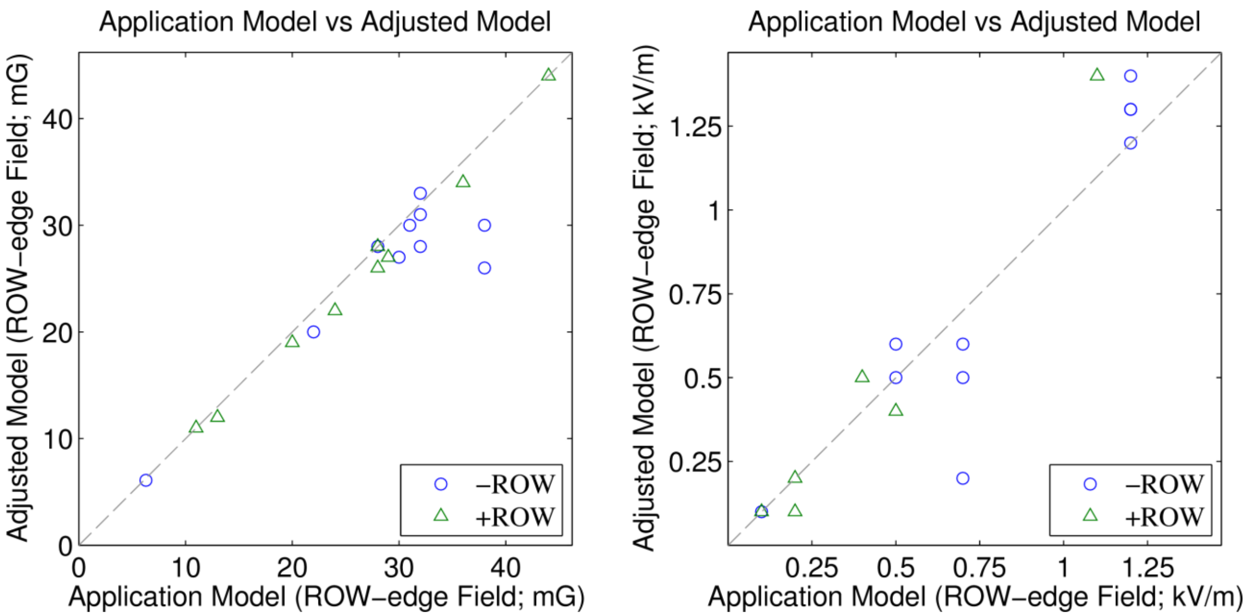


Figure 6. Comparison of modeled EMF levels from the Application (Application Model) and those adjusted to peak conditions (Adjusted Model).

ROW-edge magnetic-field levels (left) and electric-field levels (right).

Table 2. EMF levels measured and modeled in cross section XS-8d

Section Number	Condition	Distance from Centerline of ROW				
		- ROW Edge -100 ft	-ROW Edge	Max on ROW	+ROW Edge	+ROW Edge +100 ft
8d (Magnetic Field)	Post-Project (average line height and load)	2.3	8.5	75	7.4	2.4
	Post-Project (minimum line height and peak load)	6.2	38	281	28	7.4
	Measured Field (July 24, 2018)	**n/a**	**8.5**	**35**	**10**	**n/a**
	Modeled Field (for measured line height and load on July 24, 2018)	**3.7**	**13**	**42**	**11**	**3.1**
	Modeled Field (for line height and load adjusted to peak conditions)	**5.9**	**30**	**215**	**28**	**7.3**
8d (Electric Field)	Post-Project (average line height)	0.1	0.5	4.3	0.5	0.1
	Post-Project (minimum line height)	0.1	0.7	6.5	0.4	<0.1
	Measured Field (July 24, 2018)	**n/a**	**0.3**	**2.9**	**0.2**	**n/a**
	Modeled Field (for measured line height on July 24, 2018)	**0.1**	**0.4**	**3.5**	**0.6**	**0.1**
	Modeled Field (for line height adjusted to peak conditions)	**0.1**	**0.6**	**5.2**	**0.5**	**<0.1**

EMF Measurements at Road Crossings

The sites of road crossing measurements were selected by the PUC. Road crossings are often not suitable for performing detailed measurements and modeling of the EMF levels due to road traffic, line geometry in relation to the road, and other EMF sources along the road. No modeling was performed for these sites due to these factors. As an example, EMF measurements are shown in Figure 7 for the road crossing (PUC 1) at Dutton Road in Pelham. Figure 7 shows that the EMF measurements started outside the ROW edge to the west and progressed along the north side of Dutton Road to beyond the eastern ROW edge. Red dots on the aerial photograph show the locations where the transmission line conductors crossed the road and at each of these locations the recorded electric-field level (shown in green) and magnetic-field level (shown in orange) is superimposed on the image as a quick reference summarizing the measured levels. The full data captured at the first road crossing site are shown in Figure 8. The figure shows the recorded magnetic-field level and electric-field level, measured with distance along the measurement path. Magnetic-field measurements were recorded every 1 to 3 feet and so are shown as a continuous line. In contrast, electric-field measurements were recorded approximately every 5 to 30 feet, so measurements are indicated by a white square and connected by dashed lines for visual reference. In addition, each of these figures also includes red dots indicating the location where the measurement path crossed beneath the three conductors of each transmission line. Similar figures for each road crossing are also included in Appendix E.

These results show that the measured EMF levels measured on the PUC-selected road crossings are generally similar to or lower than those previously reported in the Application for pre-construction conditions of the respective cross section and are far below health-based standards and guidelines for human exposure to EMF that were discussed in the Application.

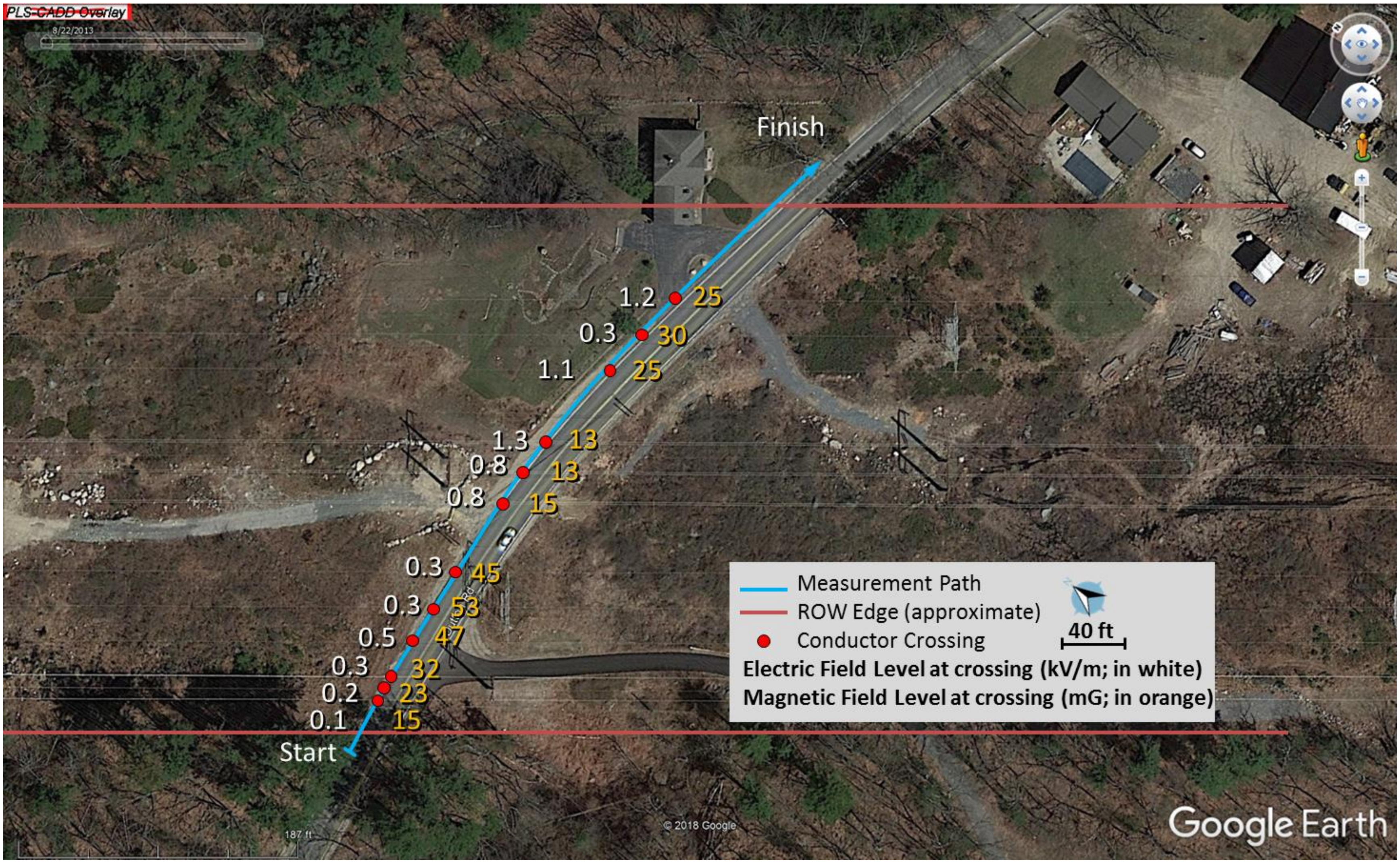
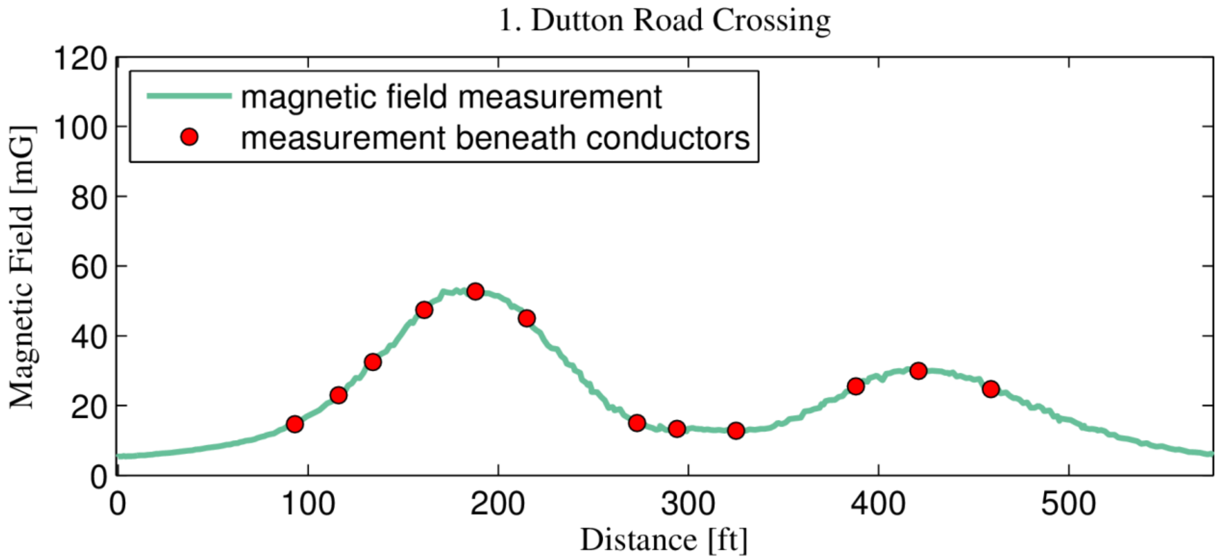


Figure 7. PUC Road Crossing 1: Dutton Road in Pelham.



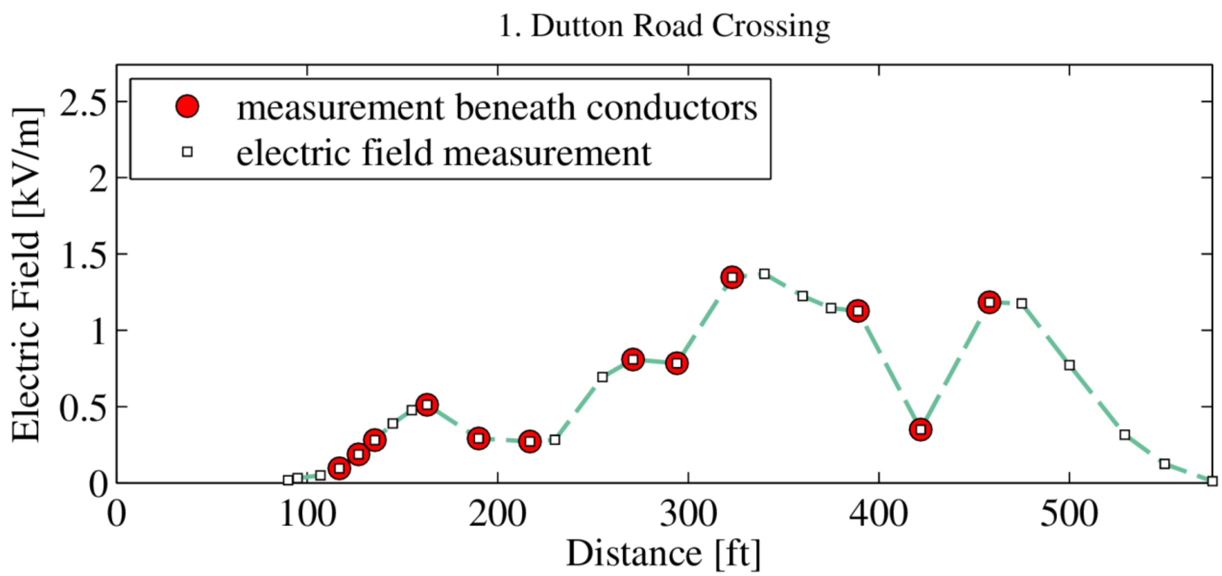


Figure 8. Detailed EMF measurement results recorded at PUC Road Crossing 1: Dutton Road in Pelham on July 24, 2018.

Conclusion

The measurements and analysis in this report were performed to comply with the NHSEC Order issued October 4, 2016, and amended November 29, 2016, to provide measured actual electric- and magnetic-field levels along the route of the MVRP. The measurement sites were determined in consultation with the PUC and were selected to be in locations and at the distances as near as possible to those identified in Tables A-1 and A-2 in Appendix AG, Attachment A, of the Application. All measurements discussed herein were performed under conditions as near as possible to conditions assumed for the post-construction configurations in the original modeling.

Measured magnetic-field levels were very similar to or lower than modeled levels and measured electric-field levels were consistently lower than modeled levels due to the shielding effect of trees, brush, terrain, and structures found on the ROW and beyond.

A comparison of the values calculated from the As-Measured – Adjusted to Peak Model to those provided in the Application at peak loading also show that the EMF levels from the transmission lines on the Project route are similar to, or lower than, those presented for post-construction conditions in the Application. The lower EMF values are primarily due to higher conductor heights at the measurement sites compared to those conservatively assumed in the Application.

The measured EMF levels are generally similar to, or lower than, those calculated from models because of the conservative assumptions used in the modeling, which are designed to ensure that reported field levels represent high but accurate estimates of the field levels being modeled. The differences observed between the measured and calculated profiles can be attributed to simplifications present in the modeling, such as the assumption of level terrain, longitudinally uniform geometry, the lack of induced currents in shieldwires, and the presence of conductive objects on and adjacent to the ROW that serve to reduce electric-field levels.

Measured and calculated EMF levels at all locations on the Project route are far below health-based standards and guidelines developed by the International Commission on Non-Ionizing Radiation Protection and the International Committee for Electromagnetic Safety and were found to be below levels that would cause exceedance of Basic Restrictions on public exposure discussed in the Application.[20] In addition, the demonstrated agreement between modeling and measurements confirmed the reasonableness of the input data used to model EMF from the transmission lines and accuracy of the modeling approach followed in the Application.

[20] 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: 818-36, 2010; 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; Reaffirmed 2007.

Appendix A

Summary Tables of Measured and Calculated EMF Levels

For both electric- and magnetic-field measurements, scenarios 1 and 2 (“Post-Project” configurations) correspond to the modeling values previously submitted to the NHSEC as part of the original Application or subsequently filed with the NHSEC. Scenarios 3 through 5 correspond to new analyses performed as part of this work. This new work is highlighted in bold for emphasis, both in the list below as well as in the following tables.

- Electric-field levels are presented for five scenarios:
    1. Post-Project (average line height)
    2. Post-Project (minimum line height)
    3. **Measured Field ([DATE])**
    4. **Modeled Field (for measured line height on [DATE])**
    5. **Modeled Field (for line height adjusted to peak conditions)**
- Magnetic-field levels are presented for five scenarios:
    1. Post-Project (average line height and load)
    2. Post-Project (minimum line height and 2023 peak load)
    3. **Measured Field ([DATE])**
    4. **Modeled Field (for measured line height and load on [DATE])**
    5. **Modeled Field (for line height and load adjusted to peak conditions)**

For the measurements summarized below, results are typically provided at the ‘–’ ROW edge, the maximum measured value, as well as the ‘+’ ROW edge. Measurements were not performed at a distance of ±100 feet from the ROW edge (as provided in the calculations). These entries are therefore entered as n/a to indicate that no measurement was performed at these locations. In addition, there were some locations (XS-12) where was not possible to measure electric- and magnetic-field levels near the ROW edge. For these locations, n/a is also used to indicate the lack of measurements.

Table A-1. Measured and calculated magnetic-field levels (mG)

Section Number	Condition	Distance from Centerline of ROW: - ROW Edge -100 ft	-ROW Edge*	Max on ROW	+ROW Edge*	+ROW Edge +100 ft
8b	Post-Project (average line height and load)	2.4	7.5†	75	7.4	2.4
	Post-Project (minimum line height and peak load)	6.1†	30†	281	28	7.4
	Measured Field (July 27, 2018)	**n/a**	**14**	**91**	**10**	**n/a**
	Modeled Field (for measured line height and load on July 27, 2018)	**5.0**	**22**	**107**	**12**	**3.7**
	Modeled Field (for line height and load adjusted to peak conditions)	**6.1**	**27**	**275**	**26**	**7.3**
8c	Post-Project (average line height and load)	2.3	8.5†	75	7.4	2.4
	Post-Project (minimum line height and peak load)	6.1†	38†	281	28	7.4
	Measured Field (July 27, 2018)	**n/a**	**15**	**63**	**11**	**n/a**
	Modeled Field (for measured line height and load on July 27, 2018)	**4.3**	**16**	**70**	**11**	**3.4**
	Modeled Field (for line height and load adjusted to peak conditions)	**5.9**	**26**	**164**	**26**	**7.1**
8d	Post-Project (average line height and load)	2.3	8.5	75	7.4	2.4
	Post-Project (minimum line height and peak load)	6.2	38	281	28	7.4
	Measured Field (July 24, 2018)	**n/a**	**8.5**	**35**	**10**	**n/a**
	Modeled Field (for measured line height and load on July 24, 2018)	**3.7**	**13**	**42**	**11**	**3.1**
	Modeled Field (for line height and load adjusted to peak conditions)	**5.9**	**30**	**215**	**28**	**7.3**
9	Post-Project (average line height and load)	2.6	8.6	75	7.4	2.4
	Post-Project (minimum line height and peak load)	7.5	28	280	29	7.6
	Measured Field (July 29, 2018)	**n/a**	**20**	**66**	**12**	**n/a**
	Modeled Field (for measured line height and load on July 29, 2018)	**4.4**	**18**	**70**	**12**	**3.3**
	Modeled Field (for line height and load adjusted to peak conditions)	**7.7**	**28**	**191**	**27**	**7.4**
10	Post-Project (average line height and load)	1.2	5.8	124	14	2.1
	Post-Project (minimum line height and peak load)	5.4	22	306	44	9.2
	Measured Field (July 27, 2018)	**n/a**	**13**	**50**	**7.6**	**n/a**
	Modeled Field (for measured line height and load on July 27, 2018)	**3.6**	**13**	**50**	**10**	**3.3**
	Modeled Field (for line height and load adjusted to peak conditions)	**5.3**	**20**	**209**	**44**	**9.5**

Section Number	Condition	Distance from Centerline of ROW: - ROW Edge -100 ft	-ROW Edge*	Max on ROW	+ROW Edge*	+ROW Edge +100 ft
11	Post-Project (average line height and load)	5.6	23	119	11	1.3
	Post-Project (minimum line height and peak load)	6.1	31	316	36	5.1
	Measured Field (July 30, 2018)	**n/a**	**12**	**54**	**12**	**n/a**
	Modeled Field (for measured line height and load on July 30, 2018)	**1.7**	**10**	**60**	**13**	**2.6**
	Modeled Field (for line height and load adjusted to peak conditions)	**6.4**	**30**	**152**	**34**	**5.5**
12	Post-Project (average line height and load)	2.4	5.6	120	4.7	0.9
	Post-Project (minimum line height and peak load)	2.4	6.3	316	11	2.7
	Measured Field (July 28, 2018)	**n/a**	**n/a**	**77**	**6.7**	**n/a**
	Modeled Field (for measured line height and load on July 28, 2018)	**0.3**	**1.2**	**90**	**5.5**	**1.6**
	Modeled Field (for line height and load adjusted to peak conditions)	**2.3**	**6.1**	**254**	**11**	**2.8**
13	Post-Project (average line height and load)	5.6	24	120	13	1.2
	Post-Project (minimum line height and peak load)	6.0	32	313	24	4.2
	Measured Field (July 29, 2018)	**n/a**	**9.0**	**67**	**12**	**n/a**
	Modeled Field (for measured line height and load on July 29, 2018)	**1.0**	**8.8**	**75**	**7.5**	**1.3**
	Modeled Field (for line height and load adjusted to peak conditions)	**6.0**	**31**	**202**	**22**	**4.3**
14	Post-Project (average line height and load)	5.7	24	120	4.5	1.0
	Post-Project (minimum line height and peak load)	6.1	32	313	13	3.4
	Measured Field (July 28, 2018)	**n/a**	**11**	**55**	**6.5**	**n/a**
	Modeled Field (for measured line height and load on July 29, 2018)	**0.9**	**7.7**	**60**	**5.6**	**1.8**
	Modeled Field (for line height and load adjusted to peak conditions)	**6.1**	**28**	**201**	**12**	**3.3**
15	Post-Project (average line height and load)	5.6	24	120	9.1	1.1
	Post-Project (minimum line height and peak load)	6.0	32	313	20	4.0
	Measured Field (July 30, 2018)	**n/a**	**23**	**77**	**12**	**n/a**
	Modeled Field (for measured line height and load on July 30, 2018)	**4.1**	**21**	**89**	**12**	**2.4**
	Modeled Field (for line height and load adjusted to peak conditions)	**7.0**	**33**	**149**	**19**	**5.1**

* The ROW edge was not accessible at all measurement sites. Reported *measurement* values in the –ROW and +ROW columns are those from the closest measurement possible to the respective ROW edge. In Section 12 the –ROW edge is 100 feet past where the ROW has been cleared so no measurement was reported at this location.

† The values submitted in the Application were later corrected as part of Supplemental response #2 in Appendix AG, revised December 23, 2015. The corrected values are used here.

Table A-2. Electric-field levels (kV/m) at average and minimum conductor height

Section Number	Condition	Distance from Centerline of ROW: -ROW Edge -100 ft	-ROW Edge*	Max on ROW	+ROW Edge*	+ROW Edge -100 ft
8b	Post-Project (average line height)	0.1	0.5†	4.3	0.5	0.1
	Post-Project (minimum line height)	0.1	0.7†	6.5	0.4	<0.1
	Measured Field (July 27, 2018)	**n/a**	**<0.1**	**2.5**	**<0.1**	**n/a**
	Modeled Field (for measured line height on July 27, 2018)	**0.1**	**0.3**	**3.1**	**0.6**	**0.1**
	Modeled Field (for line height adjusted to peak conditions)	**<0.1**	**0.5**	**8.9**	**0.5**	**0.1**
8c	Post-Project (average line height)	0.1	0.5†	4.3	0.5	0.1
	Post-Project (minimum line height)	0.1	0.7†	6.5	0.4	<0.1
	Measured Field (July 27, 2018)	**n/a**	**0.1**	**2.1**	**0.2**	**n/a**
	Modeled Field (for measured line height on July 27, 2018)	**<0.1**	**0.2**	**2.6**	**0.5**	**0.1**
	Modeled Field (for line height adjusted to peak conditions)	**<0.1**	**0.2**	**4.2**	**0.5**	**0.1**
8d	Post-Project (average line height)	0.1	0.5	4.3	0.5	0.1
	Post-Project (minimum line height)	0.1	0.7	6.5	0.4	<0.1
	Measured Field (July 24, 2018)	**n/a**	**0.3**	**2.9**	**0.2**	**n/a**
	Modeled Field (for measured line height on July 24, 2018)	**0.1**	**0.4**	**3.5**	**0.6**	**0.1**
	Modeled Field (for line height adjusted to peak conditions)	**0.1**	**0.6**	**5.2**	**0.5**	**<0.1**
9	Post-Project (average line height)	0.1	0.6	4.3	0.5	0.1
	Post-Project (minimum line height)	0.1	0.5	6.5	0.4	<0.1
	Measured Field (July 29, 2018)	**n/a**	**0.1**	**1.4**	**<0.1**	**n/a**
	Modeled Field (for measured line height on July 29, 2018)	**0.1**	**0.6**	**2.1**	**0.6**	**0.1**
	Modeled Field (for line height adjusted to peak conditions)	**0.1**	**0.6**	**4.1**	**0.5**	**0.1**
10	Post-Project (average line height)	0.1	0.6	6.6	1.2	0.1
	Post-Project (minimum line height)	0.1	0.5	8.5	1.1	0.1
	Measured Field (July 27, 2018)	**n/a**	**<0.1**	**4.4**	**0.2**	**n/a**
	Modeled Field (for measured line height on July 27, 2018)	**0.1**	**0.6**	**5.6**	**1.4**	**0.2**
	Modeled Field (for line height adjusted to peak conditions)	**0.1**	**0.5**	**7.1**	**1.4**	**0.2**

Section Number	Condition	Distance from Centerline of ROW: -ROW Edge -100 ft	-ROW Edge*	Max on ROW	+ROW Edge*	+ROW Edge -100 ft
11	Post-Project (average line height)	0.2	1.2	6.6	0.4	<0.1
	Post-Project (minimum line height)	0.1	1.2	8.6	0.5	<0.1
	Measured Field (July 30, 2018)	**n/a**	**0.1**	**3.7**	**0.1**	**n/a**
	Modeled Field (for measured line height on July 30, 2018)	**0.2**	**1.3**	**4.3**	**0.4**	**<0.1**
	Modeled Field (for line height adjusted to peak conditions)	**0.2**	**1.3**	**5.3**	**0.4**	**<0.1**
12	Post-Project (average line height)	0.1	0.2	6.6	0.2	<0.1
	Post-Project (minimum line height)	0.0	0.1	8.6	0.2	<0.1
	Measured Field (July 28, 2018)	**n/a**	**<0.1**	**4.1**	**<0.1**	**n/a**
	Modeled Field (for measured line height on July 28, 2018)	**<0.1**	**0.2**	**6.4**	**0.1**	**<0.1**
	Modeled Field (for line height adjusted to peak conditions)	**<0.1**	**0.1**	**8.6**	**0.1**	**<0.1**
13	Post-Project (average line height)	0.2	1.3	6.6	0.2	<0.1
	Post-Project (minimum line height)	0.1	1.2	8.6	0.2	<0.1
	Measured Field (July 29, 2018)	**n/a**	**0.2**	**3.7**	**<0.1**	**n/a**
	Modeled Field (for measured line height on July 29, 2018)	**0.2**	**1.3**	**4.7**	**0.2**	**<0.1**
	Modeled Field (for line height adjusted to peak conditions)	**0.2**	**1.2**	**6.6**	**0.2**	**<0.1**
14	Post-Project (average line height)	0.2	1.3	6.6	0.1	<0.1
	Post-Project (minimum line height)	0.1	1.2	8.6	0.1	<0.1
	Measured Field (July 28, 2018)	**n/a**	**<0.1**	**4.3**	**0.1**	**n/a**
	Modeled Field (for measured line height on July 28, 2018)	**0.2**	**1.3**	**5.3**	**0.1**	**<0.1**
	Modeled Field (for line height adjusted to peak conditions)	**0.2**	**1.3**	**6.5**	**0.1**	**<0.1**
15	Post-Project (average line height)	0.2	1.3	6.6	0.1	<0.1
	Post-Project (minimum line height)	0.1	1.2	8.6	0.1	<0.1
	Measured Field (July 30, 2018)	**n/a**	**<0.1**	**2.8**	**0.1**	**n/a**
	Modeled Field (for measured line height on July 30, 2018)	**0.2**	**1.4**	**4.1**	**0.1**	**<0.1**
	Modeled Field (for line height adjusted to peak conditions)	**0.2**	**1.4**	**5.0**	**0.1**	**<0.1**

* The ROW edge was not accessible at all measurement sites. Reported *measurement* values in the –ROW and +ROW columns are those from the closest measurement possible to the respective ROW edge. In Section 12 the –ROW edge is 100 feet past where the ROW has been cleared so no measurement was reported at this location.

† The values submitted in the Application were later corrected as part of Supplemental response #2 in Appendix AG, revised December 23, 2015. The corrected values are used here.

Appendix B

Graphical Profiles of Measured and Calculated EMF Levels at Cross Section Sites

A comparison of the modeling results and measurements was summarized in the body of the report. This Appendix provides a detailed analysis of the measurements and comparison with ‘as-measured’ and ‘original’ models for each individual measurement location.

Results for each of the 10 measurement sites are presented below. Both electric fields and magnetic fields were measured at each site. For each measurement site, an aerial photograph showing the location of the ROW edges and measurement locations is included in Appendix C.

Electric- and magnetic-field levels are presented in separate figures. In each of these figures actual measurement values are shown by a series of red ‘+’ markers. Magnetic-field levels were measured every 1 to 3 feet using a survey wheel in conjunction with the magnetic-field meter. The series of ‘+’ markers sometimes appear as a thick, jagged line due to the density of measurements. In contrast, electric-field measurements were performed at individual measurement locations separated by approximately 5 to 30 feet and so generally appear as discrete ‘+’ symbols indicating the measured value. In each figure, three separate models are included. An orange ‘dash-dot’ line shows the peak-loading model submitted in the Application, a solid dark blue line shows the model developed using the As-Measured configuration (and loading) at the time of measurements, a dashed light blue line shows the model developed by adjusting the As-Measured Model to peak loading conditions, while individual measurements are shown in corresponding ‘+’ markers. Table B-1 summarizes the date each measurement was performed and reproduces Table 1 from the body of the report with the site evaluation criteria for reference.

Table B-1. EMF measurement sites, measurement dates and times, and site selection criteria

Measurement Site	Cross Section Number	Measurement Date	Approximate Measurement Time	Site Evaluation Criteria*			
				Flat Terrain (no slope)	Smooth Terrain (smooth/rough)	Free of Trees/Underbrush	Perpendicular to ROW
1	XS-8b	27-Jul-18	17:45 to 19:45	2	2	3	3
2	XS-8c	27-Jul-18	15:45 to 17:45	3	3	3	2
3	XS-8d	24-Jul-18	17:15 to 19:30	1	3	3	3
4	XS-9	29-Jul-18	11:15 to 14:00	2	2	3	3
5	XS-10	27-Jul-18	11:00 to 14:30	2	2	2	3
6	XS-11	30-Jul-18	15:00 to 20:00	2	2	2	3
7	XS-12	28-Jul-18	14:00 to 17:15	2	1	2	3
8	XS-13	29-Jul-18	14:30 to 19:45	1	3	2	3
9	XS-14	28-Jul-18	10:00 to 13:00	1	1	2	3
10	XS-15	30-Jul-18	09:00 to 13:00	3	3	2	1
PUC 1	XS-8b	24-Jul-18	11:15 to 14:25	n/a	n/a	n/a	n/a
PUC 2	XS-8d	25-Jul-18	10:30 to 13:30	n/a	n/a	n/a	n/a
PUC 3	XS-8d	29-Jul-18	08:45 to 11:15	n/a	n/a	n/a	n/a
PUC 4	XS-10	27-Jul-18	08:00 to 10:30	n/a	n/a	n/a	n/a
PUC 5	XS-11	25-Jul-18	16:30 to 19:30	n/a	n/a	n/a	n/a
PUC 6	XS-11	28-Jul-18	17:15 to 20:45	n/a	n/a	n/a	n/a

*Cells highlighted in red, yellow and green indicate a criterion grade of poor, average, and good, respectively.

Site 1

Measurements at Site 1 (cross section XS-8b) were performed on July 27, 2018. A graphical summary of results are presented below.

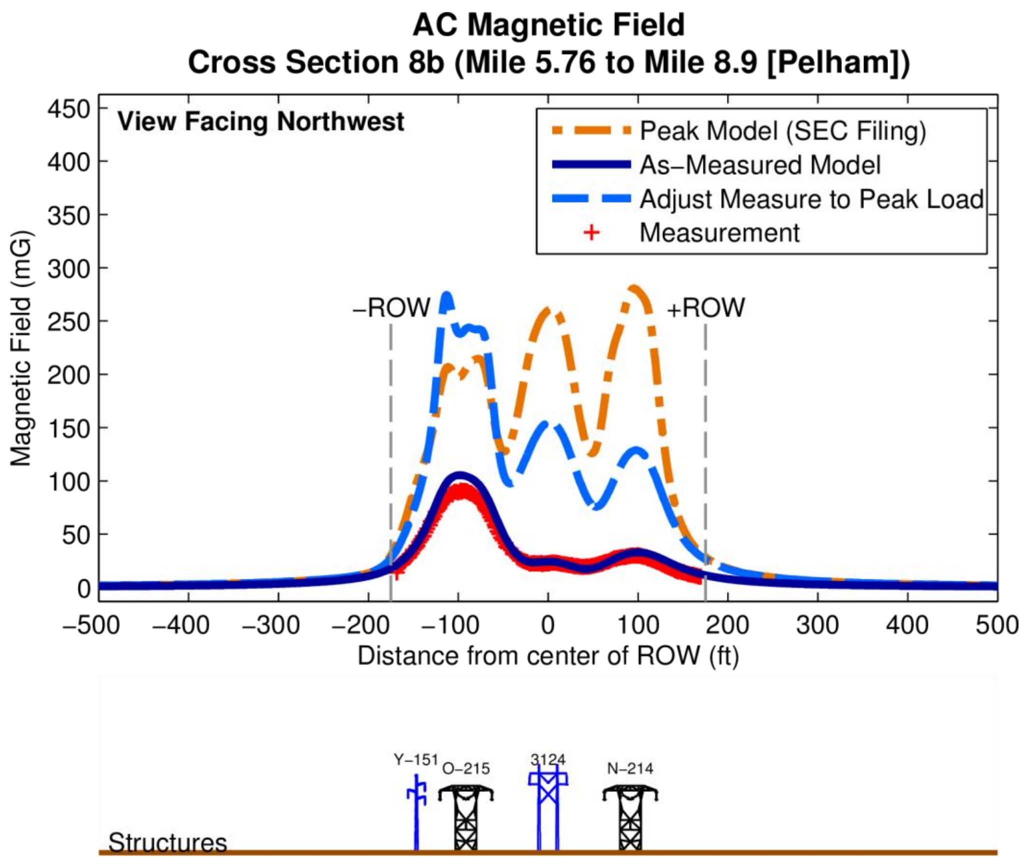


Figure B-1. Measured and modeled magnetic-field levels at Site 1 in XS-8b.

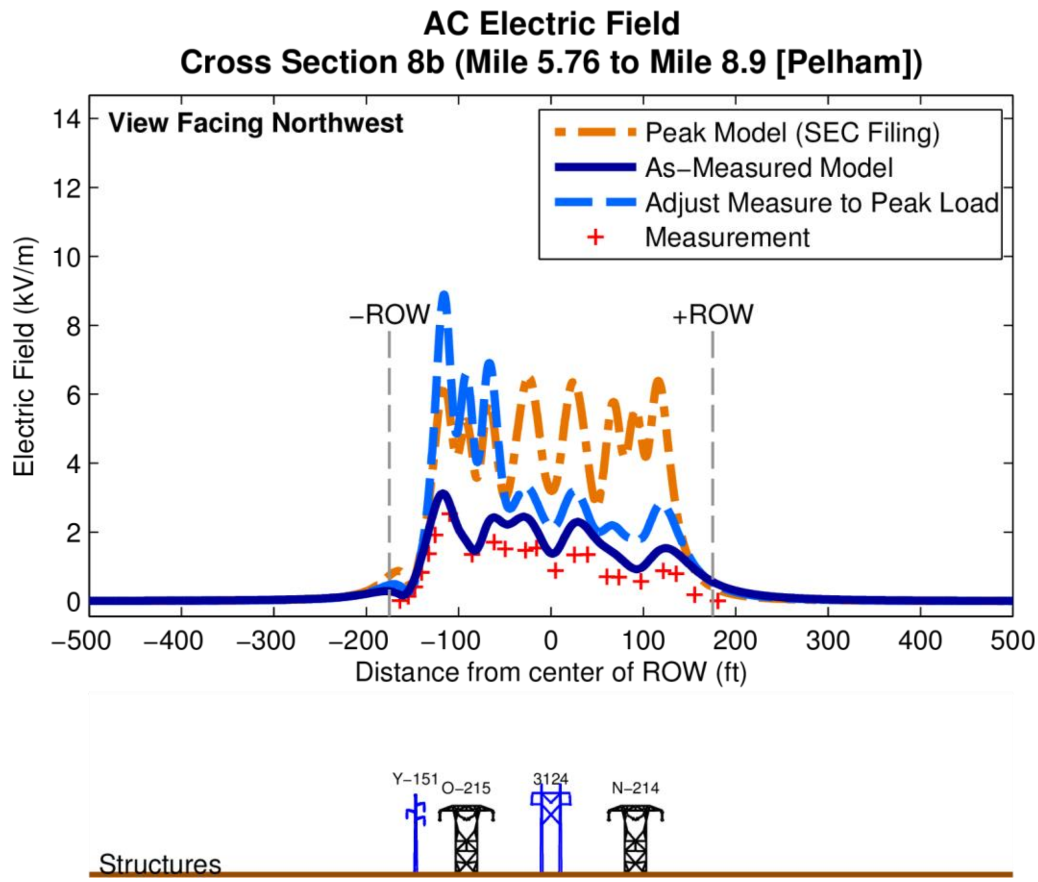


Figure B-2. Measured and modeled electric-field levels at Site 1 in XS-8b.

Site 2

Measurements at Site 2 (cross section XS-8c) were performed on July 27, 2018. A graphical summary of results are presented below.

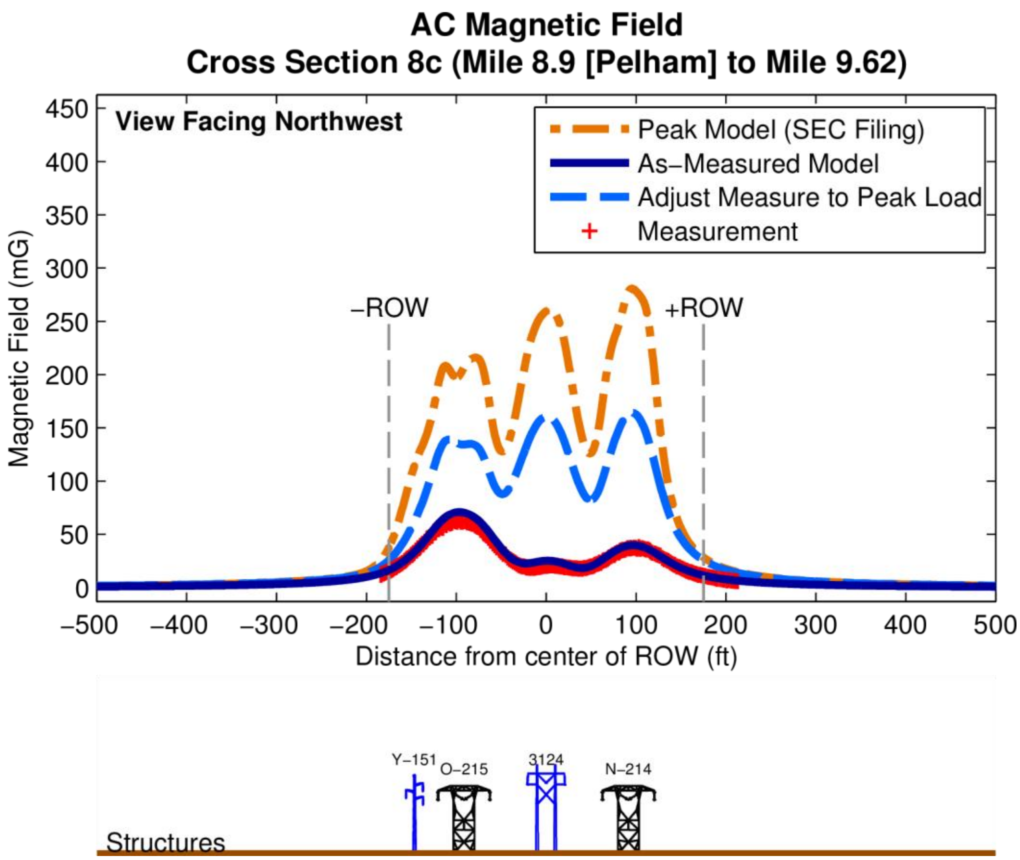


Figure B-3. Measured and modeled magnetic-field levels at Site 2 in XS-8c.

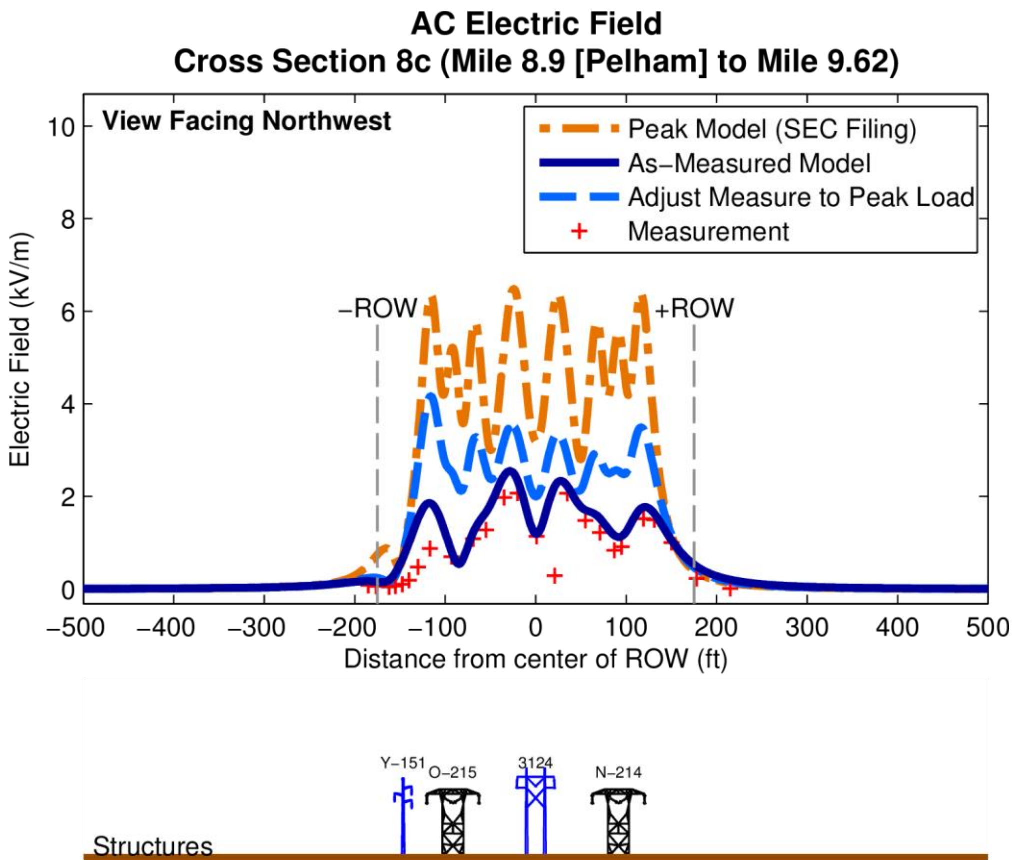


Figure B-4. Measured and modeled electric-field levels at Site 2 in XS-8c.

Site 3

Measurements at Site 3 (cross section XS-8d) were performed on July 24, 2018. A graphical summary of results are presented below.

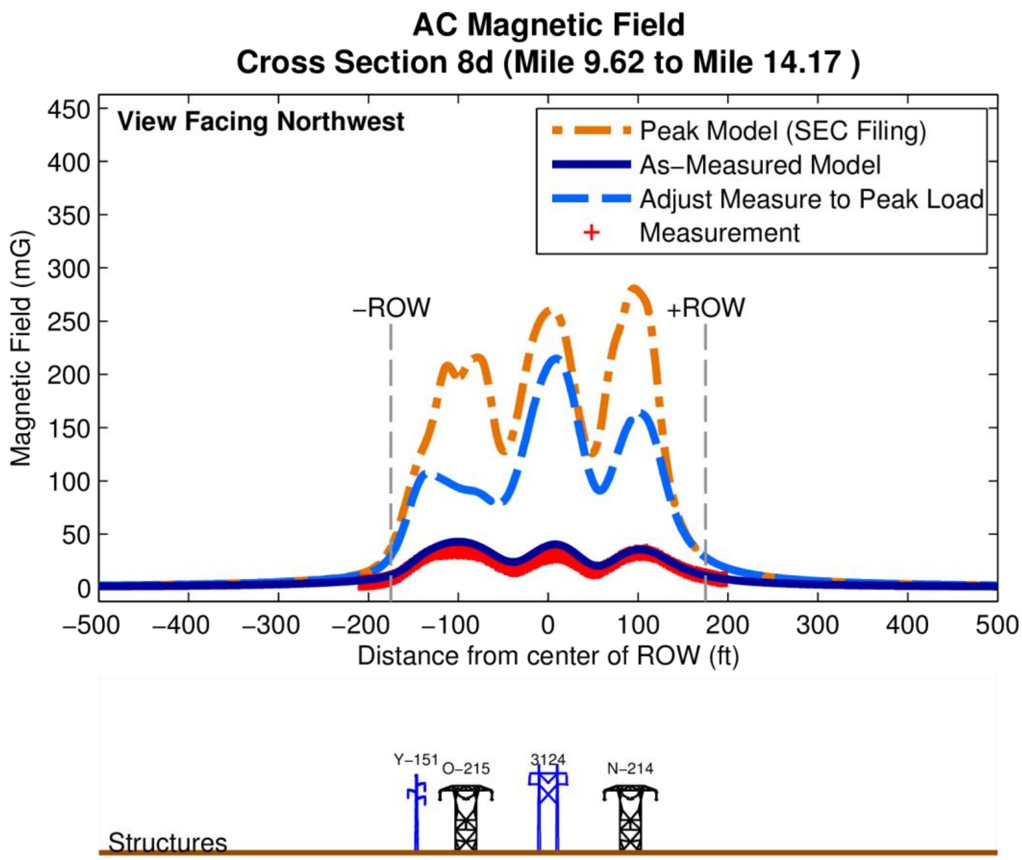


Figure B-5. Measured and modeled magnetic-field levels at Site 3 in XS-8d.

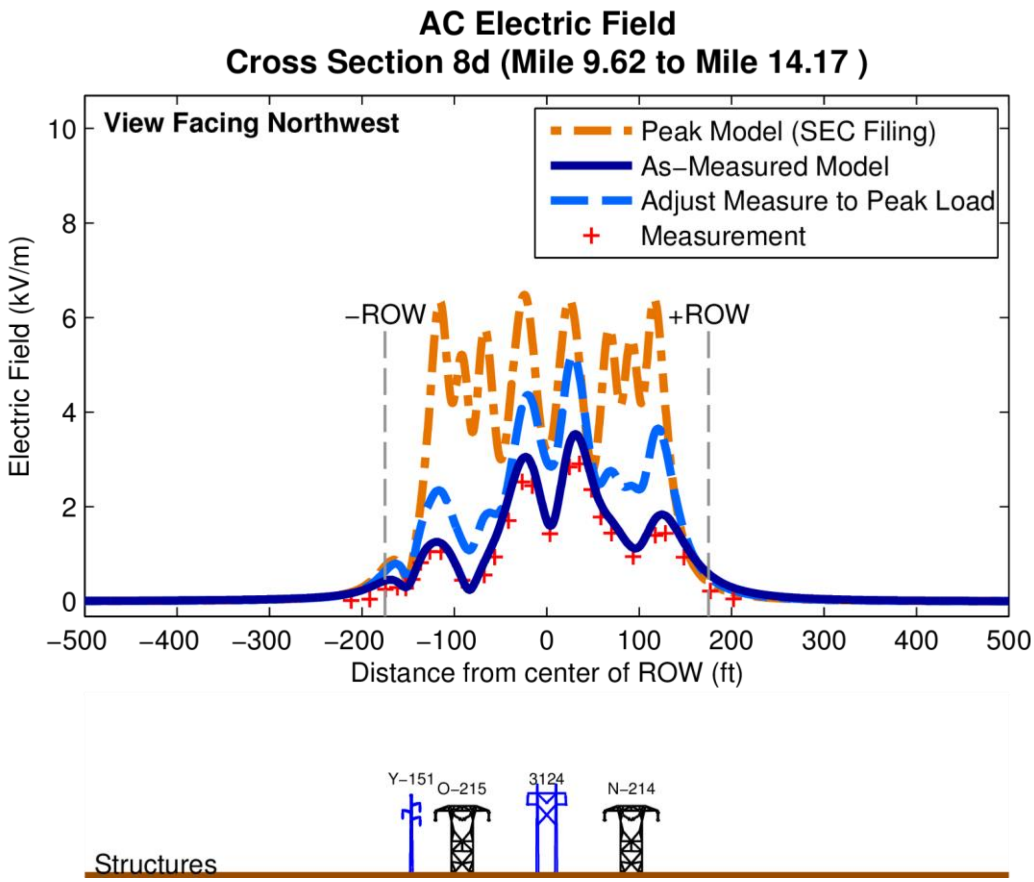


Figure B-6. Measured and modeled electric-field levels at Site 3 in XS-8d.

Site 4

Measurements at Site 4 (cross section XS-9) were performed on July 29, 2018. A graphical summary of results are presented below.

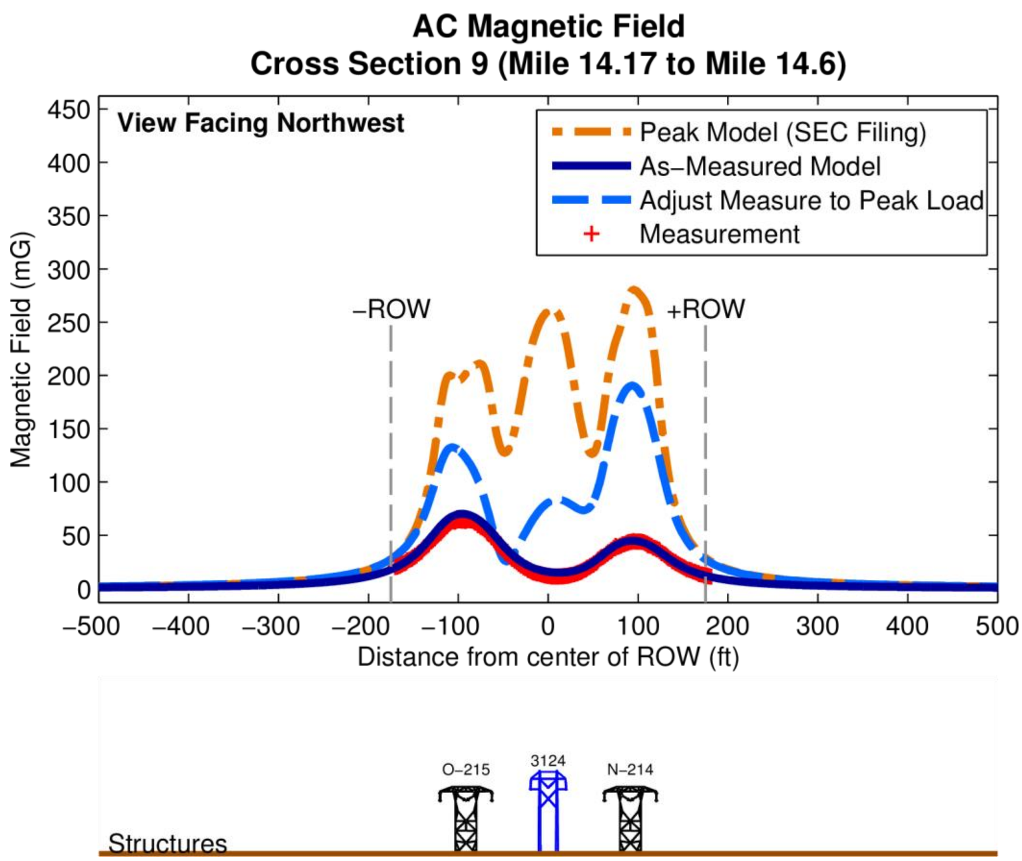


Figure B-7. Measured and modeled magnetic-field levels at Site 4 in XS-9.

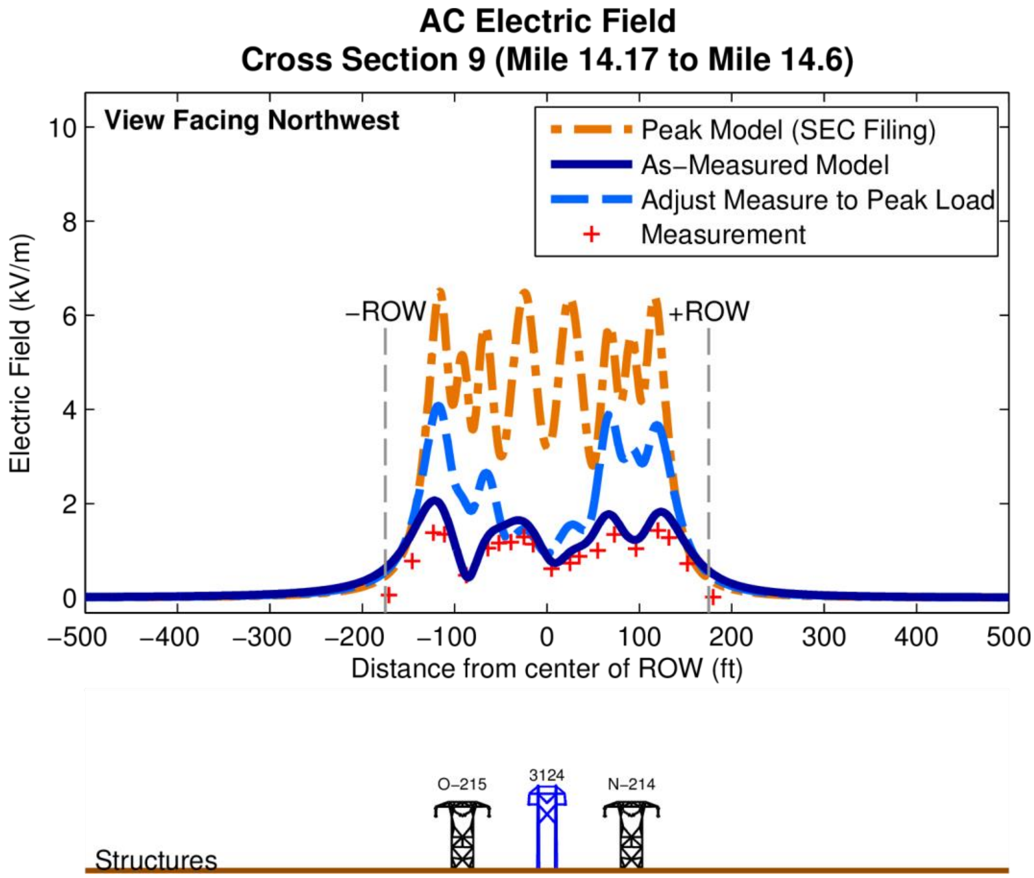


Figure B-8. Measured and modeled electric-field levels at Site 4 in XS-9.

Site 5

Measurements at Site 5 (cross section XS-10) were performed on July 27, 2018. A graphical summary of results are presented below.

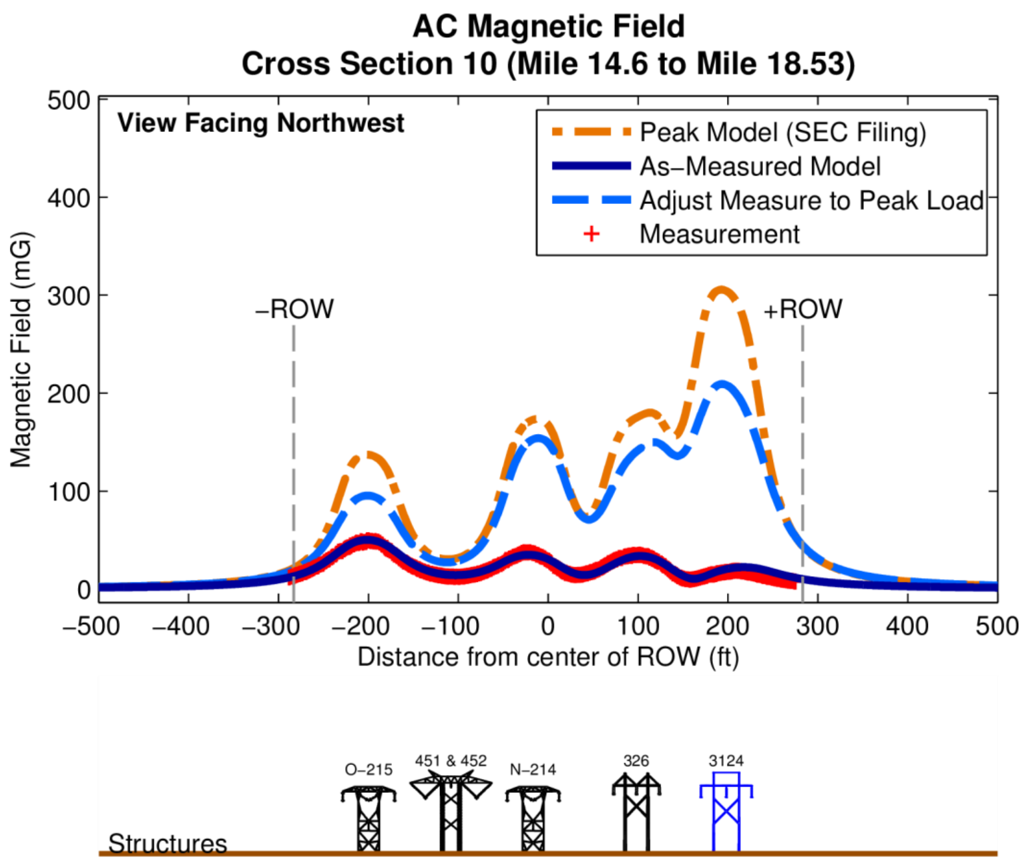


Figure B-9. Measured and modeled magnetic-field levels at Site 5 in XS-10.

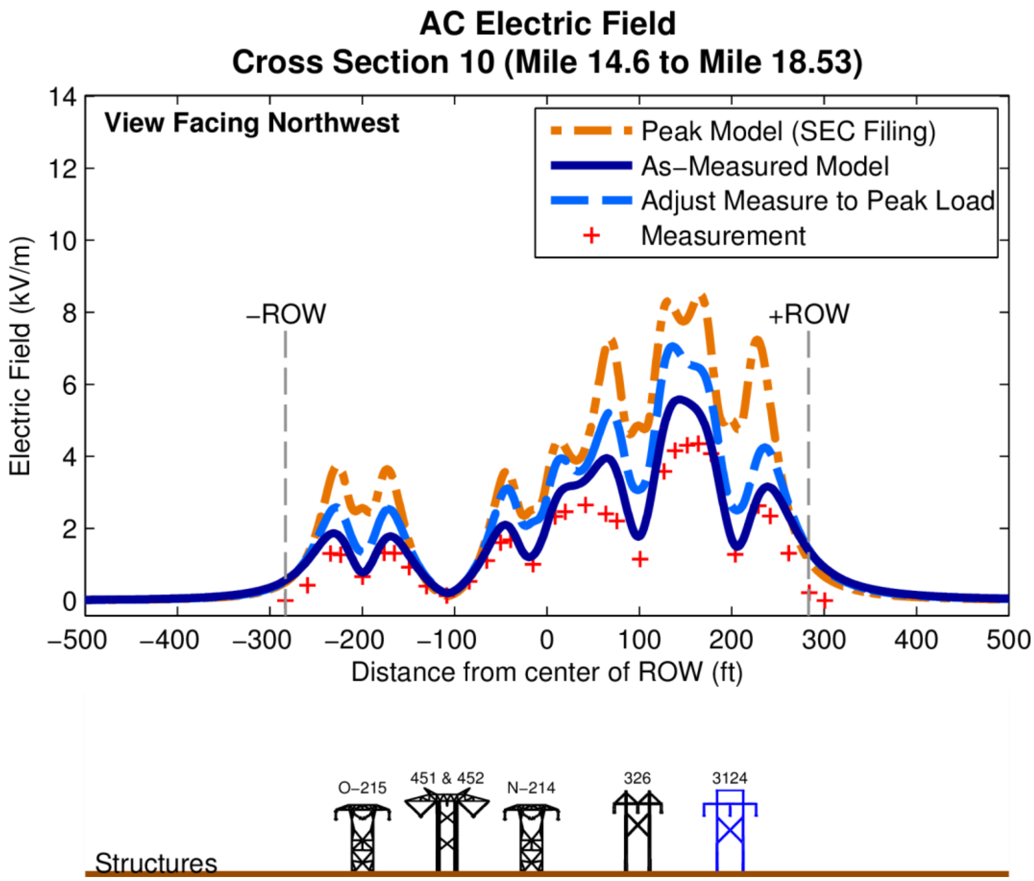


Figure B-10. Measured and modeled electric-field levels at Site 5 in XS-10.

Site 6

Measurements at Site 6 (cross section XS-11) were performed on July 30, 2018. A graphical summary of results are presented below.

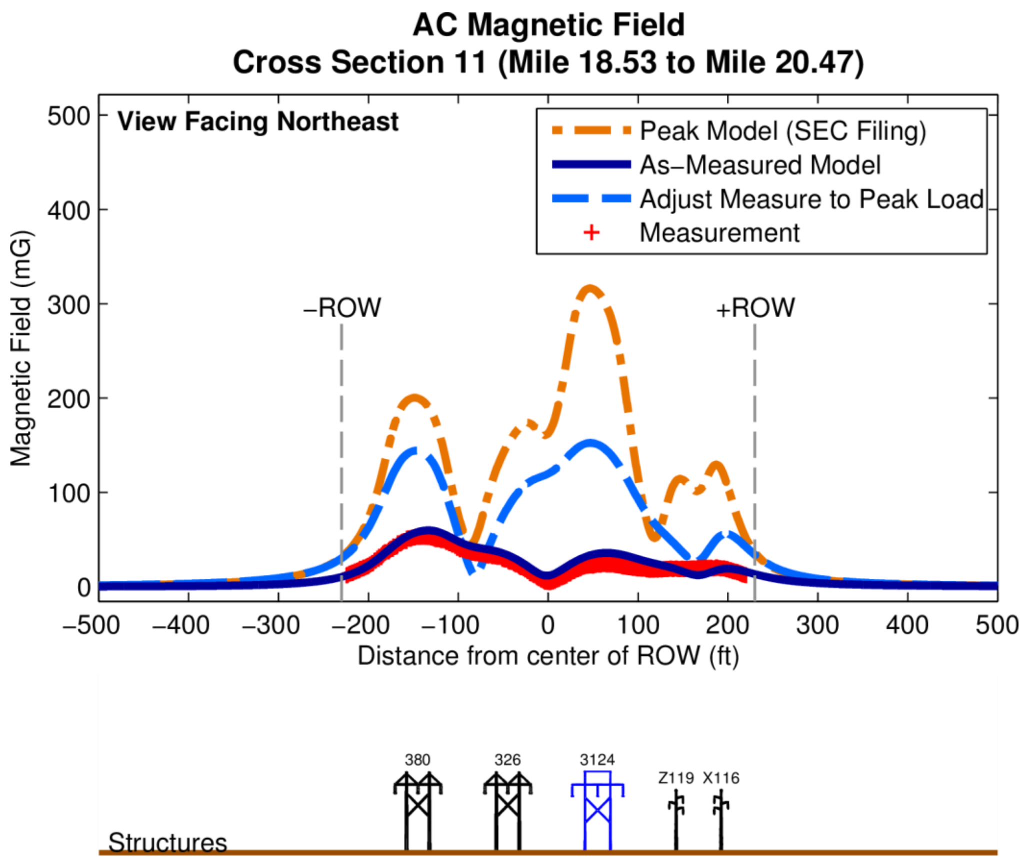


Figure B-11. Measured and modeled magnetic-field levels at Site 6 in XS-11.

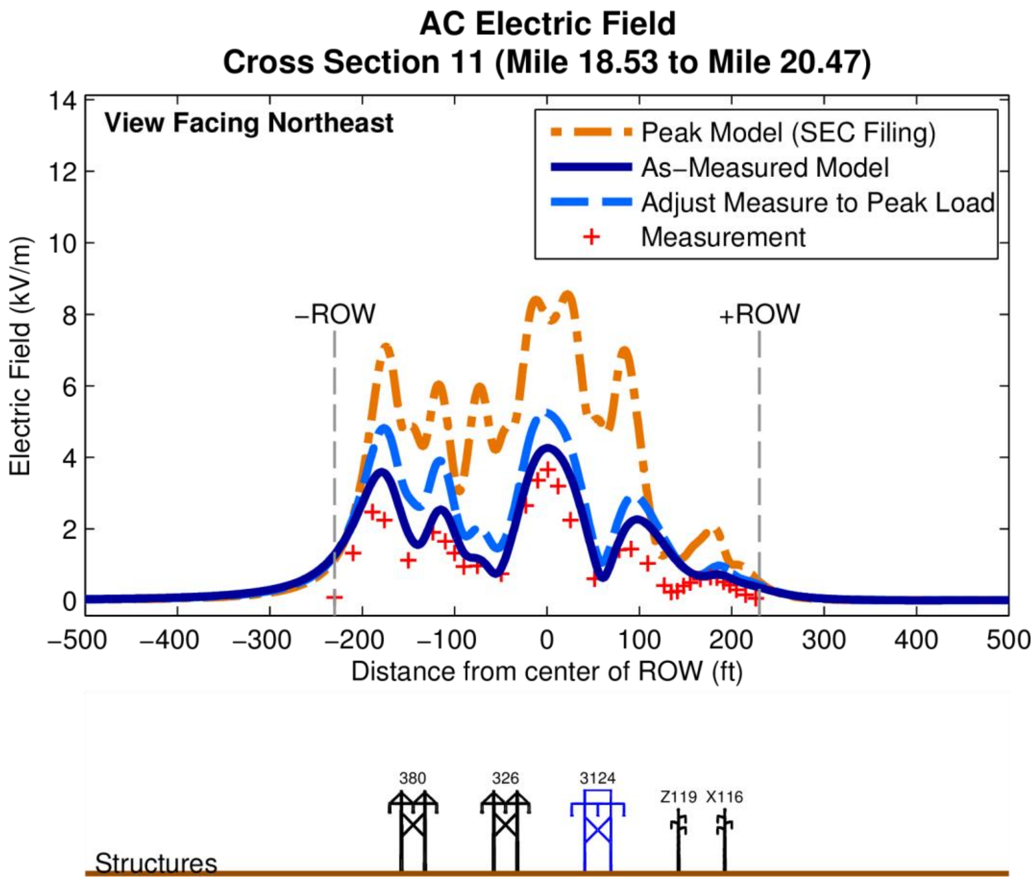


Figure B-12. Measured and modeled electric-field levels at Site 6 in XS-11.

Site 7

Measurements at Site 7 (cross section XS-12) were performed on July 28, 2018. A graphical summary of results are presented below.

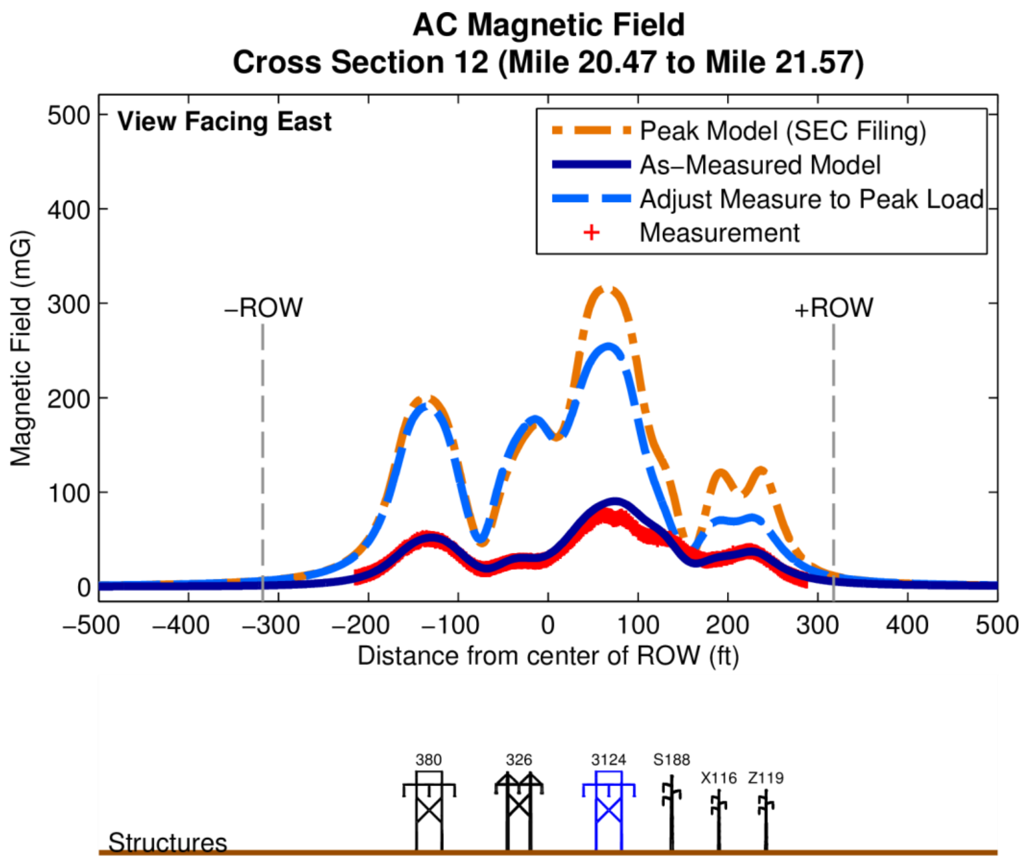


Figure B-13. Measured and modeled magnetic-field levels at Site 7 in XS-12.

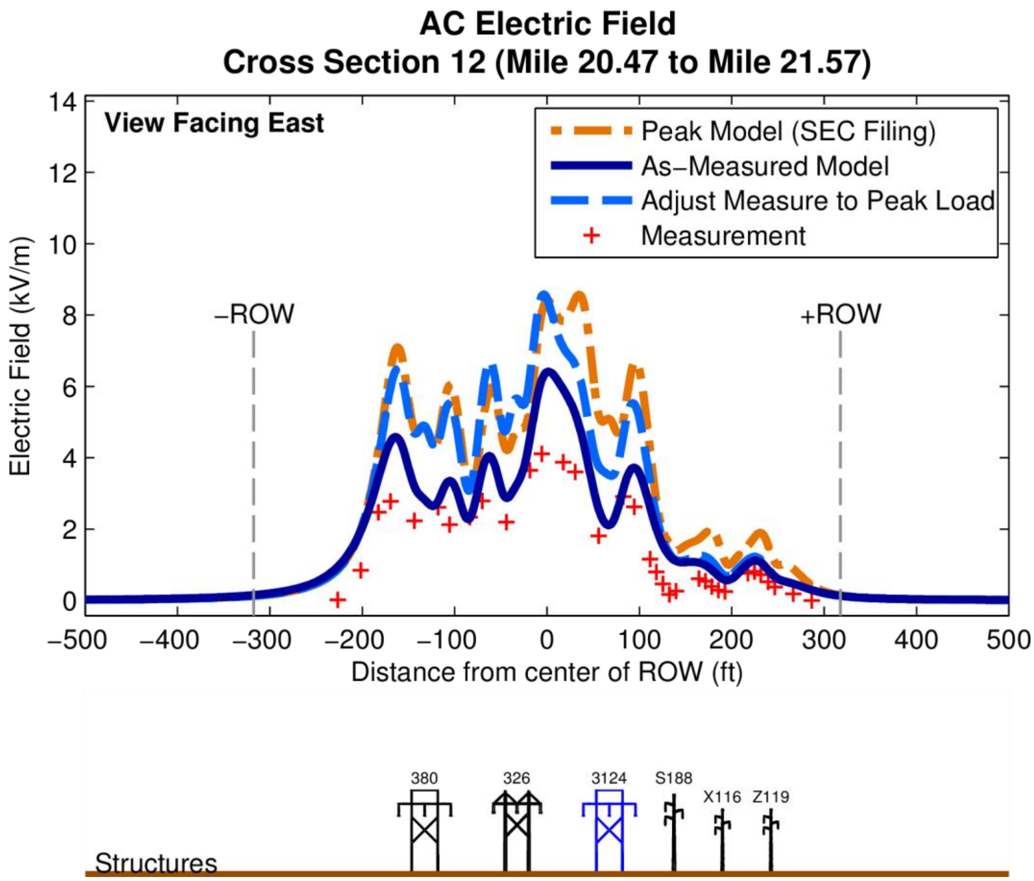


Figure B-14. Measured and modeled electric-field levels at Site 7 in XS-12.

Site 8

Measurements at Site 8 (cross section XS-13) were performed on July 29, 2018. A graphical summary of results are presented below.

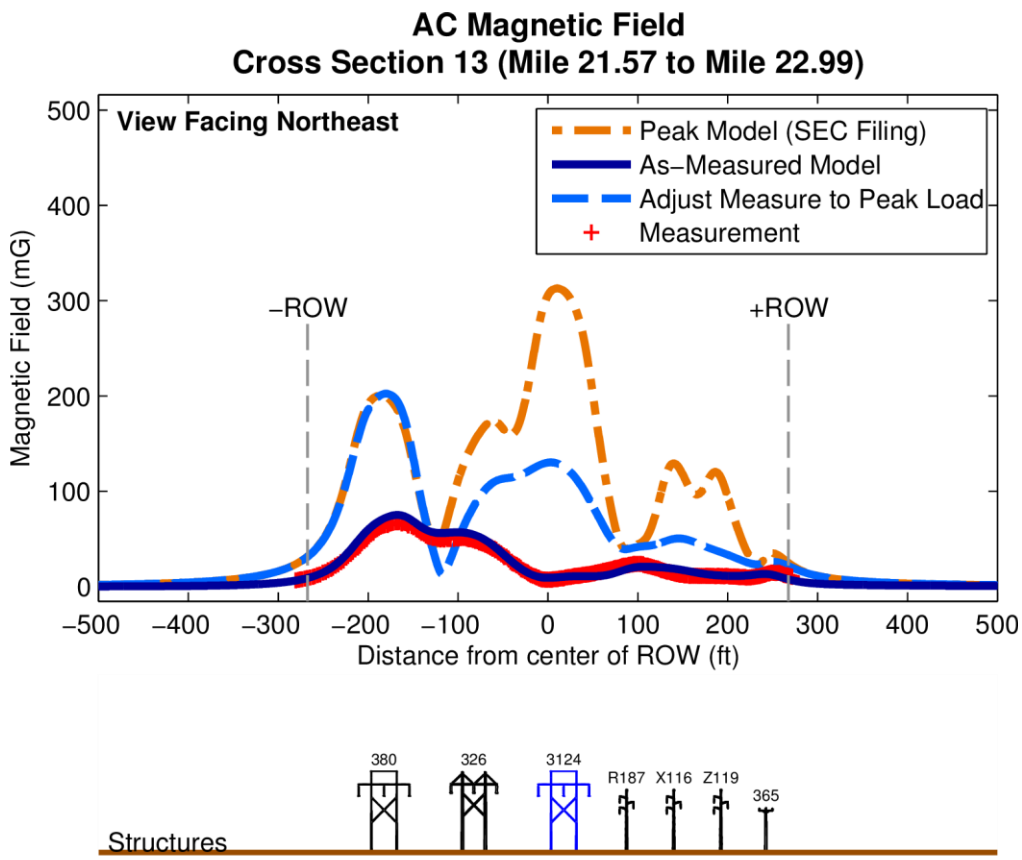


Figure B-15. Measured and modeled magnetic-field levels at Site 8 in XS-13.

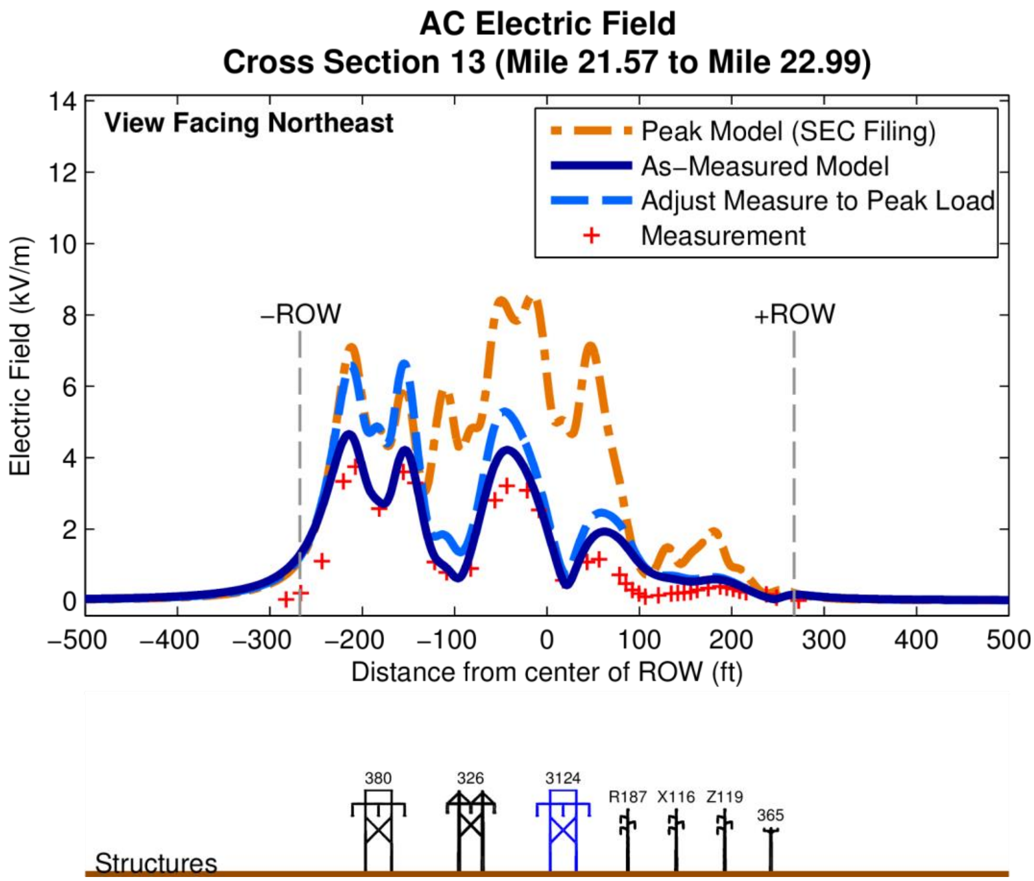


Figure B-16. Measured and modeled magnetic-field levels at Site 8 in XS-13.

Site 9

Measurements at Site 9 (cross section XS-14) were performed on July 28, 2018. A graphical summary of results are presented below.

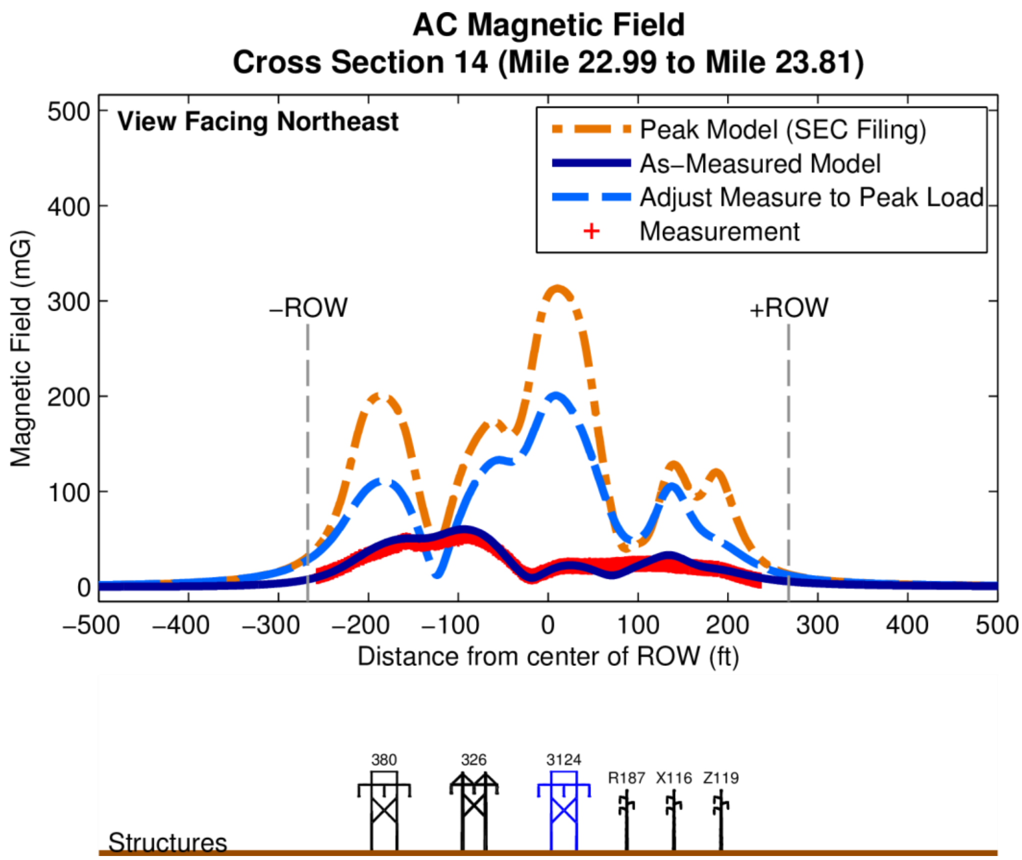


Figure B-17. Measured and modeled magnetic-field levels at Site 9 in XS-14.

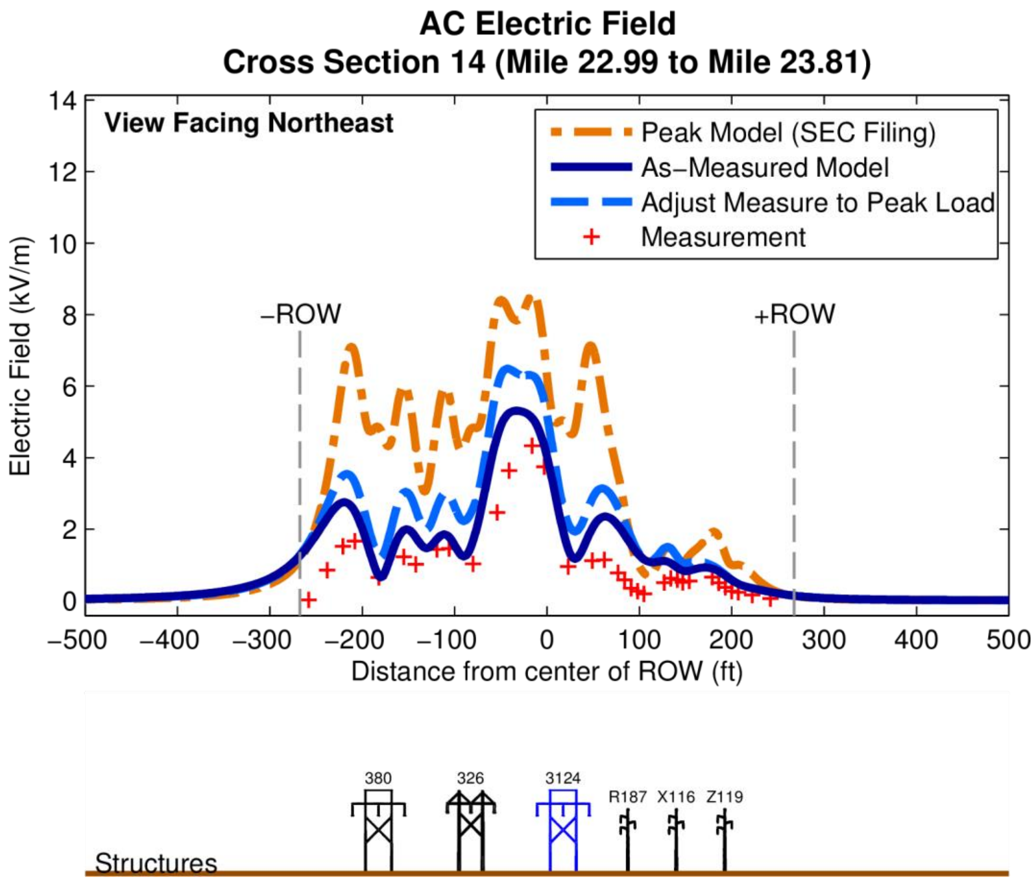


Figure B-18. Measured and modeled electric-field levels at Site 9 in XS-14.

Site 10

Measurements at Site 10 (cross section XS-15) were performed on July 30, 2018. A graphical summary of results are presented below.

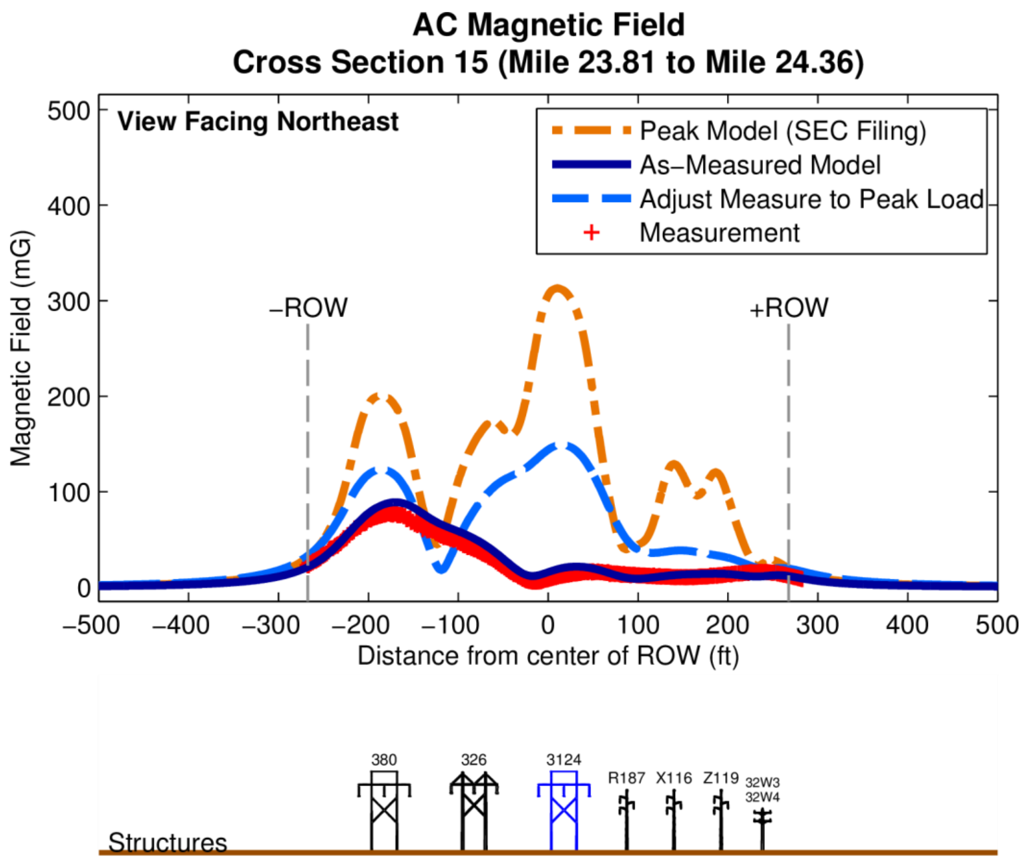


Figure B-19. Measured and modeled magnetic-field levels at Site 10 in XS-15.

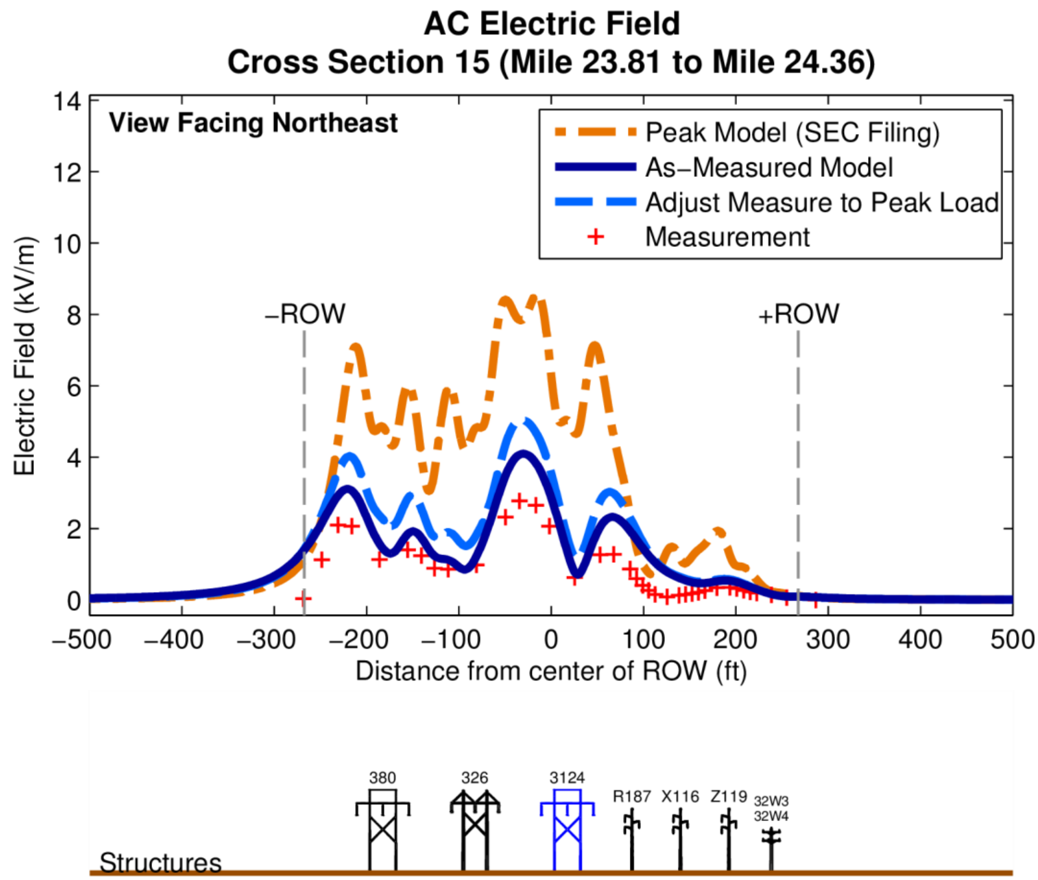


Figure B-20. Measured and modeled electric-field levels at Site 10 in XS-15.

Appendix C

Aerial Maps of Cross Section Measurement Sites

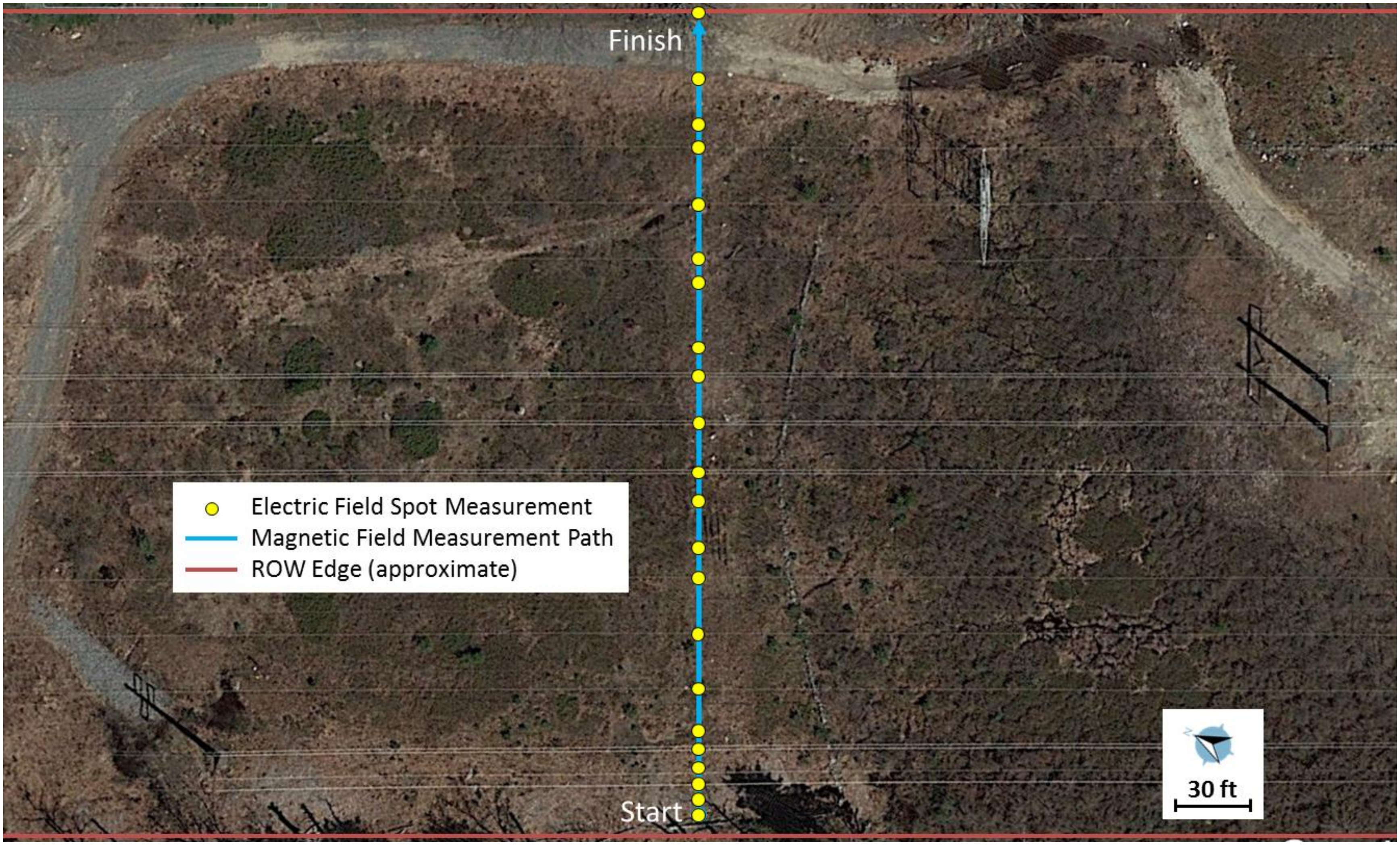


Figure C-1. Aerial photo of measurement Site 1 (in XS-8b) showing the approximate location of the magnetic field measurement path and electric field spot measurements performed on July 27, 2018.

Note aerial photograph does not show any tree or brush clearing performed.

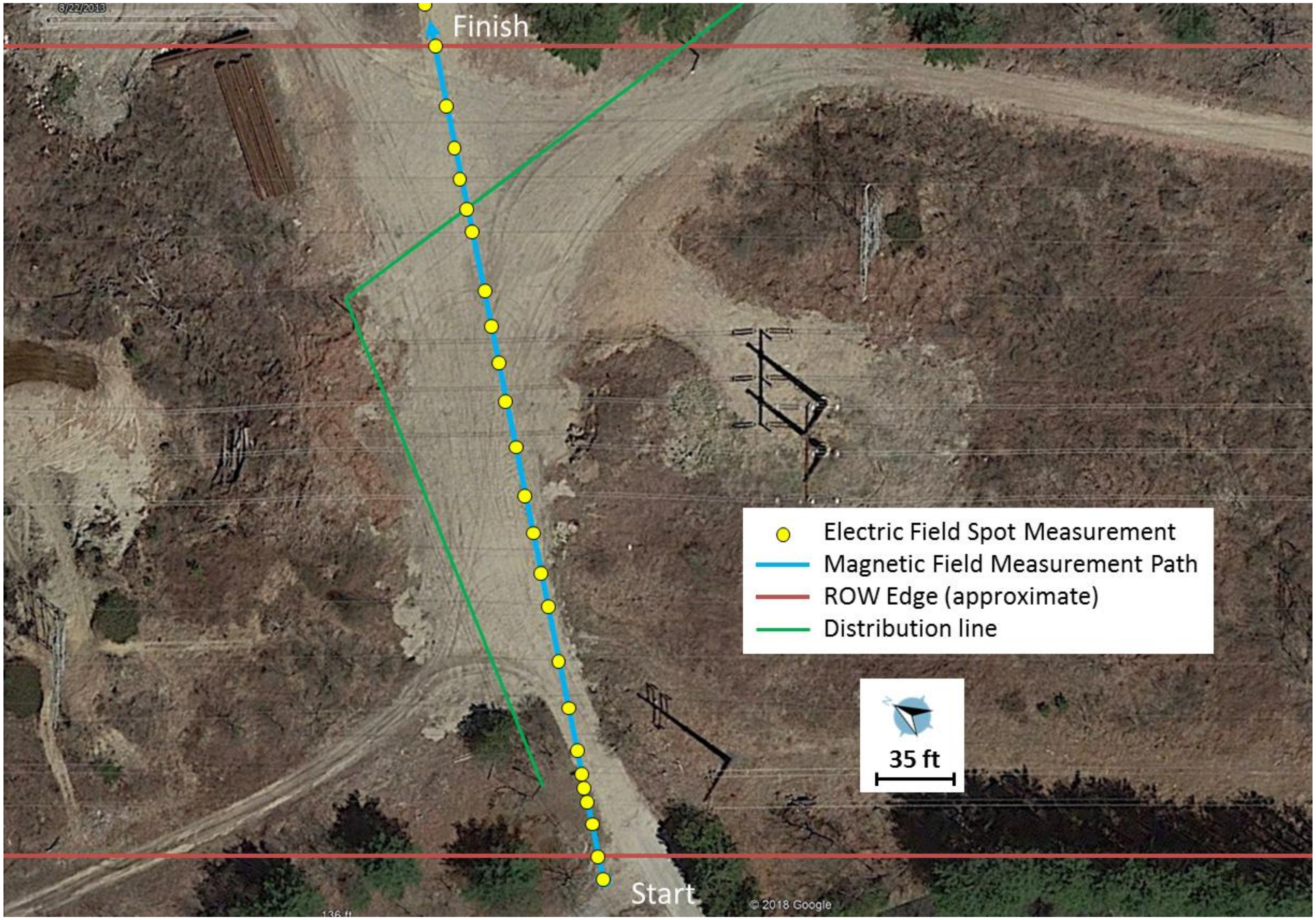


Figure C-2. Aerial photo of measurement Site 2 (in XS-8c) showing the approximate location of the magnetic field measurement path and electric field spot measurements performed on July 27, 2018.

Note aerial photograph does not show any tree or brush clearing performed.

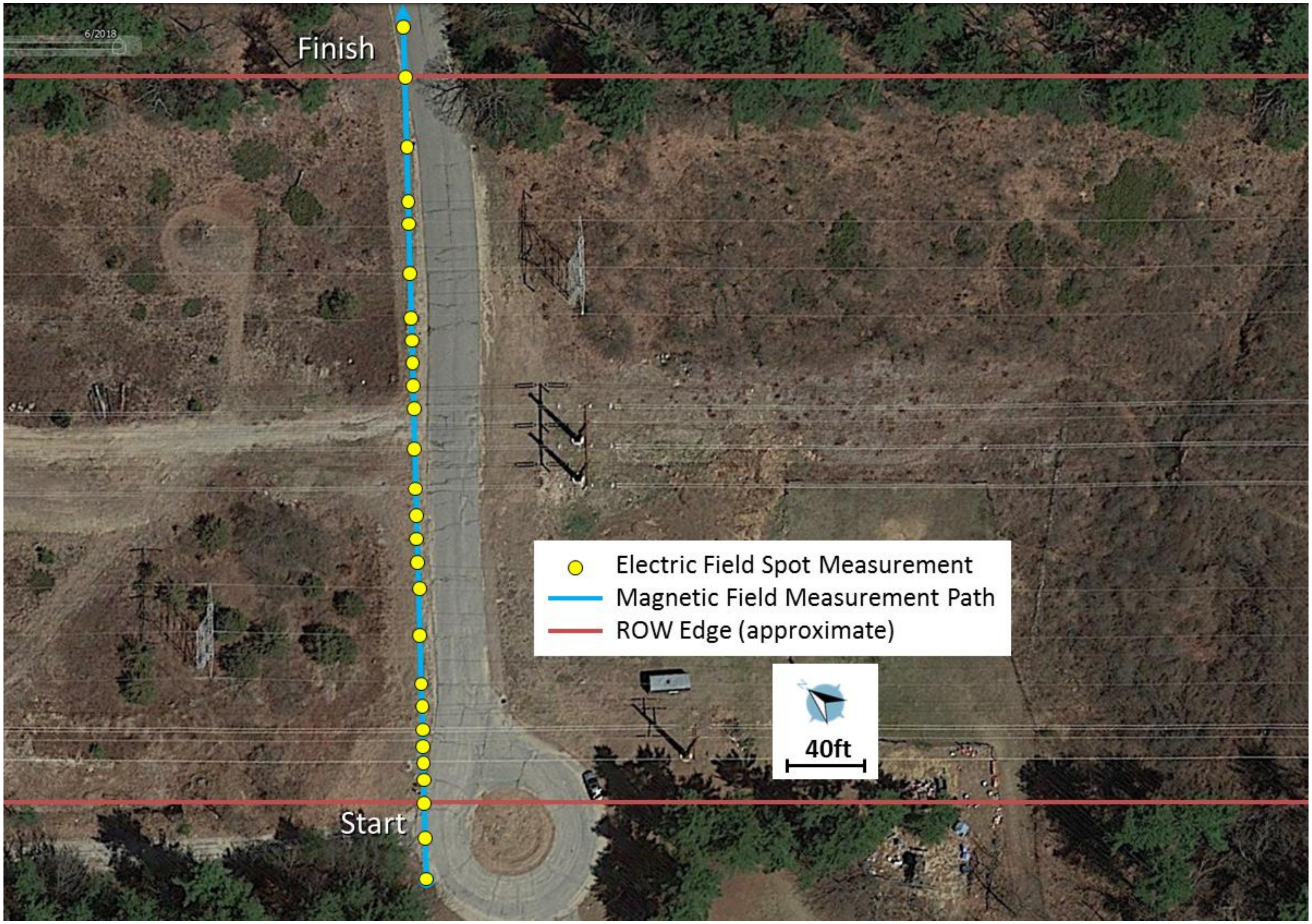


Figure C-3. Aerial photo of measurement Site 3 (in XS-8d) showing the approximate location of the magnetic field measurement path and electric field spot measurements performed on July 24, 2018.

Note aerial photograph does not show any tree or brush clearing performed.

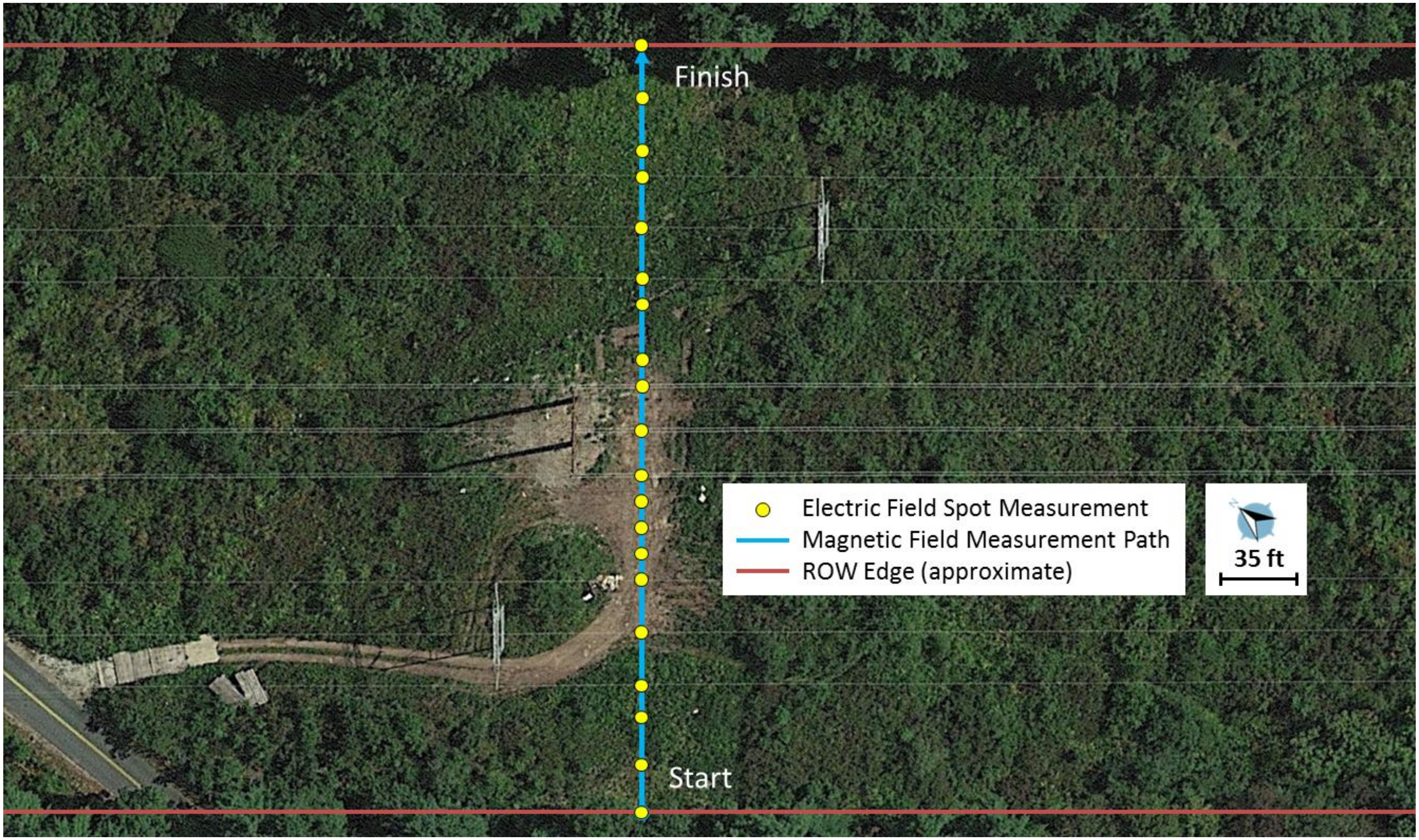


Figure C-4. Aerial photo of measurement Site 4 (in XS-9) showing the approximate location of the magnetic field measurement path and electric field spot measurements performed on July 29, 2018.

Note aerial photograph does not show any tree or brush clearing performed.

Figure C-5. Aerial photo of measurement Site 5 (in XS-10) showing the approximate location of the magnetic field measurement path and electric field spot measurements performed on July 27, 2018.

Note aerial photograph does not show any tree or brush clearing performed.

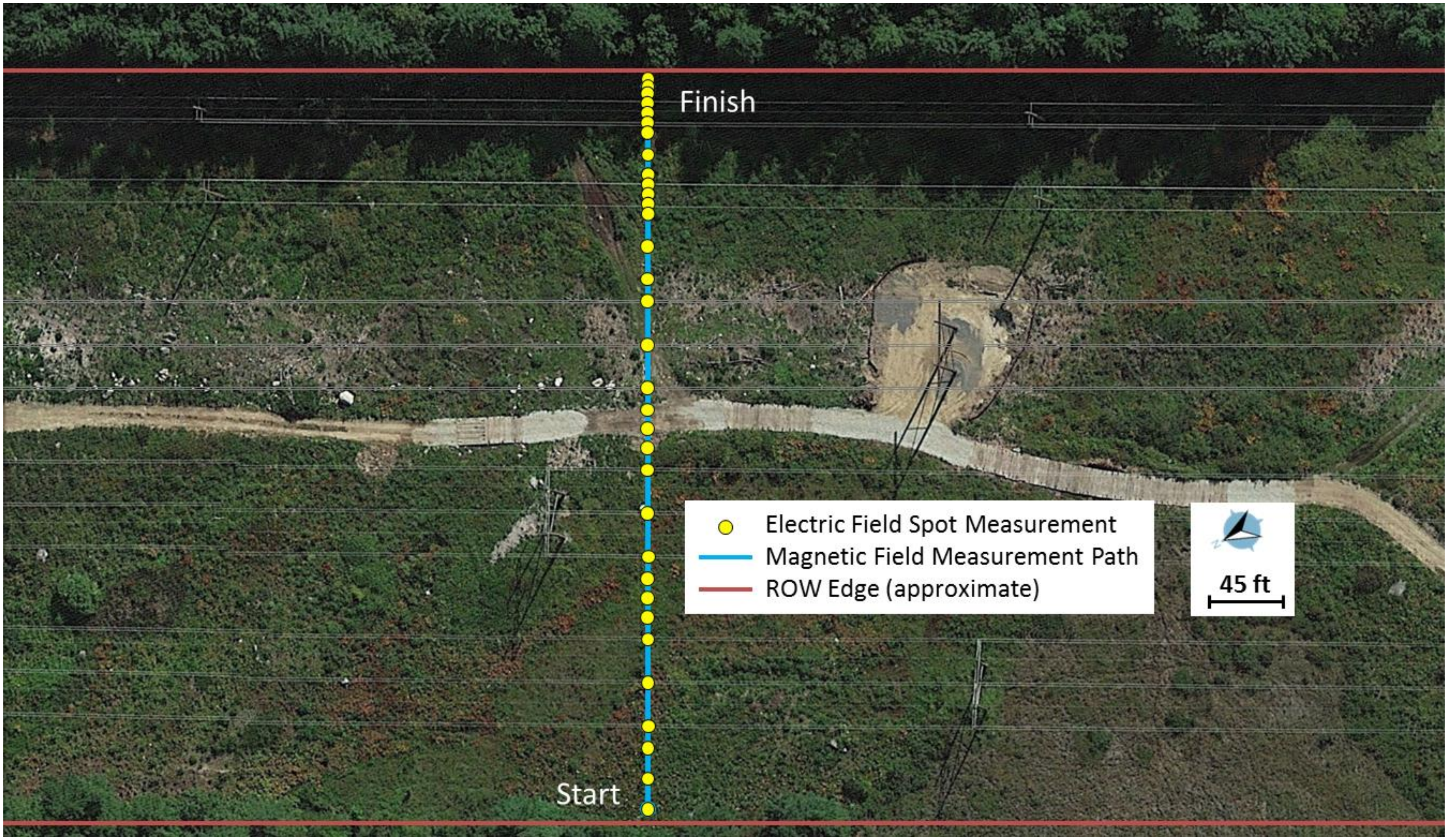


Figure C-6. Aerial photo of measurement Site 6 (in XS-11) showing the approximate location of the magnetic field measurement path and electric field spot measurements performed on July 30, 2018.

Note aerial photograph does not show any tree or brush clearing performed.

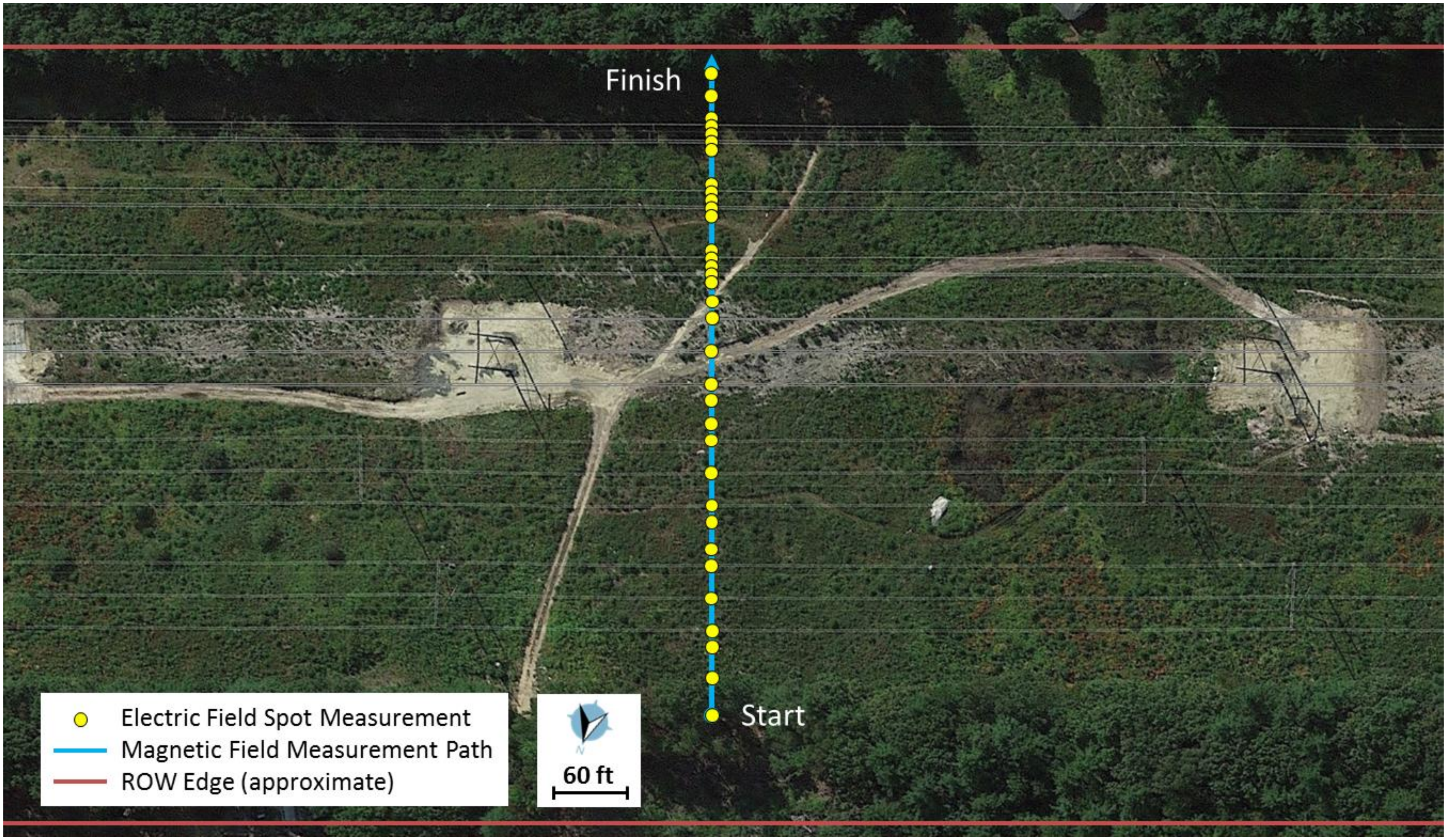


Figure C-7. Aerial photo of measurement Site 7 (in XS-12) showing the approximate location of the magnetic field measurement path and electric field spot measurements performed on July 28, 2018.

Note aerial photograph does not show any tree or brush clearing performed.

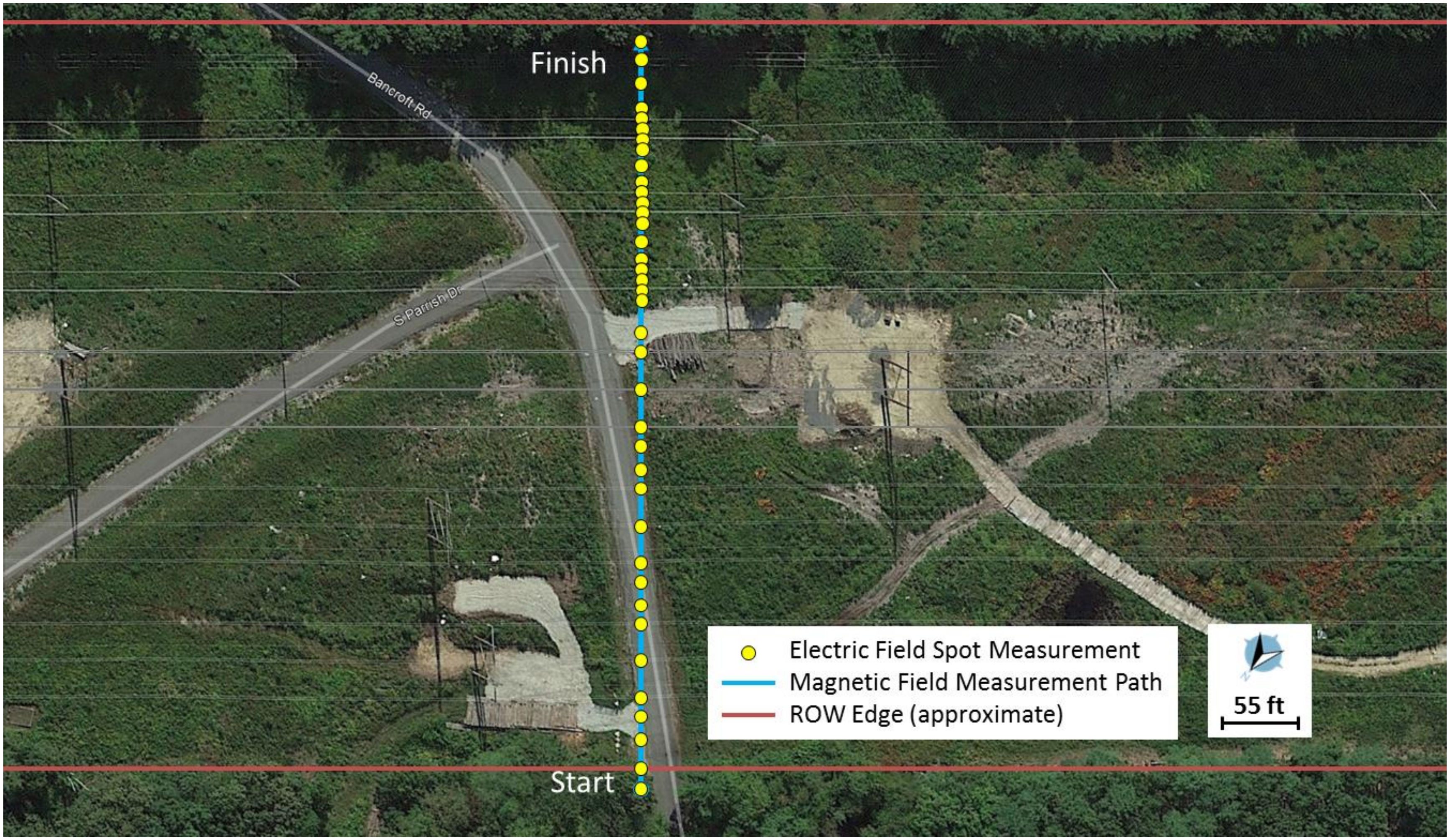


Figure C-8. Aerial photo of measurement Site 8 (in XS-13) showing the approximate location of the magnetic field measurement path and electric field spot measurements performed on July 29, 2018.

Note aerial photograph does not show any tree or brush clearing performed.

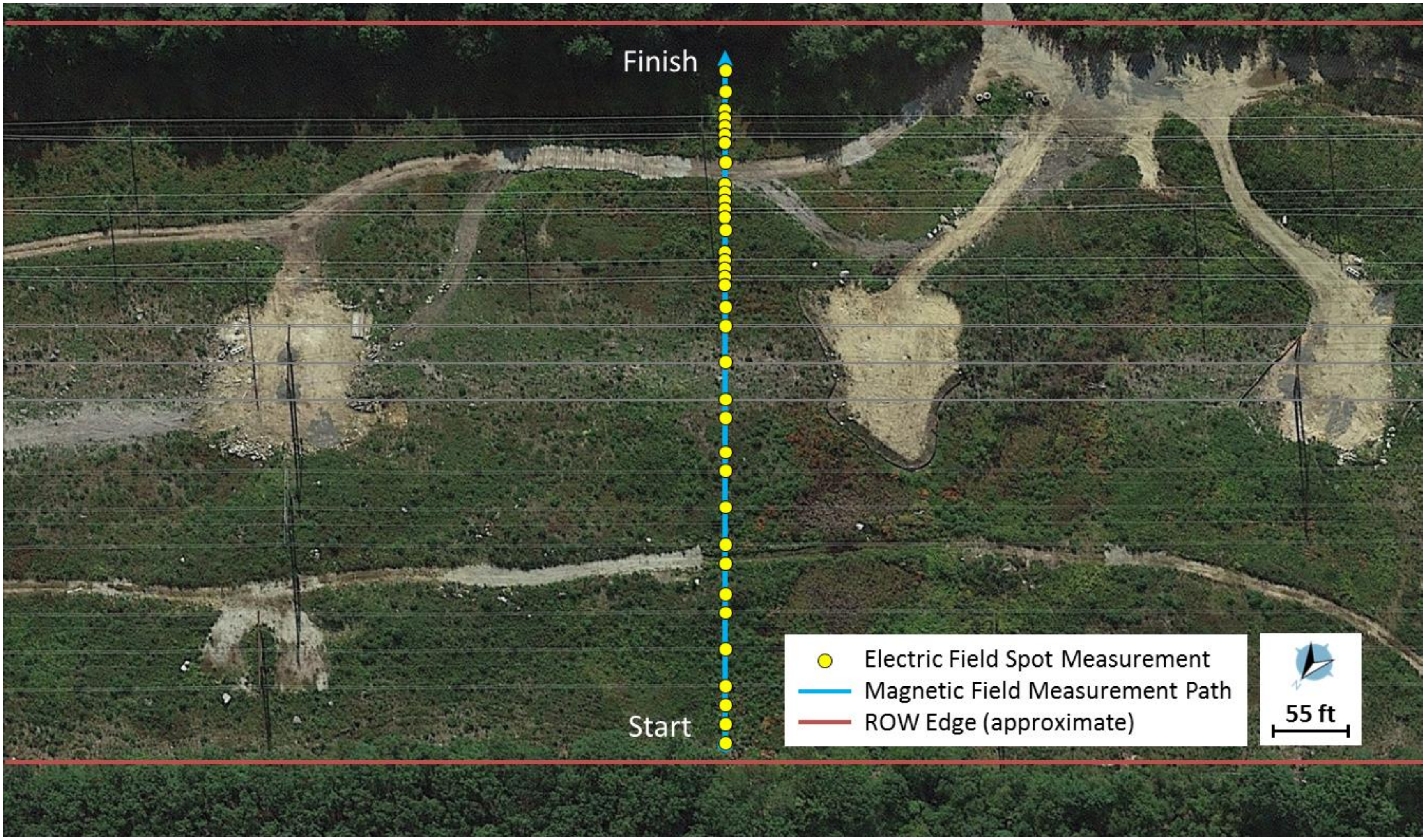


Figure C-9. Aerial photo of measurement Site 9 (in XS-14) showing the approximate location of the magnetic field measurement path and electric field spot measurements performed on July 28, 2018.

Note aerial photograph does not show any tree or brush clearing performed.

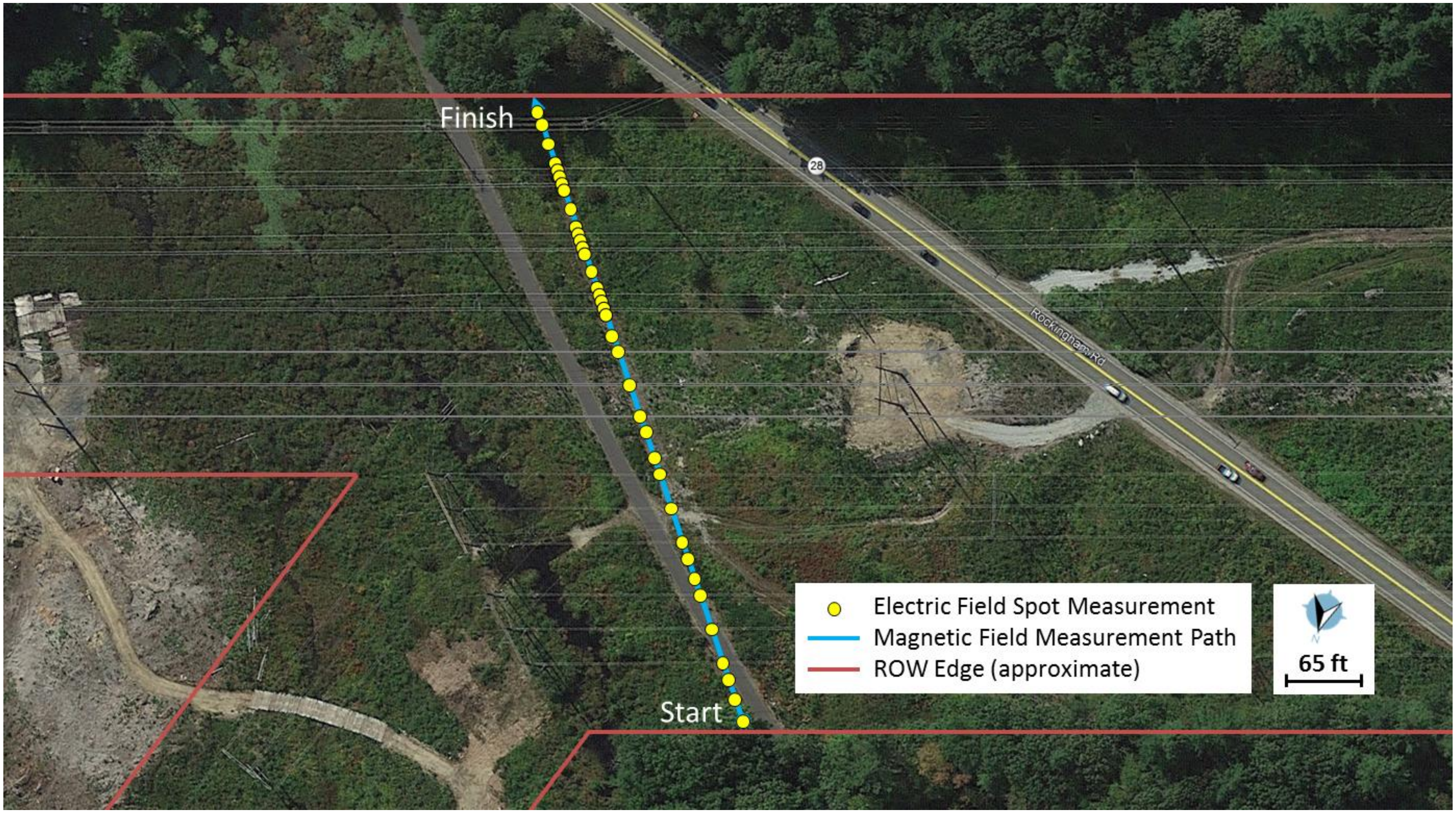


Figure C-10. Aerial photo of measurement Site 10 (in XS-15) showing the approximate location of the magnetic field measurement path and electric field spot measurements performed on July 30, 2018.

Note aerial photograph does not show any tree or brush clearing performed.

Appendix D

Transmission Line Loading and Conductor Heights at Time of Measurements

Table D-1. Table of conductor height and loading at each measurement location for pre-construction cases.

Site No. (XS-No.)	Location	Line No.	Nominal Voltage (kV)	Application (Peak Loading) Loading (MW)	Application (Peak Loading) Loading (MVAR)	Measurement Loading (MW)	Measurement Loading (MVAR)	Minimum Conductor Height (ft) Application (Average)	Minimum Conductor Height (ft) Measurement
Site 1 (XS-8b)	East of Old Lawrence Road.	Y-151	115	70.3	-6.8	-14.8	-10.0	31.0	38.0
		N-214	230	235.7	4.8	116.6	-15.0	32.0	44.9
		O-215	230	192.3	9.7	176.7	-27.4	32.0	28.4
		3124	345	652.6	-114.1	129.5	18.2	35	43.9
Site 2 (XS-8c)	Off Tina Avenue	Y-151	115	97.4	-0.3	28.7	8.2	31.0	46.1
		N-214	230	235.7	4.8	117.0	-6.9	32.0	40.8
		O-215	230	192.3	9.7	186.6	-18.9	32.0	37.5
		3124	345	652.6	-114.1	139.4	-10.3	35	43.3
Site 3 (XS-8d)	Along Winter Street	Y-151	115	97.4	-0.3	32.5	7.1	31.0	30.9
		N-214	230	235.7	4.8	102.3	-3.3	32.0	40.1
		O-215	230	192.3	9.7	160.3	-15.9	32.0	46.8
		3124	345	652.6	-114.1	173.9	-40.6	35	37.7
Site 4 (XS-9)	Southeast of Griffin Road	N-214	230	235.7	4.8	119.2	-5.0	32.0	37.0
		O-215	230	192.3	9.7	193.7	-16.1	32.0	38.8
		3124	345	652.6	-114.1	31.0	-17.0	35	54.1
Site 5 (XS-10)	South of Dan Hill Road	N-214	230	235.7	4.8	88.1	-8.5	33.0	34.8
		O-215	230	192.3	9.7	138.7	-9.5	33.0	39.3
		326	345	298.5	-87.5	-153.5	5.4	35.0	38.6
		451/452	DC	n/a	n/a	n/a	n/a	37.5	66.8
		3124	345	652.6	-114.1	112.2	-43.4	35.0	42.5
Site 6 (XS-11)	North of Wiley Hill Road	Z119	115	118.8	24.6	57.2	-1.4	24.0	45.1
		X116	115	118.7	24.6	57.8	-1.0	30.0	39.3
		326	345	298.5	-87.5	-136.3	-4.0	35.0	47.8
		380	345	454.1	-22.1	216.7	-5.7	35.0	41.7
		3124	345	652.6	-114.1	218.8	-26.5	35.0	54.0

Site No. (XS-No.)	Location	Line No.	Nominal Voltage (kV)	Application (Peak Loading)		Measurement		Minimum Conductor Height (ft)	
				Loading (MW)	Loading (MVAR)	Loading (MW)	Loading (MVAR)	Application (Average)	Measurement
Site 7 (XS-12)	Off Davis Drive	Z119	115	118.8	24.6	63.8	5.0	24.0	32.5
		X116	115	118.7	24.6	64.5	5.5	30.0	40.0
		S188	115	-79.2	19.8	-83.8	12.7	24.0	32.4
		326	345	298.5	-87.5	-1.6	-50.3	35.0	33.0
		380	345	454.1	-22.1	155.5	10.6	35.0	34.9
		3124	345	652.6	-114.1	323.9	-53.8	35.0	38.3
Site 8 (XS-13)	Along Bancroft Road	365	34.1	21.5	1.0	-10.6	-2.3	25.0	32.3
		Z119	115	118.8	24.6	50.1	2.8	24.0	53.7
		X116	115	118.7	24.6	50.9	3.0	30.0	48.8
		R187	115	-16.6	35.8	-55.8	21.7	30.0	39.3
		326	345	298.5	-87.5	-248.7	1.3	35.0	46.2
		380	345	454.1	-22.1	195.9	-12.6	35.0	33.8
		3124	345	652.6	-114.1	82.9	-50.2	35.0	58.9
Site 9 (XS-14)	Off Snow Flake Lane	Z119	115	118.8	24.6	53.8	3.9	24.0	42.5
		X116	115	118.7	24.6	54.5	4.4	30.0	32.5
		R187	115	-16.6	35.8	-51.9	23.8	30.0	42.7
		326	345	298.5	-87.5	-241.1	-16.9	35.0	41.3
		380	345	454.1	-22.1	187.0	1.5	35.0	46.1
		3124	345	652.6	-114.1	144.2	-32.6	35.0	43
Site 10 (XS-15)	Along Londonderry Rail Trail	32W4	12.7	5.9	-0.2	2.5	-0.1	25.0	50.3
		32W3	12.7	n/a	n/a	4.3	0.4	n/a	39.0
		Z119	115	118.8	24.6	58.6	-1.2	24.0	53.1
		X116	115	118.7	24.6	59.1	-1.0	30.0	57.1
		R187	115	-16.6	35.8	-14.7	6.8	30.0	51.2
		326	345	298.5	-87.5	-186.7	11.7	35.0	50.8
		380	345	454.1	-22.1	369.6	-22.8	35.0	46.4
		3124	345	652.6	-114.1	138.3	-20.1	35.0	53.8

Table D-2. Table of loading recorded during measurements at each PUC road crossings.

Road Crossing No. (XS-No.)	Location	Line No.	Nominal Voltage (kV)	Application (Peak Loading) Loading (MW)	Application (Peak Loading) Loading (MVAR)	Load During Measurements Loading (MW)	Load During Measurements Loading (MVAR)
PUC 1 (XS-8b)	Dutton Road	Y-151	115	70.3	-6.8	-1.1	-10.4
		N-214	230	235.7	4.8	105.3	-4.6
		O-215	230	192.3	9.7	175.0	-14.6
		3124	345	652.6	-114.1	63.2	-20.5
PUC 2 (XS-8d)	Shelly Drive	Y-151	115	97.4	-0.3	24.4	9.8
		N-214	230	235.7	4.8	105.2	-2.8
		O-215	230	192.3	9.7	170.1	-10.6
		3124	345	652.6	-114.1	99.5	-7.5
PUC 3 (XS-8d)	Glance Road	Y-151	115	97.4	-0.3	11.0	14.1
		N-214	230	235.7	4.8	111.5	-6.1
		O-215	230	192.3	9.7	185.4	-18.7
		3124	345	652.6	-114.1	62.7	-3.7
PUC 4 (XS-10)	David Drive	N-214	230	235.7	4.8	87.1	-3.6
		O-215	230	192.3	9.7	155.9	-12.2
		326	345	298.5	-87.5	-329.9	46.4
		451/452	DC	n/a	n/a	n/a	n/a
		3124	345	652.6	-114.1	-112.0	-9.0
PUC 5 (XS-11)	Wiley Hill Road	X116	115	118.8	24.6	66.7	0.0
		Z119	115	118.7	24.6	66.0	-0.5
		326	345	298.5	-87.5	-109.9	-8.3
		380	345	454.1	-22.1	433.3	-8.5
		3124	345	652.6	-114.1	136.5	-15.7
PUC 6 (XS-11)	Mayflower Drive	X116	115	118.8	24.6	63.8	4.8
		Z119	115	118.7	24.6	63.0	4.3
		326	345	298.5	-87.5	-5.8	-44.2
		380	345	454.1	-22.1	151.9	3.7
		3124	345	652.6	-114.1	296.9	-44.7

Appendix E

Aerial Maps and Measured EMF Levels at Road Crossing Measurement Sites

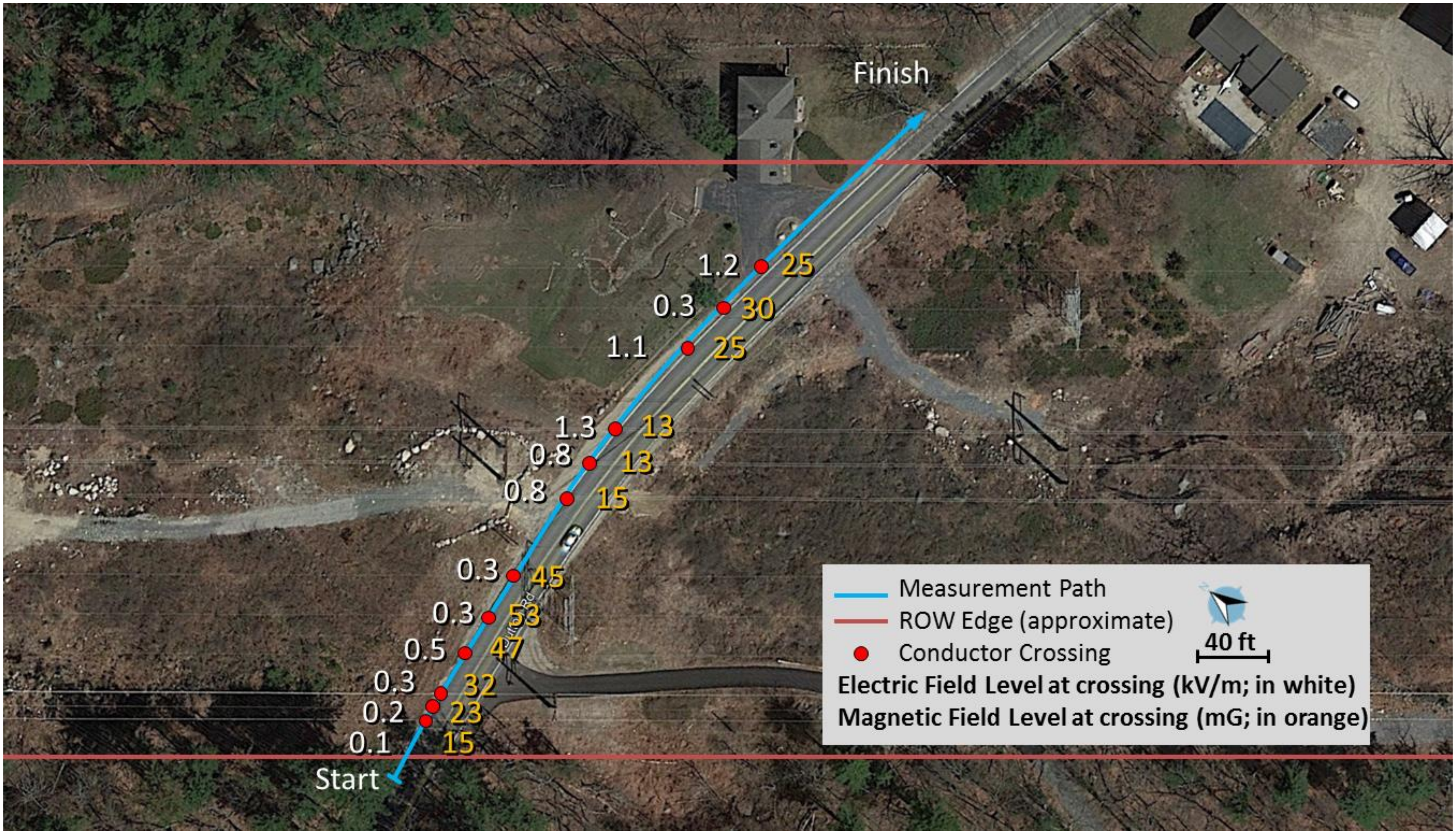


Figure E-1. Aerial photograph of measurements at PUC Site 1(Dutton Road in XS-8b) showing the path along which EMF measurements were performed on July 24, 2018.

EMF levels measured beneath conductors are shown. Aerial photograph does not show any tree or brush clearing performed.

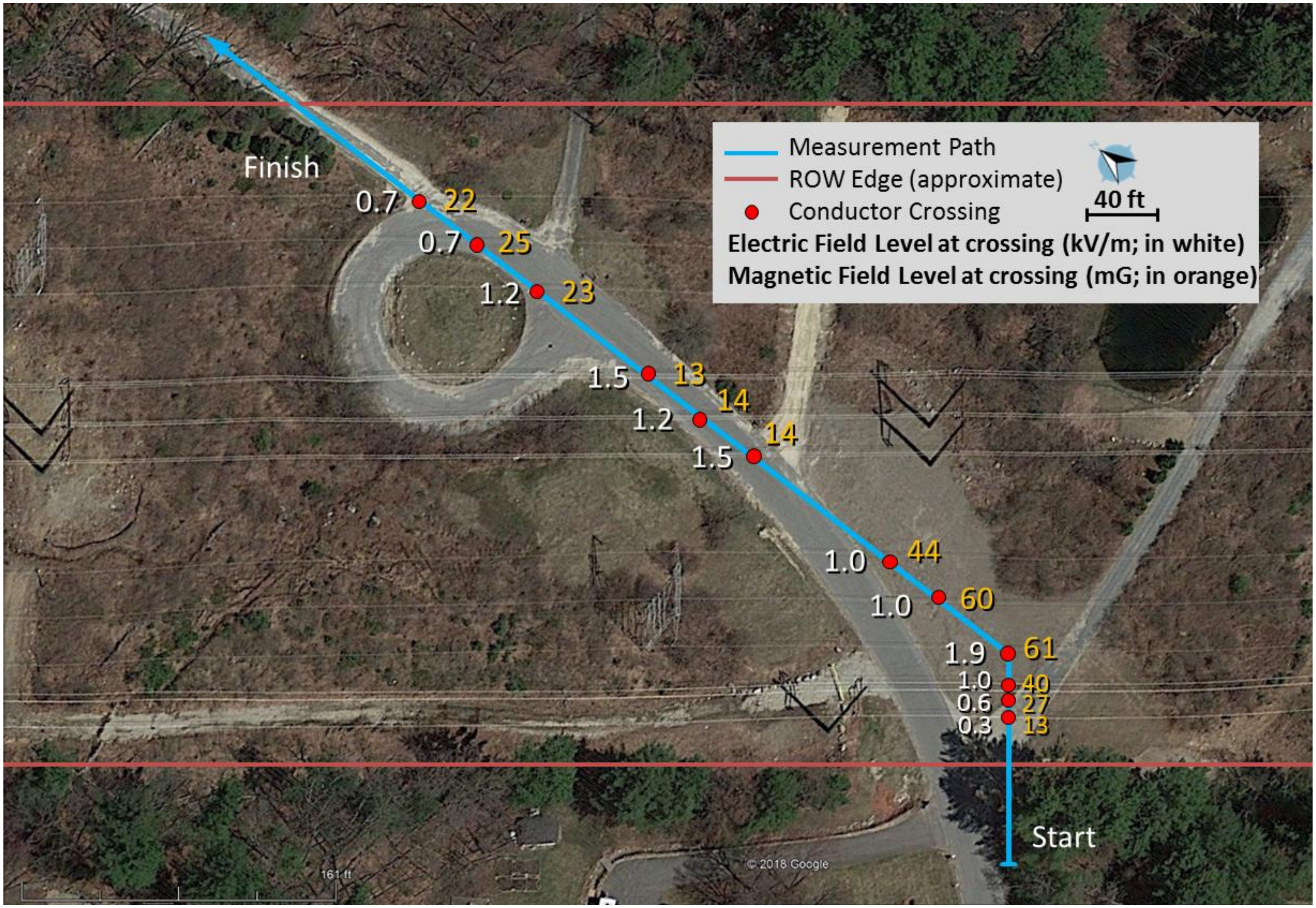


Figure E-2. Aerial photograph of measurements at PUC Site 2 (Shelly Drive Road in XS-8d) showing the path along which EMF measurements were performed on July 25, 2018.

EMF levels measured beneath conductors are shown. Aerial photograph does not show any tree or brush clearing performed.

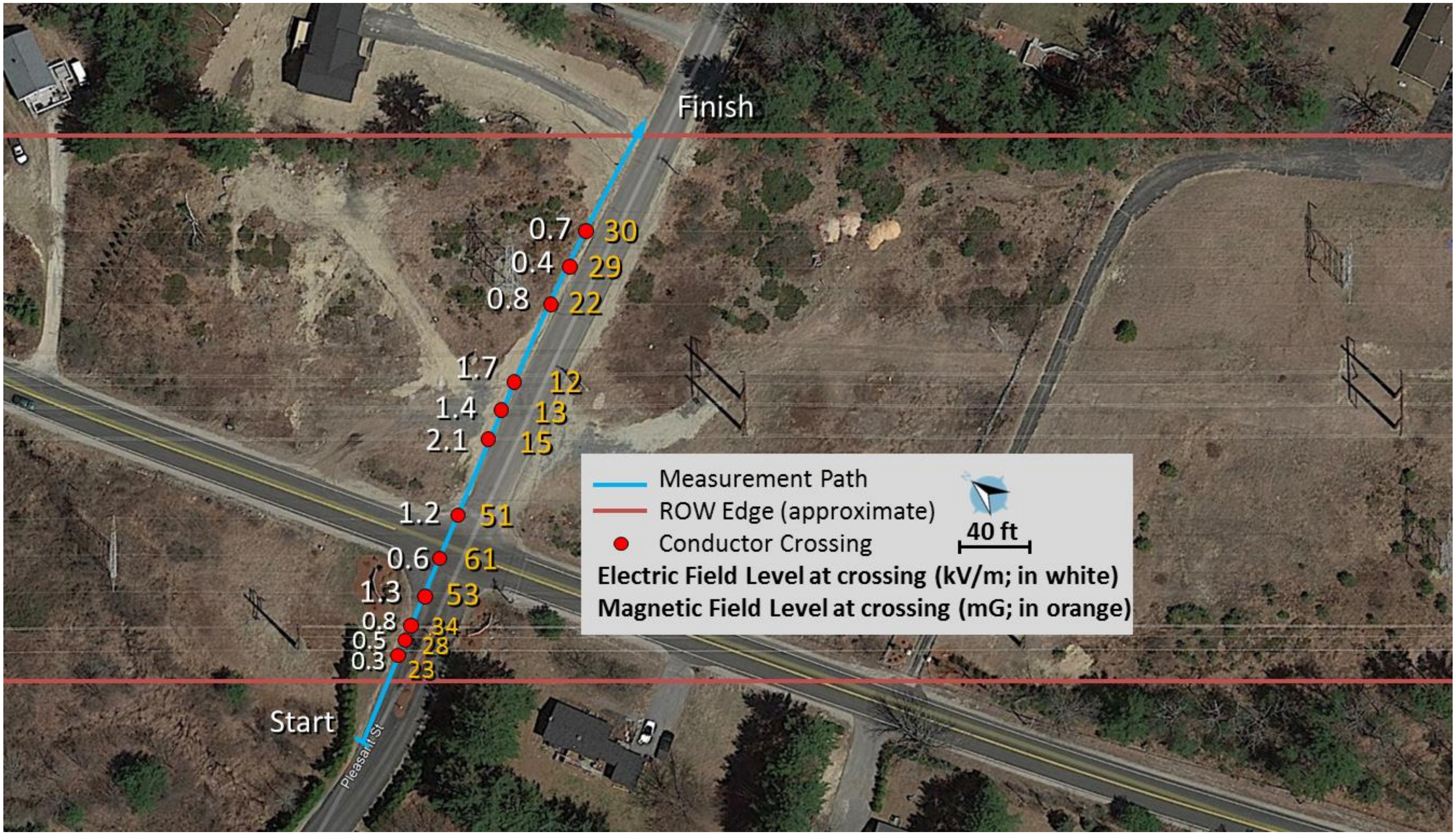


Figure E-3. Aerial photograph of measurements at PUC Site 3 (Glance Road Drive Road in XS-8d) showing the path along which EMF measurements were performed on July 29, 2018.

EMF levels measured beneath conductors are shown. Aerial photograph does not show any tree or brush clearing performed.

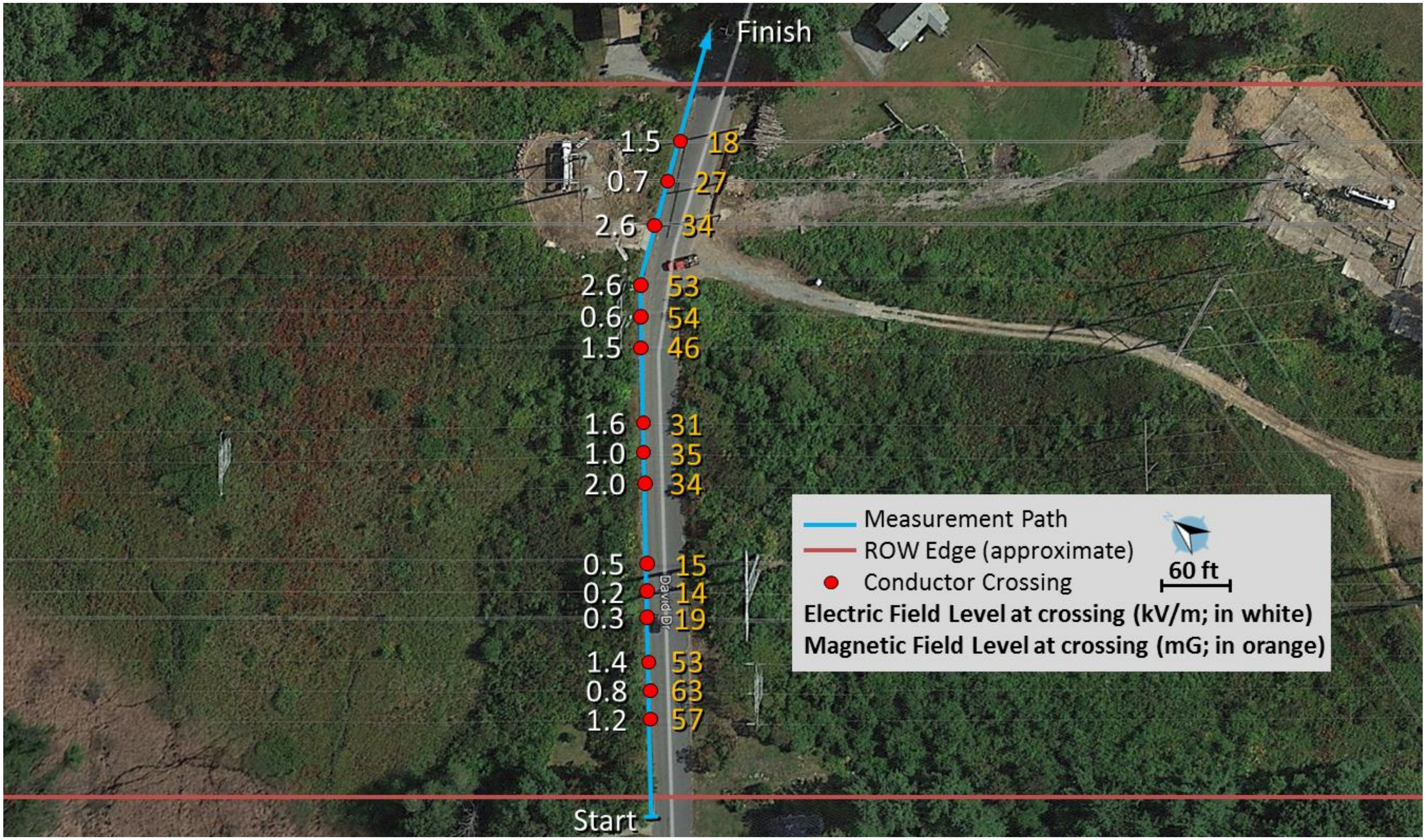


Figure E-4. Aerial photograph of measurements at PUC Site 4 (David Drive in XS-10) showing the path along which EMF measurements were performed on July 27, 2018.

EMF levels measured beneath conductors are shown. Aerial photograph does not show any tree or brush clearing performed.

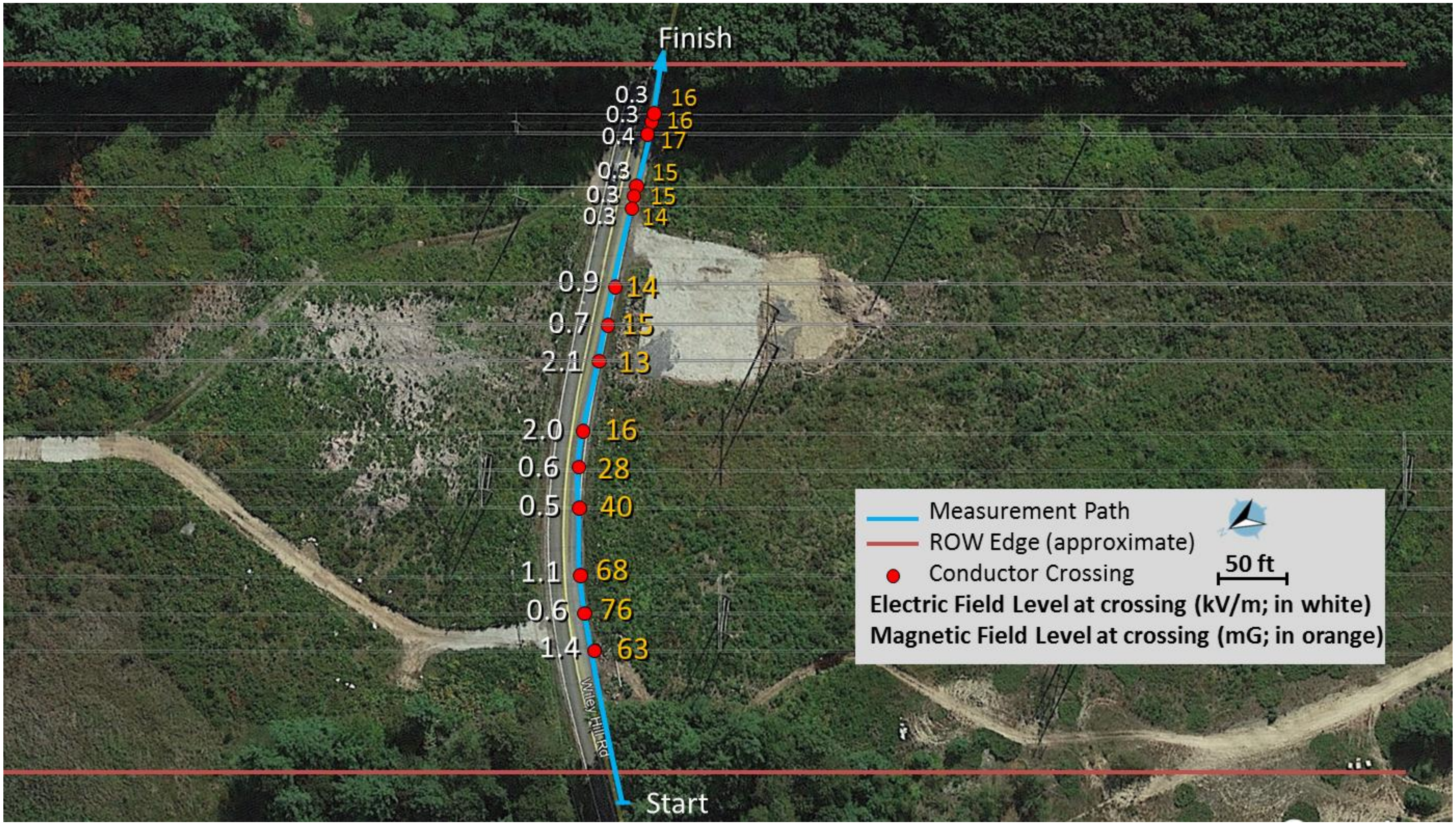


Figure E-5. Aerial photograph of measurements at PUC Site 5 (Wiley Hill Road in XS-11) showing the path along which EMF measurements were performed on July 25, 2018.

EMF levels measured beneath conductors are shown. Aerial photograph does not show any tree or brush clearing performed.

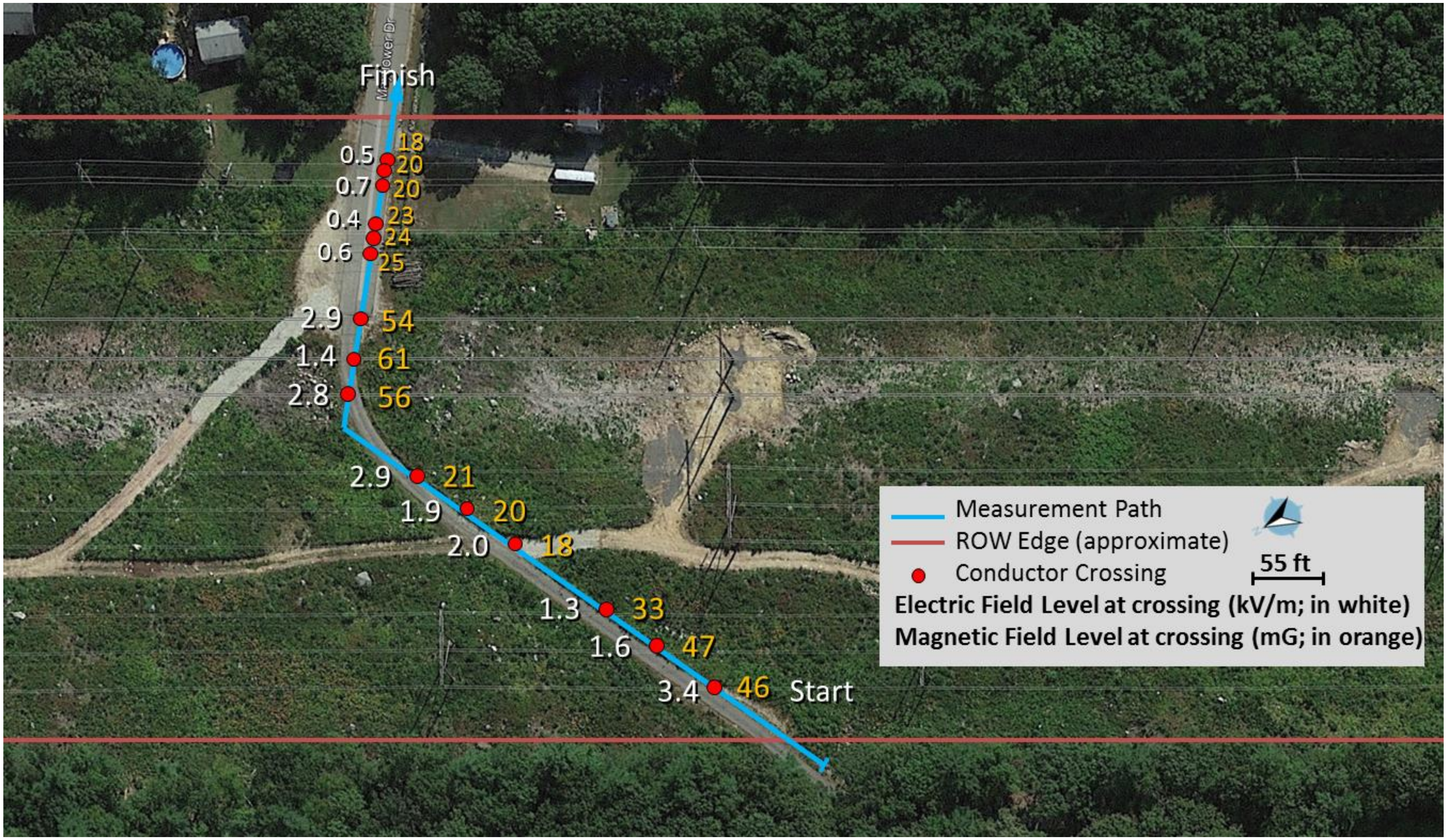


Figure C-6. Aerial photograph of measurements at PUC Site 6 (Mayflower Drive in XS-11) showing the path along which EMF measurements were performed on July 28, 2018.

EMF levels measured beneath conductors are shown. Aerial photograph does not show any tree or brush clearing performed.

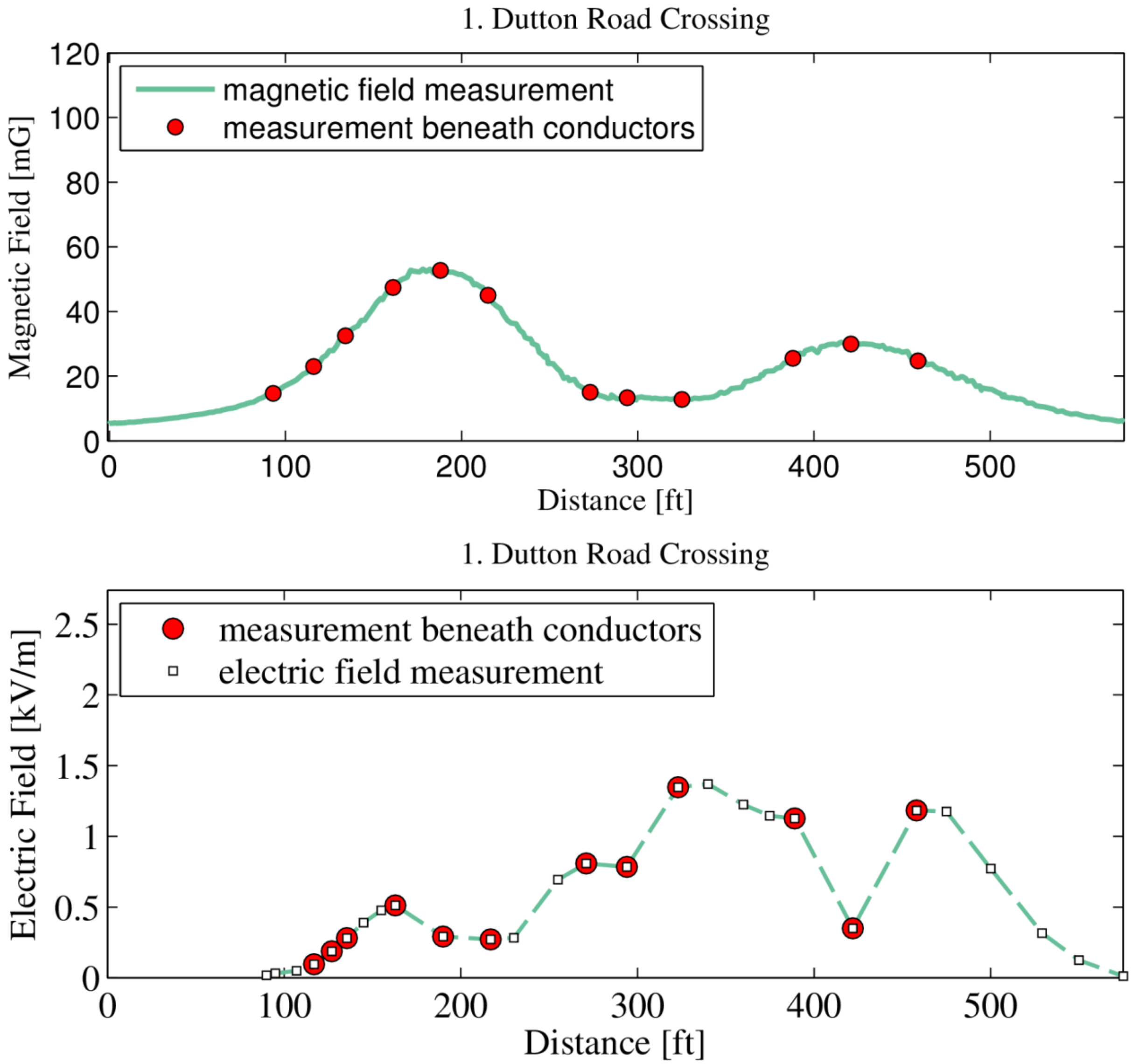


Figure E-7. Detailed EMF measurements performed at PUC Site 1 (Dutton Road in XS-8b) on July 24, 2018.

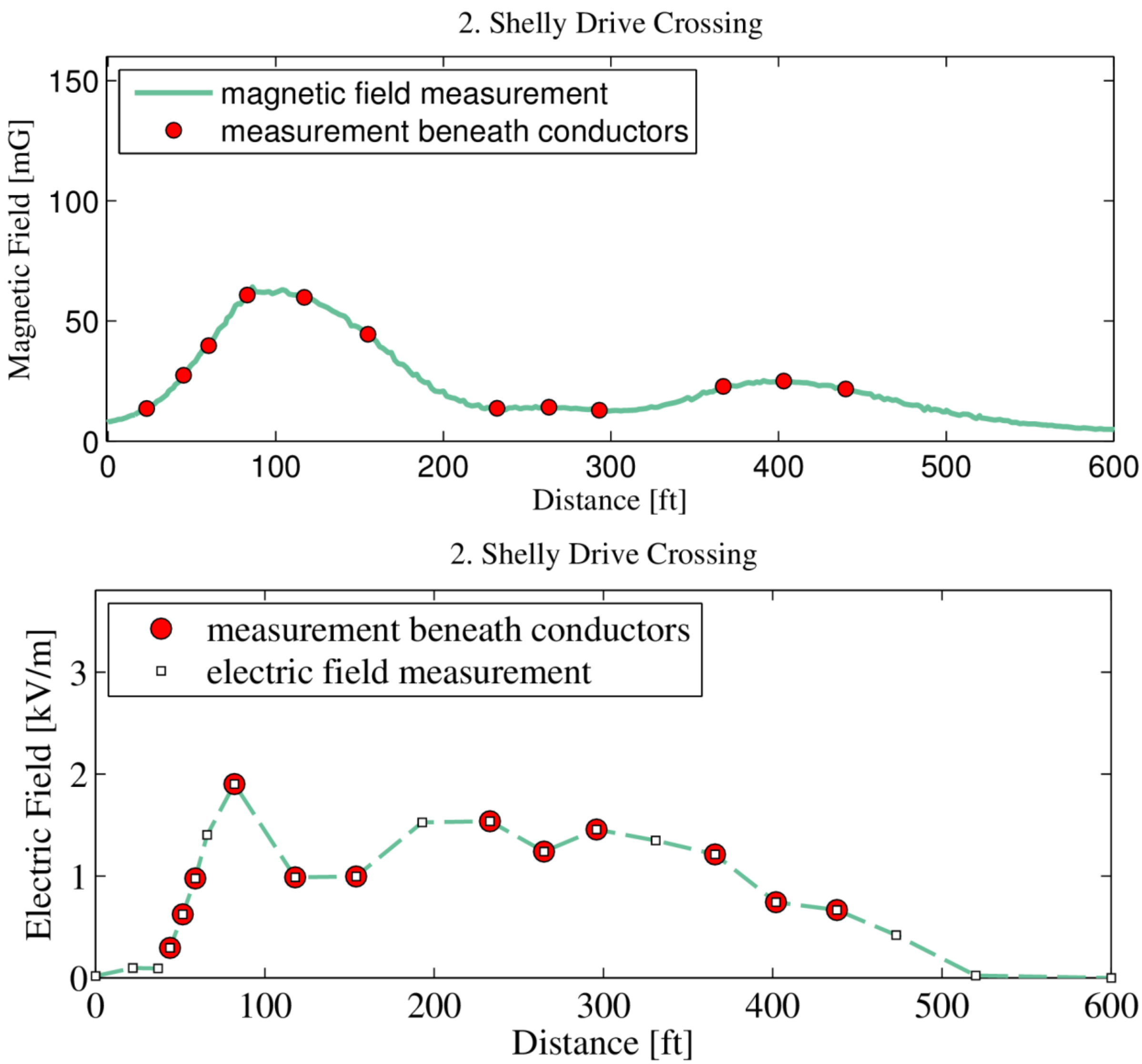


Figure E-8. Detailed EMF measurements performed at PUC Site 2 (Shelly Drive in XS-8d) on July 25, 2018.

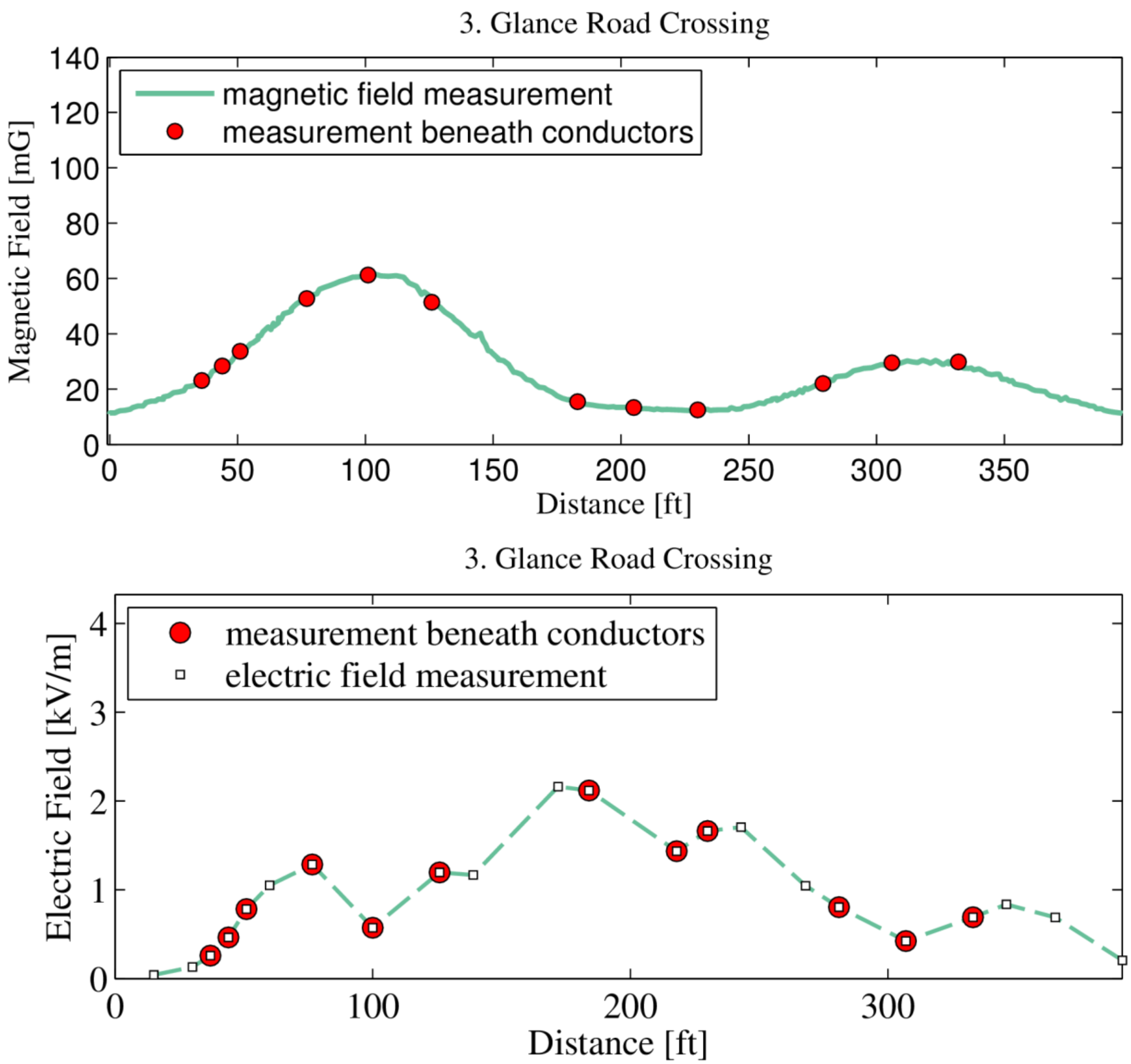


Figure E-9. Detailed EMF measurements performed at PUC Site 3 (Glance Road in XS-8d) on July 29, 2018.

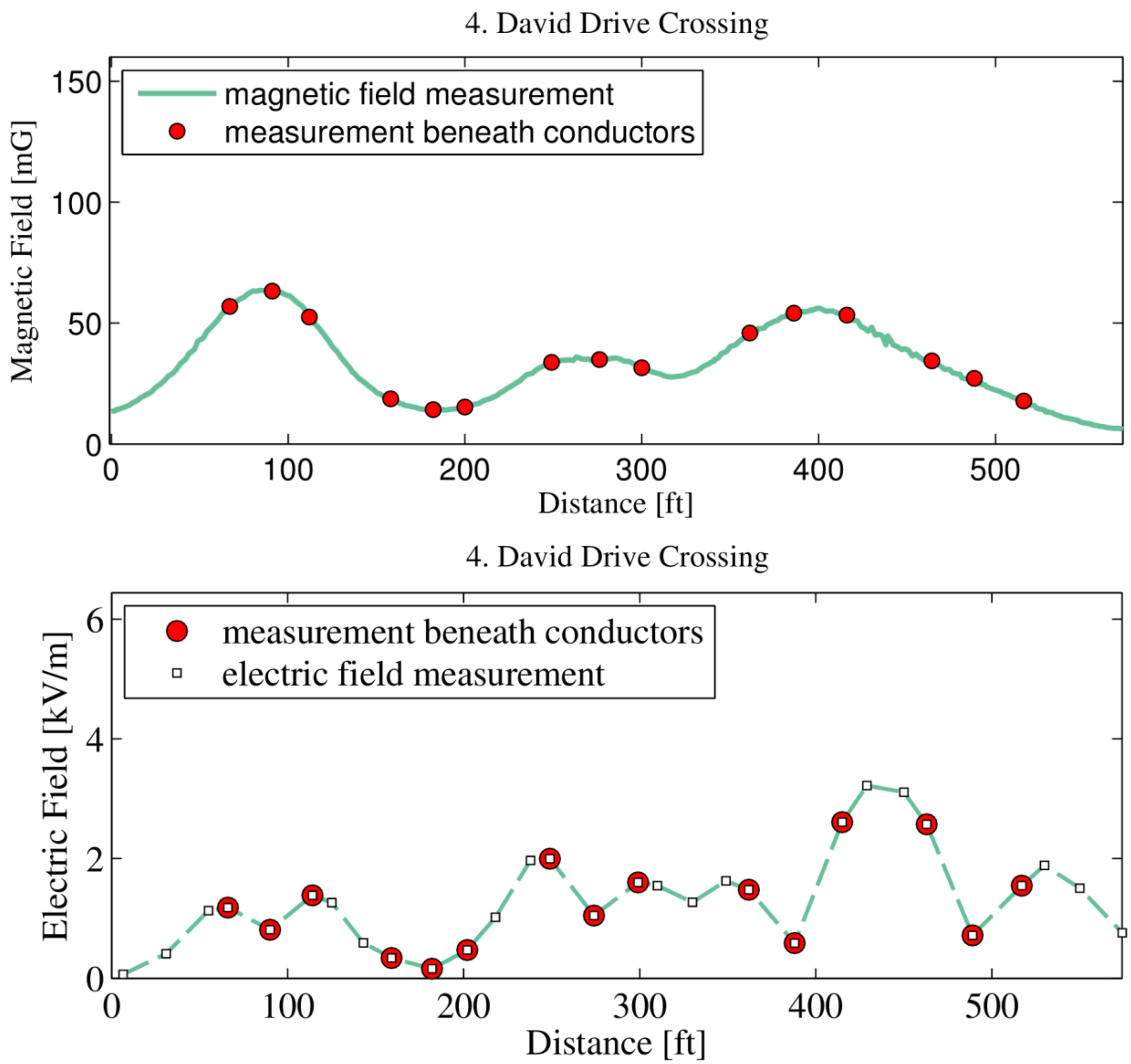


Figure E-10. Detailed EMF measurements performed at PUC Site 4 (David Drive in XS-10) on July 27, 2018.

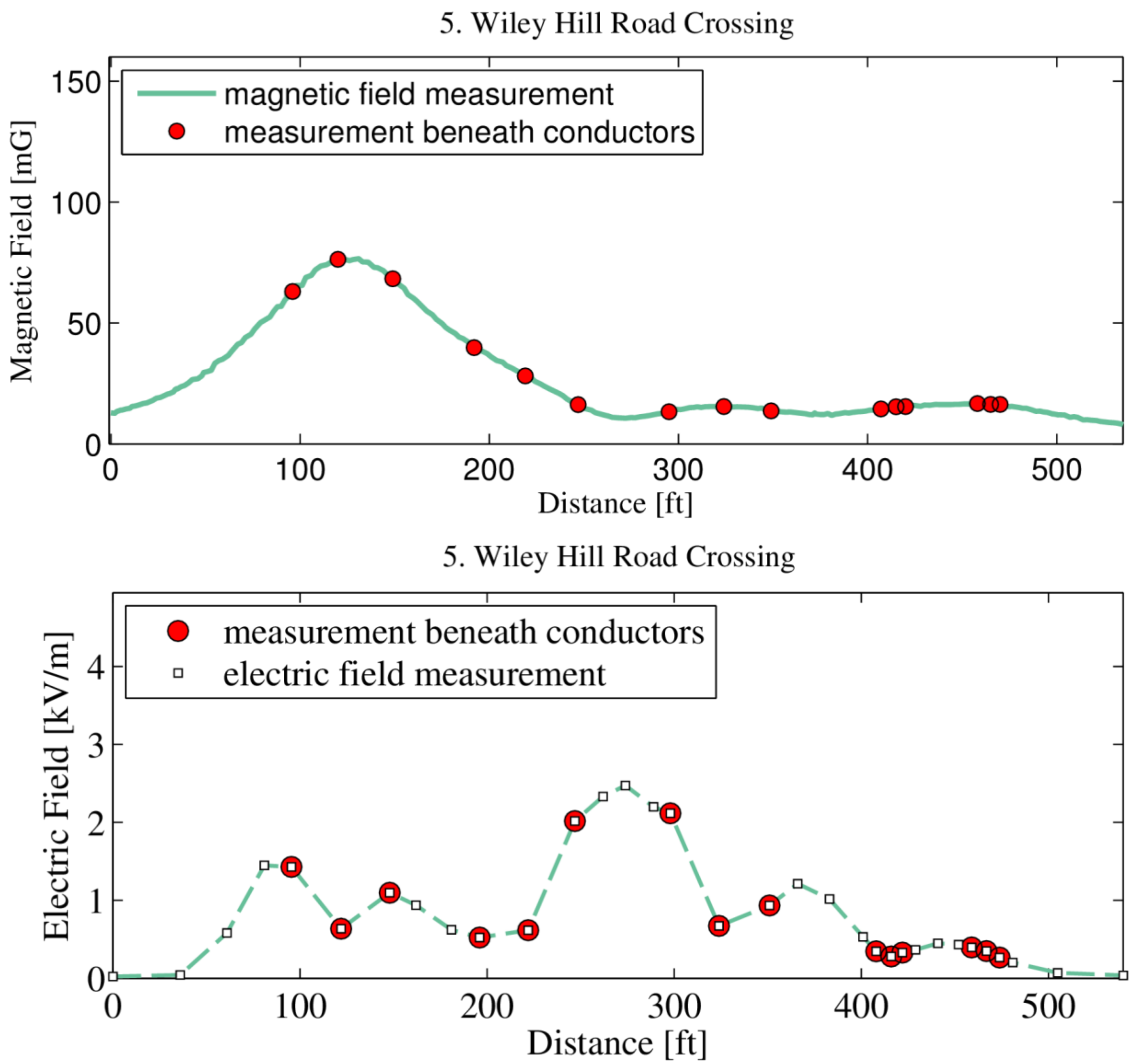


Figure E-11. Detailed EMF measurements performed at PUC Site 5 (Wiley Hill Road in XS-11) on July 25, 2018.

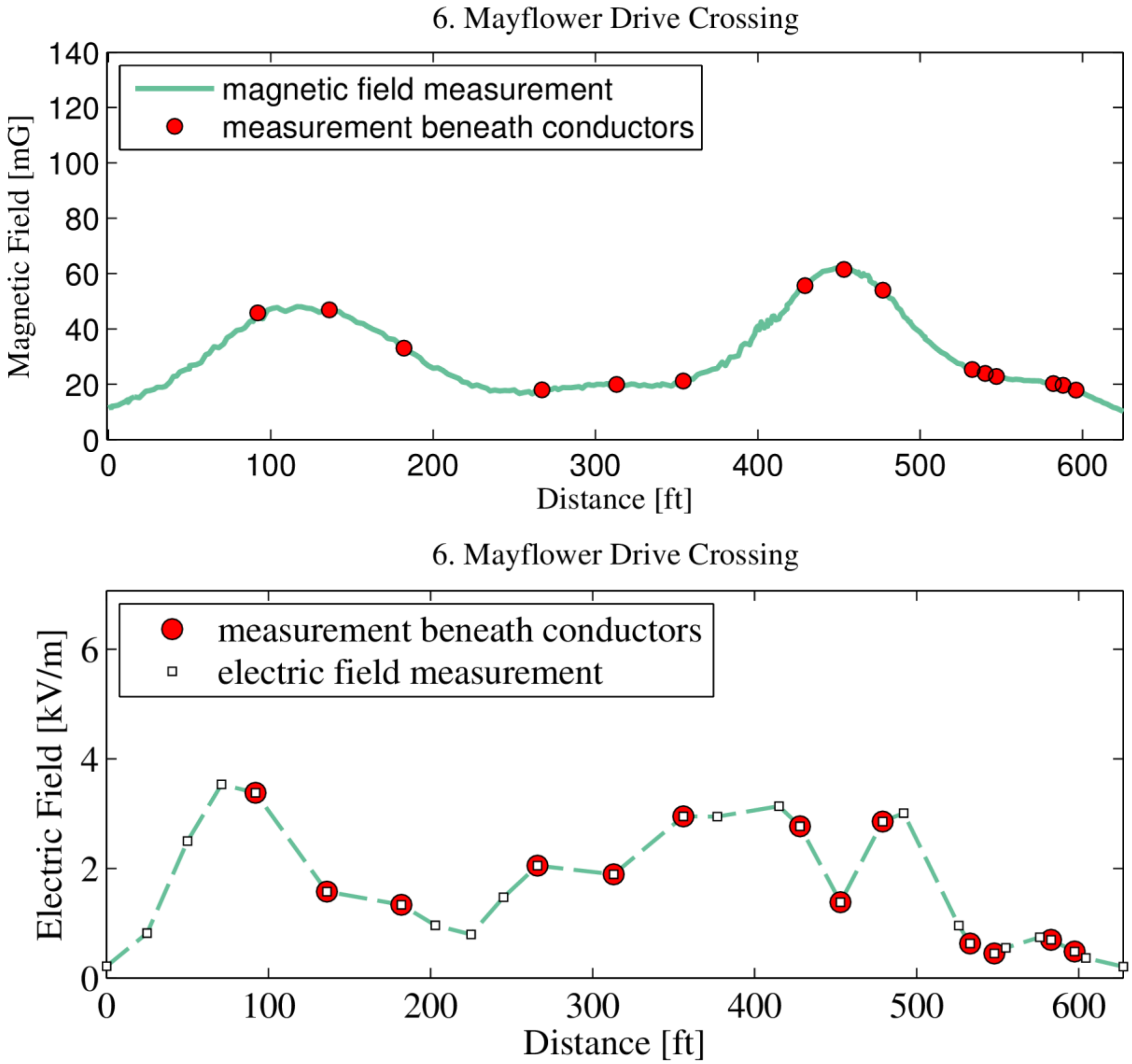


Figure E-12. Detailed EMF measurements performed at PUC Site 6 (Mayflower Drive in XS-11) on July 28, 2018.

Appendix F

Calibration Certificates

Certificate of Calibration

The calibration of this instrument was controlled by documented procedures as outlined on the attached Certificate of Testing Operations and Accuracy Report using equipment traceable to N.I.S.T., ISO 17025, and ANIZ540-1 COMPLIANT.

Instrument Model: EMDEX II

Frequency: 60 Hertz

Serial Number: 3074

Date of Calibration: 7/5/2018

Re-Calibration suggested at one year from above date.

EMDEX LLC
EMDEX-LLC
1356 Beaver Creek Drive
Patterson, California 95363
(408) 866-7266

H. Christopher Hooper
Calibration Inspector

suparule

Calibration Certificate

Holland Road,
National Technology Park,
Limerick, Ireland.

Tel: +353 (0) 61 201030
Fax: +353 (0) 61 330812

Email: info@suparule.com
Web: www.suparule.com

MODEL	*659600E*
Description	*Cable Height Meter*
Serial No.	*A53524*
Date of Calibration	*16th May 2018*
CHM Calibration Due Date	*16th May 2019*

Equipment used:

Model	Serial No.	Control No.	Calibration Due Date
SupaRule T30 Thermometer	8310412	CAL ID 041	8th May 2019
Leica Dista A2	4070150304		8th May 2019

Instrument calibrated to a national or international standards to better than ± 0.15°C (T30).

Method: After temperature stabilisation, readings taken are as follows:
Actual Temperature: 20.4°C
Temperature reading before adjustment: 20.7°C

Adjustment made.
Waveform calibrated.

Calibration accuracy:

After calibration the instrument will have an accuracy of ± 0.5% +/- 2digits provided that the displayed temperature is within ± 0.5°C of the ambient temperature. (Temperature range = 0°C to 35°C), as per its specification.

All the equipment used in this calibration are traceable to National or International standards.

Eoin O'Loughlin

Approved Signatory
Eoin O'Loughlin

ISO 9001:2008 EQA QUALITY ASSURED COMPANY

Directors: J. McDonnell, M.Meehan, B. O'Donoghue.
Suparule Systems Ltd., Registered in Ireland. Company No. 152205. Registered Office is at the above address

Kestrel®
Weather & Environmental Meters by NK

Certificate of Conformity

This instrument was produced under rigorous factory production control and documented standard procedures. It was individually visually inspected, leak tested and function tested for display, backlight, button and software performance. The accuracy of each of its primary measurements was individually calibrated and/or tested against standards traceable to the National Institute of Standards and Technology ("NIST") or calibrated intermediary standards. This instrument is certified to have performed at the time of manufacture in compliance with the following specifications as they apply to this meter's specific model, measurements and features.

Methods Used in Calibration and Testing

Wind Speed:

The Kestrel Weather & Environmental Meter impeller installed in this unit was individually tested in a subsonic wind tunnel operating at approximately 300 fpm (1.5 m/s) and 1200 fpm (6.1 m/s) monitored by a Gill Instruments Model 1350 ultrasonic time-of-flight anemometer. The Standard's maximum combined uncertainty is +/–1.04% within the airspeed range 706.6 to 3923.9 fpm (3.59 to 19.93 m/s), and +/–1.66% within the airspeed range 166.6 to 706.6 fpm (0.85 to 3.59 m/s).

Temperature:

Temperature response is verified in comparison with a Eutechnics 4600 Precision Thermometer or a standard Kestrel 4000 Weather & Environmental Meter calibrated weekly against the Eutechnics 4600. The Eutechnics 4600 is calibrated annually and is traceable to NIST with a system accuracy of +/– 0.05 °C.

Direction / Heading

The sensitivity of the magnetic directional sensor is verified at the component level by applying a magnetic field to the sensor and measuring the signal output at 4 points, as well as after assembly by orienting the unit to the cardinal directions and measuring the magnetic field output. In both cases, the compass output must be accurate to within +/– 5 degrees.

Relative Humidity:

Relative humidity receives a two-point calibration in humidity and temperature controlled chambers at 75.3% RH and 32.8% RH at 25° C. The calibration tanks are monitored with an Edgetech Model 2002 DewPrime II Standard Chilled Mirror Hygrometer. Following calibration, performance is further verified at an RH of approximately 43.2% against the Edgetech Hygrometer. The Edgetech Hygrometer is calibrated annually and is traceable to NIST with a maximum relative expanded uncertainty of +/– 0.2% RH.

Barometric Pressure:

Pressure response is verified against a Vaisala PTB210A Digital Barometer or a standard Kestrel 4000 Weather & Environmental Meter calibrated weekly against the Vaisala Barometer. The Vaisala Barometer is calibrated annually and is traceable to NIST with an accuracy of +/-0.15 hPa at +20°C defined as the root sum of the squares (RSS) of end point non-linearity, hysteresis error, repeatability error and calibration uncertainty at room temperature.

Approved By:

Michael Naughton, Engineering Manager

The enclosed Kestrel Weather & Environmental Meter was manufactured by Nielsen-Kellerman Co. at its facilities located at 21 Creek Circle, Boothwyn, PA 19061 USA.

Appendix G

Measurement Protocol Sent to PUC and NHSEC on June 18, 2018

Exponent®

M E M O R A N D U M

TO:	Randy Knepper, Director of Safety NH PUC; Paul Kasper, NH PUC; Pamela Monroe, NH SEC Administrator
FROM:	Exponent, National Grid, and Eversource
DATE:	June 18, 2018
PROJECT:	Merrimack Valley Reliability Project (NH SEC Docket 2015-05)
SUBJECT:	Measurements of Electric and Magnetic Fields

Introduction

To comply with the Order and Certificate of Site and Facility with Conditions issued by the New Hampshire Site Evaluation Committee (SEC) for the Merrimack Valley Reliability Project on October 4, 2016, as revised by the SEC's Order on Applicants' Motion for Clarification and Amended Order of Certificate of Site and Facility, National Grid and Eversource, through Exponent, provided a proposed protocol in consultation with the Safety Division of the New Hampshire Public Utilities Commission (PUC) for performing measurements of electric and magnetic fields (EMF) before the Project was placed into service. These measurements were carried out in January 2017 and a report on the findings was submitted on March 27, 2017. The measurements were supplemented by the Applicants' Memorandum of Magnetic Field Calibration on April 18, 2018.

The construction phase of the MVRP project is complete, and the MVRP lines are energized and in-service. Post-energization measurements are planned to be performed in July and August 2018 to comply with the revised Certificate condition requiring that measurements be performed at or near summer peak loading of the lines, with the acknowledgement that the Applicants cannot know in advance when peak loading will occur.

Proposed Post-Construction Measurement Protocol

The proposed measurement protocol is divided into several sections including Measurement Preparation, Measurement Procedure, and Reporting.

Locations for measurements in each of the 10 cross sections, specified in Tables A-1 and A-2 in the Application, at Appendix AG were previously selected for pre-energization measurements. Post-energization measurements will be performed at the same pre-energization measurement locations. Where that is not feasible and it is still deemed necessary to take post-energization measurements at another location, the Companies and Exponent will work with the PUC to find another, suitable location for post-energization measurements.

Measurements to be performed July 23 – August 3, 2018

It is anticipated that all measurements can be performed in one week. However, since foul weather (particularly precipitation) will interfere with the function of the measurement instruments and the valid measurement of electric fields, a two-week measurement period beginning July 23, 2018 and extending until August 3, 2018 is proposed. This two-week period is proposed to allow for all measurements to be completed in one measurement trip despite delays caused by foul weather. The Applicants will coordinate with PUC Safety Staff and the SEC administrator to the greatest extent practicable to identify specific dates and times that Exponent will conduct measurements in the field.

This timeframe has been discussed with National Grid and Eversource to confirm that there are no expected line outages, logging or system repairs, or other unusual line conditions scheduled for that period. Additionally, utility personnel will work with appropriate departments to ensure that necessary data (e.g., loadings of all transmission lines at the measurement locations) can be logged and available during the proposed measurement period

Measurement Procedure (same as pre-energization measurements)

At each identified measurement location, the National Grid or Eversource will clear underbrush and other conductive objects, if necessary, which may affect measurements. Exponent engineers will then photo-document the condition of the ROW and transmission lines. Engineers will then lay a long measuring tape on the ground beneath the lines which will be used to identify the horizontal location of conductors. The vertical height of each conductor over the tape will be measured and recorded using an acoustic and/or optical line height sensor. The time and date of the field measurements will be noted so that the loading on each of the lines at the time of field measurements can be matched.

Engineers will then proceed to perform EMF measurements by using measurement equipment and methodology outlined in *Institute of Electrical and Electronics Engineers* IEEE Standard 644-1994 (R2008). Measurements will be performed at a height of 1 meter above ground and will be performed for a transect perpendicular to the transmission line. If a transect other than perpendicular is necessary, the angle of the transect to the transmission lines will be noted and measurement distances will be adjusted accordingly.

Both electric fields and magnetic fields will be measured as the total field computed as the resultant of field vectors measured along vertical, transverse, and longitudinal axes.[1] The magnetic-field will be measured in units of milligauss (mG) by orthogonally-mounted sensing coils whose output is recorded by a digital meter (EMDEX II) manufactured by Enertech Consultants. The electric field will be measured in units of kilovolts per meter (kV/m) with a single-axis sensor accessory manufactured by Enertech Consultants for the EMDEX II meter. The single-axis sensor will be aligned sequentially along vertical, transverse, and longitudinal axes to capture the full vector electric field. These instruments meet the IEEE instrumentation standard for obtaining accurate field measurements at power line frequencies (IEEE Std.1308-

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[1] Measurements along the vertical, transverse, and longitudinal axes will be recorded as root-mean-square magnitude, which refers to the common mathematical method of defining the effective voltage, current, or field of an alternating current system.

1994). All meters and measurement accessories will be calibrated by the manufacturer using methods like those described in IEEE Std. 644-1994.

An effort has been made to perform measurements during a time period characteristic of peak loading. However, it is impossible to determine *a priori* whether peak loading will occur during the time of measurements. Therefore, if measurements are performed at line loadings lower than peak levels, field levels will be adjusted for peak loading conditions on all lines for comparisons to values in Table A-1 and A-2 in the Petition.

Measurement Procedure at PUC-Specified Road Crossings

Road crossings are often not suitable for performing detailed measurements and modeling of the EMF levels due to road traffic, line geometry and height in relation to the road, and other EMF sources along the road. Due to these factors, no modeling will be performed for these sites and thus detailed conductor position and height information will not be recorded. However, the measurement procedure will be similar to that outlined above and will include measurements of the total electric and magnetic field at each measurement location. Measurements will be performed specifically beneath the conductors of each transmission line with additional measurements performed between transmission lines as possible given the above described factors.

Report

Exponent will prepare a report detailing measurement methodology and a summary of both measurements taken before and after the Project is placed into service. This report will include aerial maps from Google Earth of each measurement location with annotations reflecting the specific locations of electric and magnetic field measurements as well as a graphical summary of both electric and magnetic field measurements. Consistent with the NHSEC Certificate of Site and Facility, measurements that are performed outside of near-peak or peak loading conditions will be summarized both in raw form as well as adjusted for peak loading conditions.