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VIA ELECTRONIC MAIL AND HAND DELIVERY

March 28, 2017

New Hampshire Site Evaluation Committee
Pamela G. 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 and New England Power Company d/b/a National Grid: Applicants' Report Summarizing Pre-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 Applicants' report summarizing Pre-Construction Measurements of Electric and Magnetic Field Levels.

Please contact me directly should you have any questions.

Sincerely,

Adam M. Dumville

AMD:
Enclosure

cc: SEC Distribution List
Mr. Robert J. Wyatt, NH PUC
Assistant Director, Safety Division

Electrical Engineering and
Computer Science Practice

Exponent®

Eversource / National Grid Merrimack Valley Reliability Project

Pre-Construction Measurements of Electric and Magnetic Field Levels

Exponent®

Eversource / National Grid Merrimack Valley Reliability Project

Pre-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

Exponent
17000 Science Drive, Suite 200
Bowie, MD 20715

March 27, 2017

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Acronyms and Abbreviations

AAL	Annual average loading
AC	Alternating current
EMF	Electric and magnetic fields
IEEE	Institute of Electrical and Electronics Engineers
kV	Kilovolt
kV/m	Kilovolts per meter
MW	Megawatt
MVAR	Megavolt-ampere reactive
MVRP	Merrimack Valley Reliability Project
mG	Milligauss
ROW	Right-of-way
V/m	Volts per meter

Limitations

At the request of the Public Service Company of New Hampshire, d/b/a Eversource Energy (Eversource), and the New England Power Company (NEP), d/b/a National Grid, Exponent measured and modeled the levels of electric and magnetic fields associated with the existing 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) includes the construction of a new 345-kilovolt transmission line (designated the 3124 Line) that is planned to run 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-construction measurements of electric and magnetic fields (EMF). 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 before these lines were moved and 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 ten cross sections of the proposed line specified in Tables A-1 and A-2, Appendix AG, Attachment A, of the Application. The PUC further requested EMF measurements at six road crossings of the right-of-way (ROW).

For each of the ten 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 which 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 a site, are consistently 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. In addition, the demonstrated agreement between modeling and measurements confirms the reasonableness of the input data used for modeling the EMF from existing transmission lines and accuracy of the modeling approach followed in the Application.

Introduction

The Merrimack Valley Reliability Project (MVRP or Project) includes the construction of a new 345-kilovolt (kV) transmission line (designated the 3124 Line) that is planned to run approximately 24.4 miles from the Tewksbury 22A Substation in Tewksbury, Massachusetts, to the Scobie Pond Substation in Londonderry, New Hampshire. Approximately 18 miles of the line will pass through Londonderry, Hudson, Windham, and Pelham in New Hampshire, and 6.5 miles through Dracut, Andover, and Tewksbury in Massachusetts. Of the 18 miles in New Hampshire, Eversource will construct 10 miles of line through Londonderry and Hudson, and National Grid will construct 8 miles of line through Hudson, Windham, and Pelham.

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-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 December 2, 2016, letter 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 ten measurement sites (four in National Grid service territory and six 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 ROW.[1]

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).

The measurement methods and protocol were outlined in the memorandum *"Measurements of Electric and Magnetic Fields"* sent on November 11, 2016, to the PUC and NHSEC. A copy is attached in Appendix G.[2] At each of the ten selected cross sections, Exponent recorded the conductor position and height of all transmission lines 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).

[1] 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.

[2] A copy of this memorandum is attached in Appendix G

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 ten sites along the route. Measurements 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 ten 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 prior to moving any existing lines 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 the 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

Prior to performing any measurements, Exponent, National Grid, and Eversource engineers jointly developed a measurement protocol, the purpose of which was to ensure compliance with the NHSEC Order for making measurements of EMF levels from the existing lines before these lines were moved and under conditions as near as possible to conditions assumed in the original modeling. This protocol, titled Measurements of Electric and Magnetic Fields, was sent to both the NHSEC and the PUC for review and comment. 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, which was used 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).[3,4] 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.[5] The magnetic field was measured in units of milligauss (mG) by orthogonally-mounted sensing coils

[3] 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.

[4] 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.

[5] 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.

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 meter.[6] 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 644-1994-R2008.[7]

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). 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.

6 Measurement equipment was manufactured by Enertech Consultants, Cupertino, CA.

7 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).

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 (BPA), which also were used for the modeling of EMF levels in the Application (BPA, 1991). The inputs to the program include data regarding voltage, current flow, phasing, and conductor positions measured on-site at each location.

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 locations were divided into two segments based upon whether the transmission lines were primarily in National Grid or Eversource service territory.

The locations of the measurement sites, including the PUC road crossings, are shown in Figure 1 (National Grid service territory) and Figure 2 (Eversource service territory). The ten 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 midspan of lines).

3) Free of underbrush, trees, or other conductive objects.

4) Provide a measurement transect perpendicular to the transmission line conductors.[8]

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.

[8] 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, below in Table 1.[9] With the exception of Site 2 in XS-8c, in which a single-phase local distribution circuit was present, all measurement sites were selected without additional sources of EMF.[10] All measurement sites had tall trees located along both ROW edges, which generally provided some reduction of electric-field levels within approximately 50 feet of either ROW edge.[11]

The discussion below provides a more detailed description of the cross sections as well as 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 Number	Date	Municipality	Monitoring Location
1	XS-8b	1/12/2017	Pelham	East of Old Lawrence Road
2	XS-8c	1/16/2017	Pelham	Off Tina Avenue
3	XS-8d	1/13/2017	Windham	Along Winter Street
4	XS-9	1/13/2017	Hudson	Southeast of Griffin Road
5	XS-10	1/25/2017	Londonderry	South of Dan Hill Road
6	XS-11	1/27/2017	Londonderry	North of Wiley Hill Road
7	XS-12	1/20/2017	Londonderry	Off Davis Drive
8	XS-13	1/19/2017	Londonderry	Along Bancroft Road
9	XS-14	1/20/2017	Londonderry	Off Snow Flake Lane
10	XS-15	1/19/2017	Londonderry	Along Londonderry Rail Trail
PUC 1	XS-8b	1/12/2017	Pelham	Dutton Road
PUC 2	XS-8d	1/13/2017	Pelham	Shelly Drive
PUC 3	XS-8d	1/13/2017	Windham	Glance Road
PUC 4	XS-10	1/17/2017	Hudson	David Drive
PUC 5	XS-11	1/17/2017	Londonderry	Wiley Hill Road
PUC 6	XS-11	1/25/2017	Londonderry	Mayflower Drive

9 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.

10 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.

11 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.

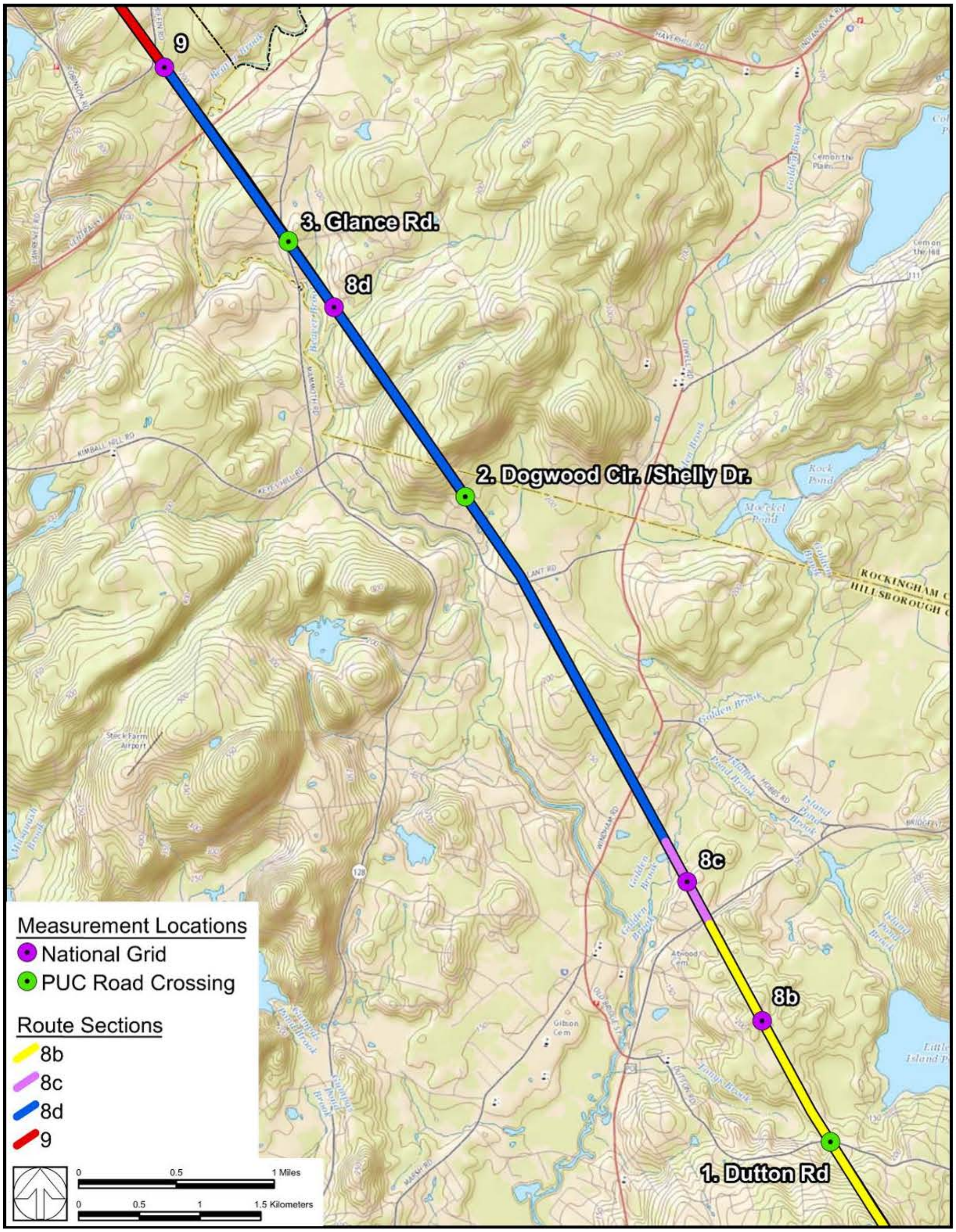


Figure 1. Route of the transmission line and locations of measurement sites in National Grid service territory.

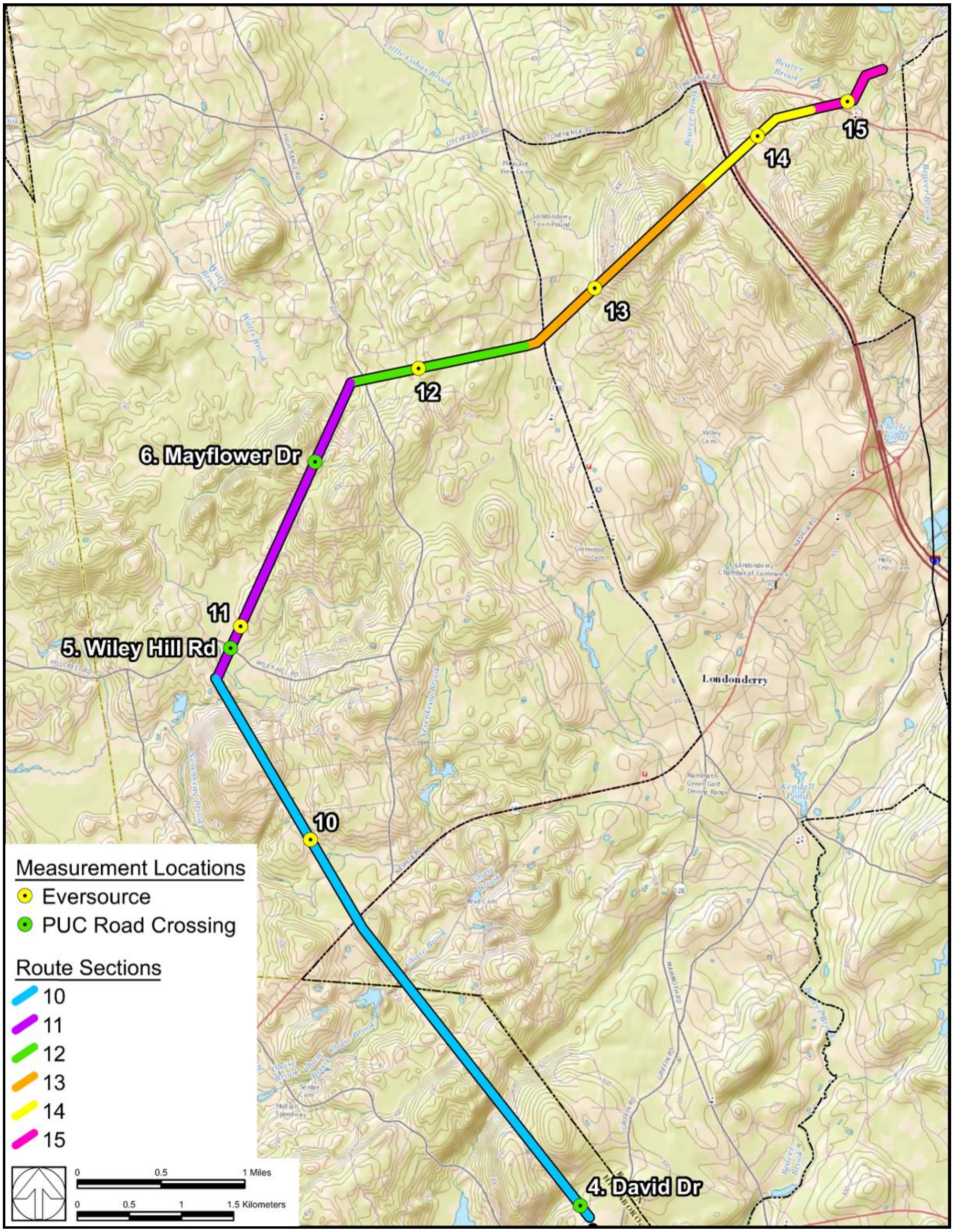


Figure 2. Route of the transmission line and locations of measurement sites in Eversource service territory.

Measurement Site 1 is located in cross section XS-8b where the ROW width is 350 feet. The measurements were performed January 12, 2017 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. A 115-kV transmission line (Y-151) is constructed on H-frame structures at the center of the ROW. The terrain varied somewhat (less than approximately 4-5 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.

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 the 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 as the measurement path was taken along a dirt road. A Y-151 structure was located approximately 50 feet to the south of the measurement path, on top of a hill. 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 (Measurements: January 16, 2017).

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 N-214 and O-215 transmission lines in XS-8d is identical to that of XS-8b and XS-8c, but the phase of the Y-151 line differs from previous sections. 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 [*south side*] of Winter Street) (Measurements: January 13, 2017).

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 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 2-3 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 2-3 feet in height) crossed the measurement path near the inside conductor of the N-214 line, and the measurement transect was located approximately 75 feet north of the nearest N-214 structure and approximately 65 feet south of the nearest O-215 structure (Measurements: January 13, 2017).

Measurement Site 5 is located south of Dan Hill Road in Londonderry in XS-10 on a portion of the ROW approximately 567 feet in width. This ROW currently contains transmission lines O-215, 451/452 (a direct current transmission line), N-214, and 326, respectively from west to east. The terrain at this location was quite rough, and varied slightly over most of the ROW, but beyond the 326 line, the terrain sloped downward significantly to the ROW edge. While Eversource cleared a measurement path across the ROW, significant tall brush and hills remained on both sides of the measurement path (Measurements: January 25, 2017).

Measurement Site 6 is located on a portion of XS-11, north of Wiley Hill Road in Londonderry. XS-11 is a 460-foot wide ROW with transmission lines 380, 326, Z119, and X116 from west to east. The terrain along this path was very rough with hillocks characteristic of a bog on the west side of the ROW and dense underbrush on the east side. Despite clearing of the ROW by Eversource, the remaining small brush stalks increased the roughness of the terrain. In addition, a 10-foot wide pool of water was located between the Z119 and X116 lines; for this reason there is a break in measurements at this point (Measurements: January 27, 2017).

Measurement Site 7 is located on a portion of XS-12, off Davis Drive in Londonderry. This 635-foot wide ROW has transmission lines 380, 326, S188, X116, and Z119 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 remaining small brush stalks increased the roughness of the terrain and there is tall brush immediately outside the cleared area (Measurements: January 20, 2017).

Measurement Site 8 is located on a portion of XS-13 along the south side of Bancroft Road in Londonderry. The transmission lines located on this portion of the row, from west to east, include 380, 326, R187, X116, and Z119, along with distribution line 365. The terrain on this ROW slopes significantly up from west to east, but since measurements were taken on the shoulder of the road, the site was generally quite smooth. There are dirt berms and tall brush on the side of the road, as well as some brush remaining after the ROW was cleared (Measurements: January 19, 2017).

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, R187, X116, and Z119 (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 (Measurements: January 20, 2017).

Measurement Site 10 is located in 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, R187, X116, and Z119 (from north to south across the ROW), as well as a double-circuit distribution circuit near the southern ROW edge. The terrain along this portion of the route (much of which is 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 (Measurements: January 19, 2017).

Results

EMF measurements were performed on January 12, 13, 16, 17, 19, 20, 25, and 27, 2017, in various portions of the route. 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. Consistent with the NHSEC Order, since all measurements during this period were measured outside of near-peak or peak-loading conditions, the results have been summarized both in raw form, as well as adjusted for peak-loading conditions.

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

In order 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.

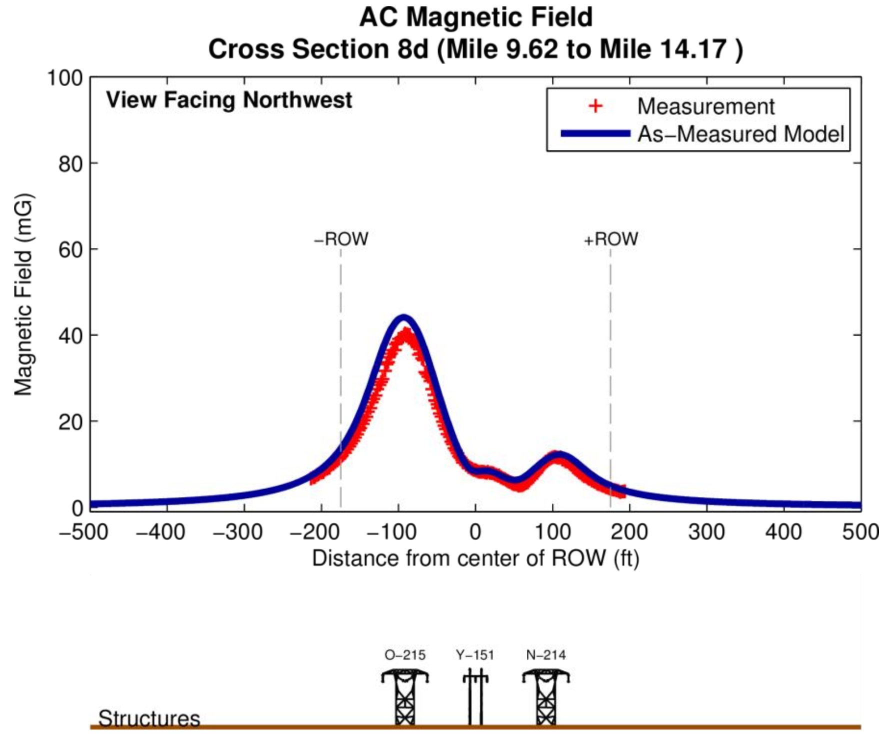
3) differences in the roughness or slope of the terrain; and

4) for electric-field measurements, the presence of conductive objects such as trees, brush, transmission line structures, or 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 selected because the site conditions were among the most consistent with the conditions assumed in the calculation model described in the Application. Consequently the match between modeling and measurements is among the best.

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 solid dark blue line. Magnetic-field measurements were measured every 1-3 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 5-50 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.



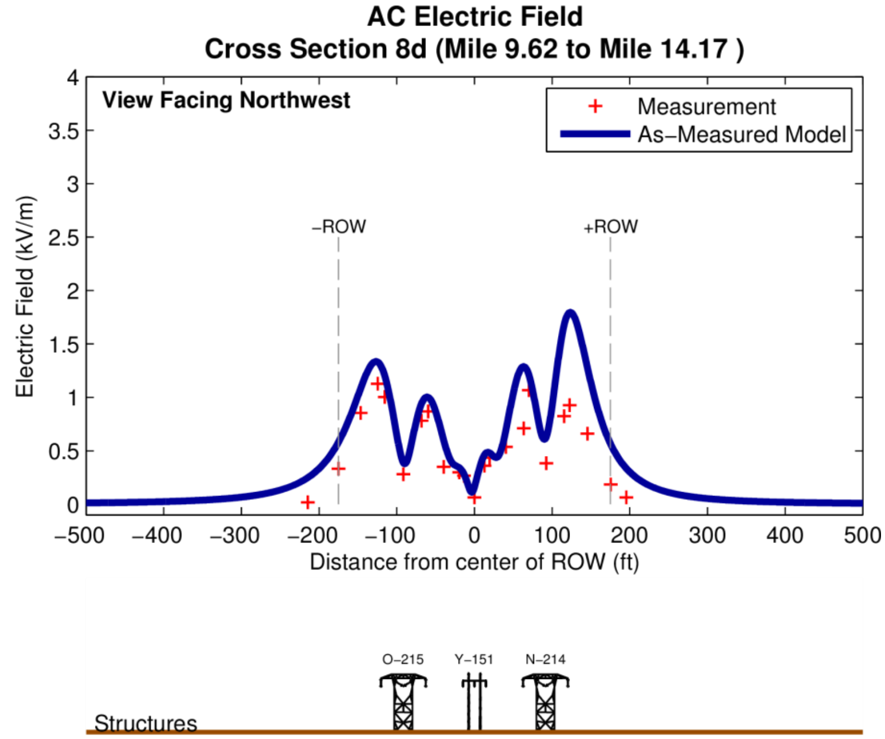


Figure 3. Comparison of measurements at Site 3 (XS-8d) with calculations from the As-Measured Model.

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

The measurements and calculated values match well at this site because of the relatively smooth terrain, the general lack of trees and underbrush, the lack of extraneous sources of EMF, and because the measurement path was very close to perpendicular to the transmission line. The slope of the ground over the width of the ROW likely reduces the match between measurement and modeling somewhat, but measurements and modeling overall match quite well. 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 11% for the magnetic field. This deviation would have been much smaller, both at Site 8d and elsewhere 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 greater (a mean deviation of 35%), 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.

The degree of match between measurements and modeling at other locations was found to depend strongly 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 1, 3, and 4 (XS-8b, 8d, and 9—generally good measurement locations) all had a mean deviation between measurements and modeling of approximately 12% or less. Measurement Sites 2, and 5 through 8 (XS-8c, and XS-10 through XS-13) had a magnetic-field mean deviation between measurements and modeling of approximately 16-22%, while measurement Sites 9 and 10 (XS-14 and XS-15) had larger deviations of 33% and 54%, respectively.

Magnetic-field levels at the ROW edge

In addition to comparing the EMF levels across the ROW, it is also useful to compare the ROW-edge field levels between modeling and measurements. This comparison is shown in a bar graph (Figure 4) in which the measured field level at the ROW edge is shown in a blue bar and the modeled field level at the same 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 12 mG is slightly lower than the modeled level of 14 mG at the same location. Likewise, on the '+' ROW edge, the measured magnetic-field level of 4.4 mG is slightly lower than the modeled level of 5.0 mG.

Comparison of ROW-edge EMF levels in other sections shows a similar trend with the measured field level lower than the modeled level. There are a couple of exceptions—for example, the measured magnetic-field level at the '–' ROW edge in XS-9 and XS-10 is slightly higher than the modeled level at the same location. The ROW-edge electric-field levels are also shown, but generally provide less information because the trees ubiquitous at the ROW edges significantly attenuate the electric field at these locations.

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

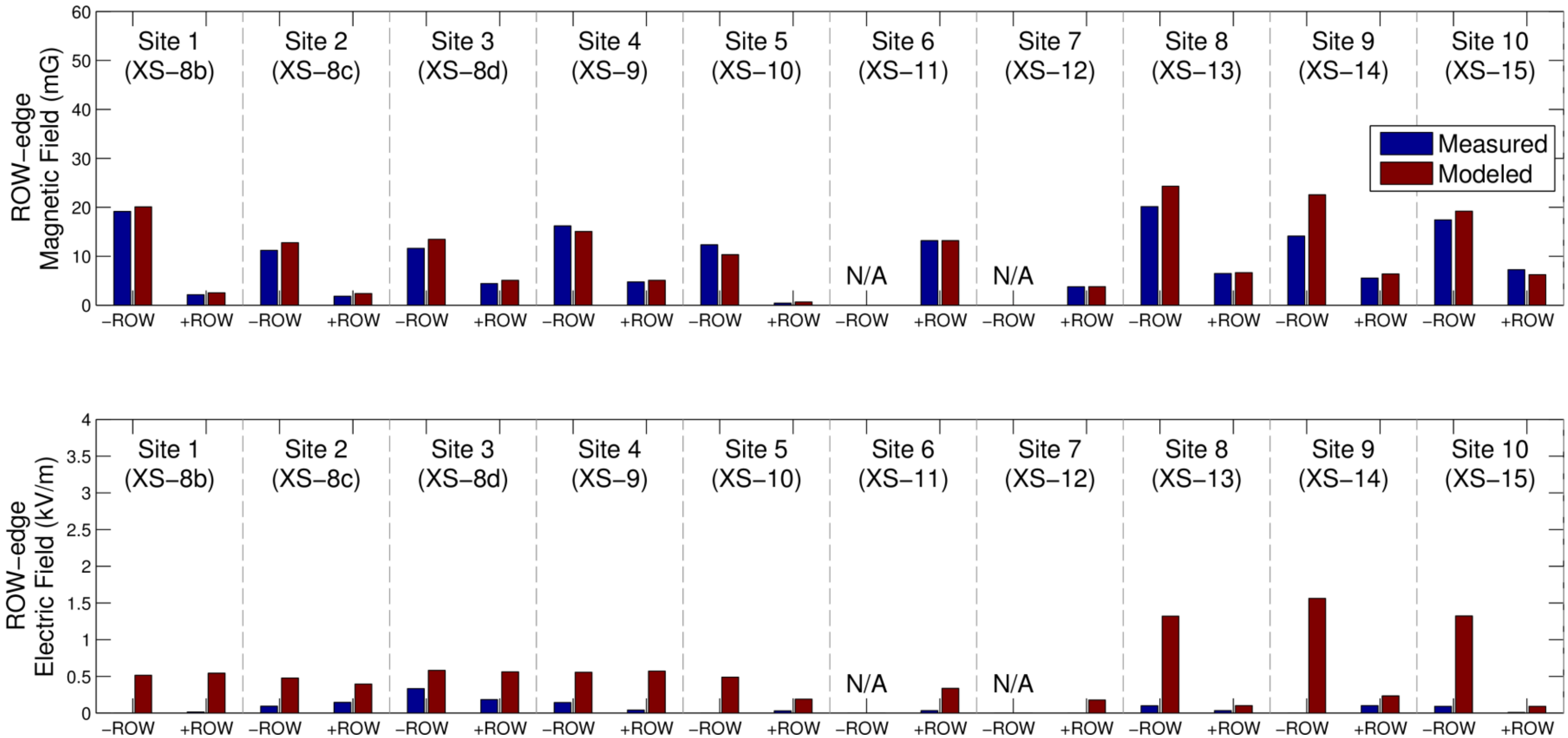


Figure 4. Comparison of measured and modeled EMF levels at the ROW edges.

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

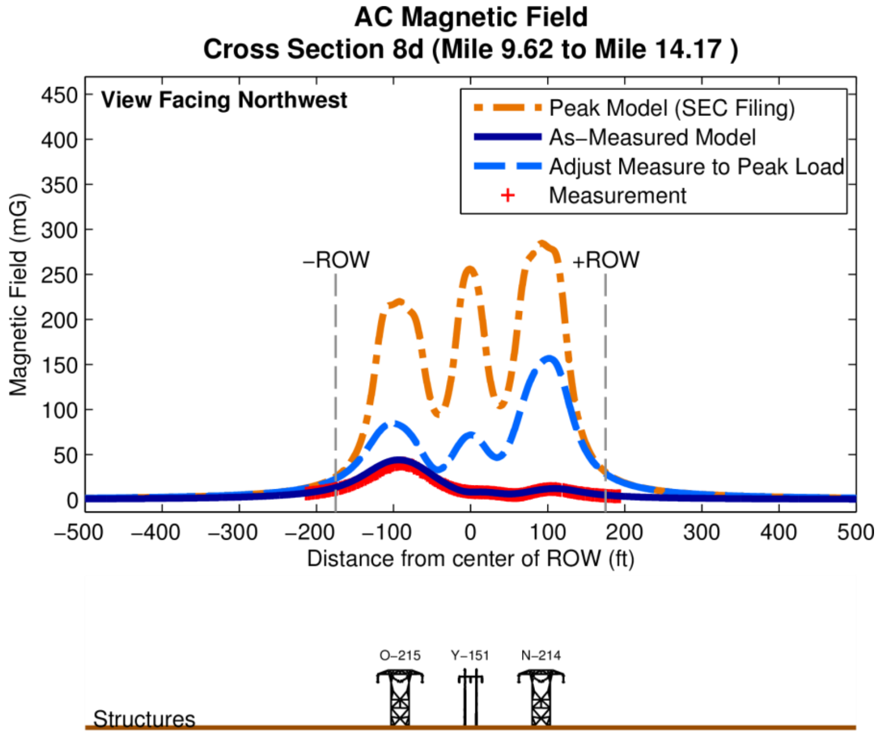
The EMF levels associated with each of the ten existing transmission line configurations were provided in the Application for both average- and peak-loading conditions. Direct comparisons of measurements of magnetic-field levels with calculations in the Application are complicated by differences in power 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:

- Measured electric fields are similar to or lower than values presented in the Application.
- Measured magnetic fields adjusted to peak loading are similar to or lower than magnetic fields at peak-loading presented in the Application.
- Measured magnetic fields are generally similar to or lower than calculated magnetic fields at average loading presented in the Application.
- 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.

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 (NHSEC Filing). 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, above, Figure 5 also shows both the field levels for the pre-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 field levels as well as EMF field 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 34, 40, and 48 feet for the Y-151, N-214, and O-215 lines, respectively) than was conservatively assumed in the Application (20.8, 32, and 32 feet for the Y-151, N-214, 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 "Pre-Project AAL [annual average loading]" and "Pre-Project annual peak (2018)" correspond to the modeling values previously submitted to the NHSEC. The remaining scenarios: "As-Measured (Measurements)," "As-Measured (Model)," and "As-Measured (Adjusted for Peak)" 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 Pre-Project annual peak (2018) loading condition, but also below the annual average loading condition. Magnetic-field levels at the ROW edge from the As-Measured – Adjusted for Peak Model (23-29 mG) are slightly lower than ROW-edge magnetic-field levels previously submitted to the NHSEC for peak loading (25-30 mG).



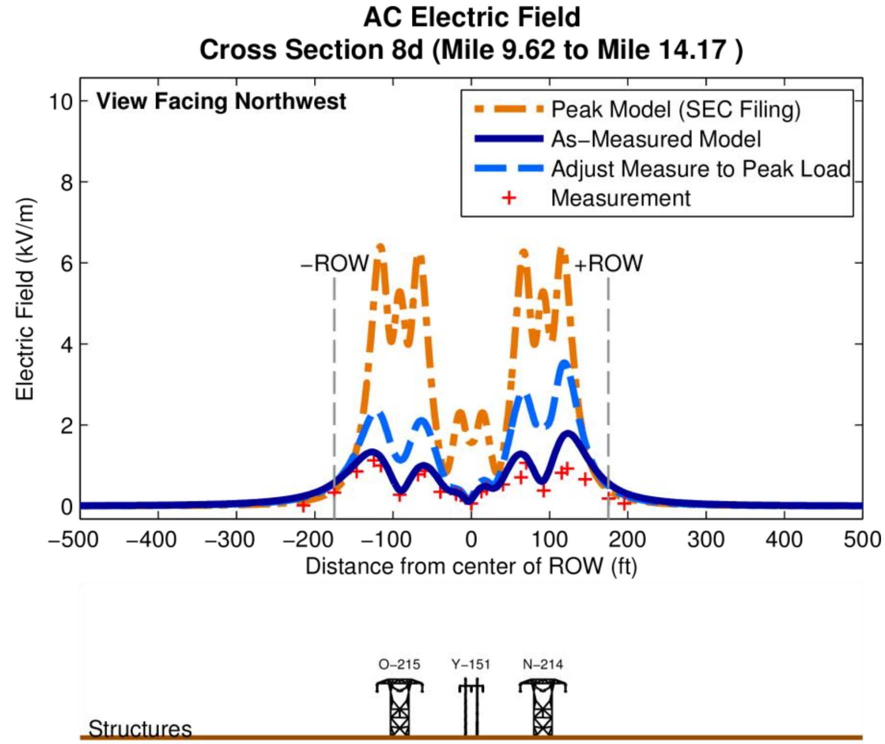


Figure 5. Comparison of measurements at Site 3 (XS-8d) with calculations from the As-Measured Model, the As-Measured – Adjusted to Peak Model and the calculations (at annual-peak loading) provided in the Application.

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

Results at other cross sections also show similar trends to those presented here with EMF levels similar to or lower than those presented in the Application. 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.

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

		Distance from Centerline of ROW				
Section Number	**Condition**	**- ROW Edge -100 ft**	**-ROW Edge**	**Max on ROW**	**+ROW Edge**	**+ROW Edge +100 ft**
8d (Magnetic Field)	Pre-Project (average height and load)	1.9	7.3	60	6.6	1.8
	Pre-Project (minimum height and peak load)	6.5	25	285	30	7.3
	Measured Field (1/13/2017)	**n/a**	**12**	**40**	**4.4**	**n/a**
	Modeled Field (for measured line height and load on 1/13/2017)	**3.5**	**14**	**44**	**5.0**	**1.7**
	Modeled Field (for line height and load peak conditions)	**6.4**	**23**	**157**	**29**	**7.2**
8d (Electric Field)	Pre-Project (average height)	0.1	0.5	2.7	0.5	0.1
	Pre-Project (minimum height)	0.0	0.4	6.4	0.4	0.0
	Measured field (1/13/2017)	**n/a**	**0.3**	**1.1**	**0.2**	**n/a**
	Modeled Field (for measured line height on 1/13/2017)	**0.1**	**0.6**	**1.8**	**0.6**	**0.1**
	Modeled Field (for line height adjusted peak load conditions)	**0.1**	**0.6**	**3.5**	**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. Due to these factors no modeling was performed for these sites. As an example, EMF measurements are shown below in Figure 6 for the road crossing (PUC 1) at Dutton Road in Pelham. Figure 6 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 have been placed on the aerial photograph at 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 7. The figure shows the recorded magnetic-field level (top) and electric-field level (bottom), measured with distance along the measurement path. Magnetic field measurements were recorded every 1-3 feet and so are shown as a continuous line. In contrast, electric field measurements were recorded every 5 to 50 feet and so measurements are indicated by a white square connected by dashed lines for visual reference. In addition, each of these figures also includes red dots for reference 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 line cross section and are far below health-based standards and guidelines for human exposure to EMF that were discussed in the Application.

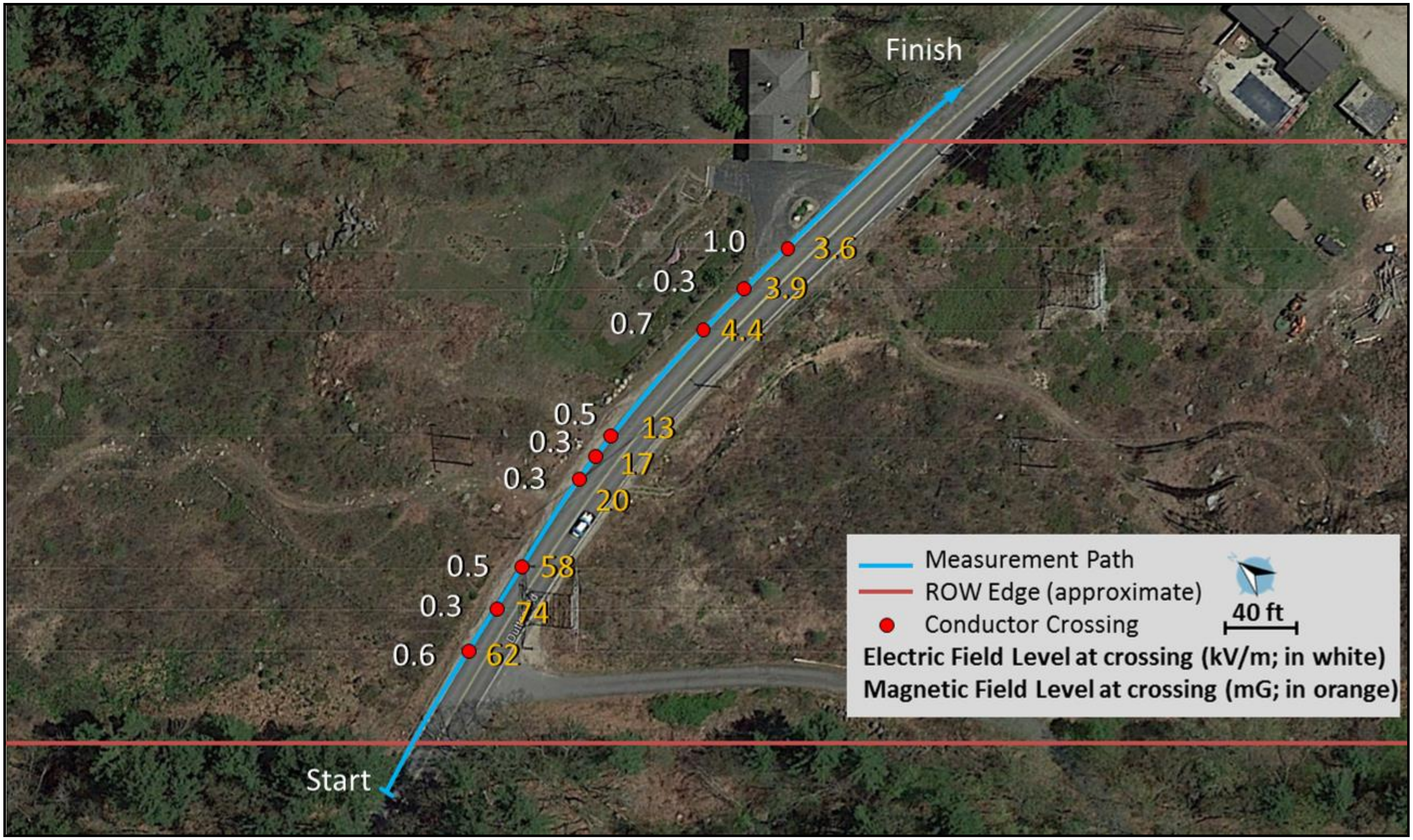
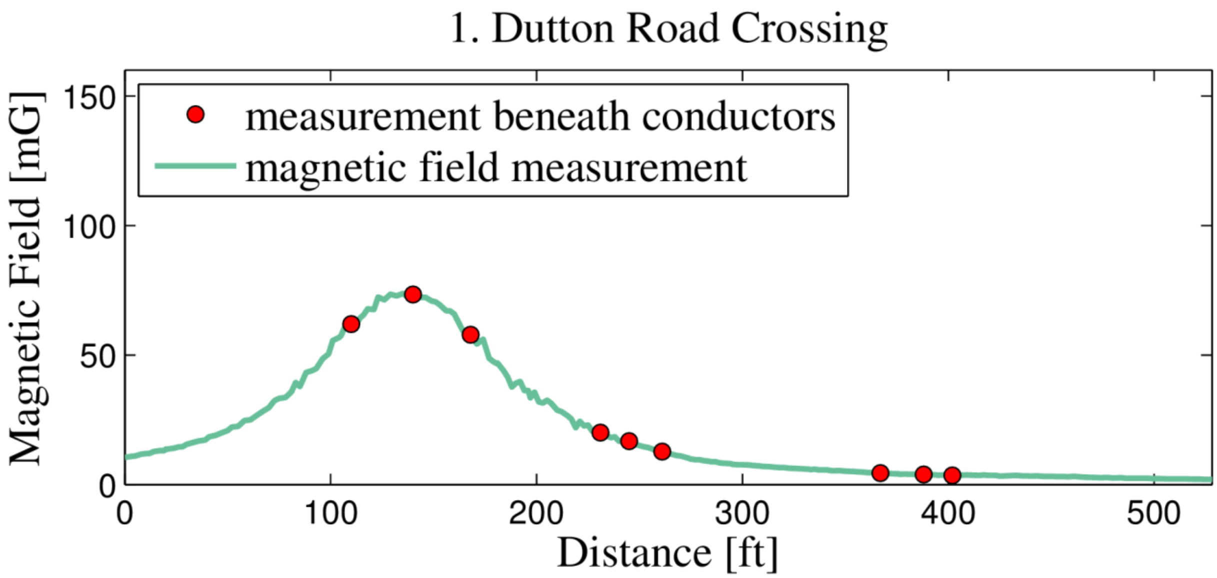


Figure 6. PUC Road Crossing 1: Dutton Road in Pelham.



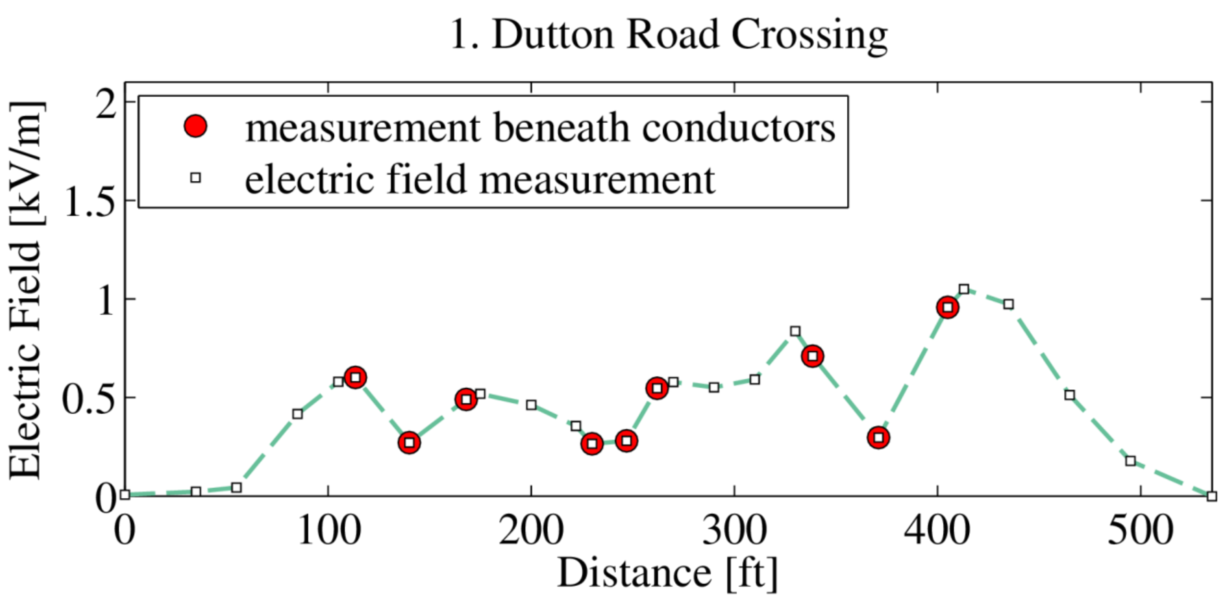


Figure 7. Detailed EMF measurement results recorded at PUC Road Crossing 1: Dutton Road in Pelham.

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 before any existing lines were moved and under conditions as near as possible to conditions assumed in the original modeling.

Measured magnetic-field levels are very similar to or lower than modeled levels and measured electric-field levels are 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 existing transmission lines on the Project route are similar to or lower than those presented in the Application. The lower EMF values are primarily due to higher conductor heights at the measurement sites compared to lower conductor heights 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 a high but accurate estimate 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. In addition the demonstrated agreement between modeling and measurements confirms the reasonableness of the input data used to model EMF from the existing lines (pre-construction) and accuracy of the modeling approach followed in the Application.

Appendix A

Summary Tables of Measured and Calculated EMF Levels

For both electric- and magnetic-field measurements, below, scenarios 1 and 2 ("Pre-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. Pre-Project (average line height)
    2. Pre-Project (minimum 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. Pre-Project (average height and load)
    2. Pre-Project (minimum line height and 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 never performed at a distance of ±100 feet from the ROW edge (as is 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 measurement locations (XS-11 and XS-12) for which it was not possible to measure electric- and magnetic-field levels at 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	Pre-Project (average line height and load)	1.4	6.2	52	5.5	1.3
	Pre-Project (minimum line height and peak load)	4.7	21	297	26	5.5
	Measured Field (1/12/2017)	**n/a**	**19**	**111**	**2.1**	**n/a**
	Modeled Field (for measured line height and load on 1/12/2017)	**4.3**	**20**	**118**	**2.4**	**1.2**
	Modeled Field (for line height and load adjusted to peak conditions)	**4.7**	**21**	**238**	**24**	**5.4**
8c	Pre-Project (average line height and load)	1.4	6.2	71	5.5	1.4
	Pre-Project (minimum line height and peak load)	4.8	21	311	26	5.5
	Measured Field (1/16/2017)	**n/a**	**11**	**51**	**1.8**	**n/a**
	Modeled Field (for measured line height and load on 1/16/2017)	**3.0**	**13**	**55**	**2.4**	**1.0**
	Modeled Field (for line height and load adjusted to peak conditions)	**4.6**	**20**	**165**	**22**	**5.2**
8d	Pre-Project (average line height and load)	1.9	7.3	60	6.6	1.8
	Pre-Project (minimum line height and peak load)	6.5	25	285	30	7.3
	Measured Field (1/13/2017)	**n/a**	**12**	**40**	**4.4**	**n/a**
	Modeled Field (for measured line height and load on 1/13/2017)	**3.5**	**14**	**44**	**5.0**	**1.7**
	Modeled Field (for line height and load adjusted to peak conditions)	**6.4**	**23**	**157**	**29**	**7.2**
9	Pre-Project (average line height and load)	1.6	6.5	34	5.7	1.4
	Pre-Project (minimum line height and peak load)	5.3	23	292	28	6.1
	Measured Field (1/13/2017)	**n/a**	**16**	**64**	**4.7**	**n/a**
	Modeled Field (for measured line height and load on 1/13/2017)	**3.6**	**15**	**67**	**5.1**	**1.7**
	Modeled Field (for line height and load adjusted to peak conditions)	**5.1**	**21**	**198**	**26**	**6.0**
10	Pre-Project (average line height and load)	0.7	5.3	151	6.0	2.4
	Pre-Project (minimum line height and peak load)	4.2	20	261	5.6	1.9
	Measured Field (1/25/2017)	**n/a**	**12**	**45**	**0.4**	**n/a**
	Modeled Field (for measured line height and load on 1/25/2017)	**2.4**	**10**	**43**	**0.6**	**0.3**
	Modeled Field (for line height and load adjusted to peak conditions)	**4.0**	**18**	**194**	**5.8**	**2.0**

Section Number	Condition	Distance from Centerline of ROW: - ROW Edge -100 ft	-ROW Edge	Max on ROW	+ROW Edge	+ROW Edge +100 ft
11	Pre-Project (average line height and load)	7.6	28	139	10	2.1
	Pre-Project (minimum line height and peak load)	11	44	234	30	3.0
	Measured Field (1/27/2017)	**n/a**	**n/a**	**54**	**13**	**n/a**
	Modeled Field (for measured line height and load on 1/27/2017)	**5.5**	**20**	**66**	**13**	**2.9**
	Modeled Field (for line height and load adjusted to peak conditions)	**11**	**43**	**186**	**32**	**5.7**
12	Pre-Project (average line height and load)	3.5	7.6	140	3.3	1.1
	Pre-Project (minimum line height and peak load)	5.1	11	233	7.3	1.7
	Measured Field (1/20/2017)	**n/a**	**n/a**	**108**	**3.8**	**n/a**
	Modeled Field (for measured line height and load on 1/20/2017)	**1.6**	**4.1**	**108**	**2.8**	**0.6**
	Modeled Field (for line height and load adjusted to peak conditions)	**5.1**	**11**	**240**	**7.5**	**1.7**
13	Pre-Project (average line height and load)	7.6	29	140	11	0.8
	Pre-Project (minimum line height and peak load)	11	44	234	20	1.7
	Measured Field (1/19/2017)	**n/a**	**20**	**110**	**6.5**	**n/a**
	Modeled Field (for measured line height and load on 1/19/2017)	**5.5**	**25**	**127**	**6.5**	**0.6**
	Modeled Field (for line height and load adjusted to peak conditions)	**11**	**45**	**224**	**18**	**1.7**
14	Pre-Project (average line height and load)	7.7	29	140	3.1	1.3
	Pre-Project (minimum line height and peak load)	11	44	234	8.7	1.6
	Measured Field (1/20/2017)	**n/a**	**14**	**57**	**5.5**	**n/a**
	Modeled Field (for measured line height and load on 1/20/2017)	**4.4**	**18**	**66**	**2.5**	**0.5**
	Modeled Field (for line height and load adjusted to peak conditions)	**11**	**39**	**134**	**7.7**	**1.7**
15	Pre-Project (average line height and load)	7.6	29	140	7.5	0.9
	Pre-Project (minimum line height and peak load)	11	44	234	15	1.6
	Measured Field (1/19/2017)	**n/a**	**17**	**79**	**7.2**	**n/a**
	Modeled Field (for measured line height and load on 1/19/2017)	**4.0**	**19**	**88**	**4.5**	**0.9**
	Modeled Field (for line height and load adjusted to peak conditions)	**12**	**45**	**167**	**10**	**1.4**

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	Pre-Project (average line height)	0.1	0.5	2.7	0.5	0.1
	Pre-Project (minimum line height)	<0.1	0.4	6.5	0.4	<0.1
	Measured Field (1/12/2017)	**n/a**	**<0.1**	**2.2**	**<0.1**	**n/a**
	Modeled Field (for measured line height on 1/12/2017)	**0.1**	**0.5**	**2.9**	**0.6**	**0.1**
	Modeled Field (for line height adjusted to peak conditions)	**<0.1**	**0.3**	**7.4**	**0.5**	**0.1**
8c	Pre-Project (average line height)	0.1	0.5	2.7	0.5	0.1
	Pre-Project (minimum line height)	<0.1	0.4	6.5	0.4	<0.1
	Measured Field (1/16/2017)	**n/a**	**0.1**	**1.6**	**0.1**	**n/a**
	Modeled Field (for measured line height on 1/16/2017)	**0.1**	**0.5**	**1.9**	**0.5**	**0.1**
	Modeled Field (for line height adjusted to peak conditions)	**<0.1**	**0.5**	**3.8**	**0.4**	**0.1**
8d	Pre-Project (average line height)	0.1	0.5	2.7	0.5	0.1
	Pre-Project (minimum line height)	<0.1	0.4	6.4	0.4	<0.1
	Measured Field (1/13/2017)	**n/a**	**0.3**	**1.1**	**0.2**	**n/a**
	Modeled Field (for measured line height on 1/13/2017)	**0.1**	**0.6**	**1.8**	**0.6**	**0.1**
	Modeled Field (for line height adjusted to peak conditions)	**0.1**	**0.6**	**3.5**	**0.5**	**0.1**
9	Pre-Project (average line height)	0.1	0.5	2.6	0.5	0.1
	Pre-Project (minimum line height)	<0.1	0.4	6.4	0.4	<0.1
	Measured Field (1/13/2017)	**n/a**	**0.1**	**1.6**	**<0.1**	**n/a**
	Modeled Field (for measured line height on 1/13/2017)	**0.1**	**0.5**	**2.1**	**0.6**	**0.1**
	Modeled Field (for line height adjusted to peak conditions)	**<0.1**	**0.5**	**4.7**	**0.5**	**0.1**
10	Pre-Project (average line height)	0.1	0.6	5.2	0.1	<0.1
	Pre-Project (minimum line height)	0.1	0.5	7.3	0.1	<0.1
	Measured Field (1/25/2017)	**n/a**	**<0.1**	**3.0**	**<0.1**	**n/a**
	Modeled Field (for measured line height on 1/25/2017)	**0.1**	**0.6**	**3.9**	**0.2**	**<0.1**
	Modeled Field (for line height adjusted to peak conditions)	**0.1**	**0.6**	**5.1**	**0.1**	**<0.1**

Section Number	Condition	Distance from Centerline of ROW: -ROW Edge -100 ft	-ROW Edge	Max on ROW	+ROW Edge	+ROW Edge -100 ft
11	Pre-Project (average line height)	0.2	1.2	5.0	0.5	<0.1
	Pre-Project (minimum line height)	0.1	1.2	7.1	0.5	<0.1
	Measured Field (1/27/2017)	**n/a**	**n/a**	**2.7**	**<0.1**	**n/a**
	Modeled Field (for measured line height on 1/27/2017)	**0.2**	**1.3**	**4.2**	**0.3**	**0.1**
	Modeled Field (for line height adjusted to peak conditions)	**0.2**	**1.2**	**5.7**	**0.4**	**0.1**
12	Pre-Project (average line height)	0.1	0.2	5.0	0.1	<0.1
	Pre-Project (minimum line height)	<0.1	0.1	7.1	0.1	<0.1
	Measured Field (1/20/2017)	**n/a**	**n/a**	**3.4**	**<0.1**	**n/a**
	Modeled Field (for measured line height on 1/20/2017)	**0.1**	**0.2**	**4.9**	**0.1**	**<0.1**
	Modeled Field (for line height adjusted to peak conditions)	**<0.1**	**0.1**	**7.1**	**0.1**	**<0.1**
13	Pre-Project (average line height)	0.2	1.3	5.0	0.2	<0.1
	Pre-Project (minimum line height)	0.1	1.2	7.1	0.2	<0.1
	Measured Field (1/19/2017)	**n/a**	**0.1**	**3.4**	**<0.1**	**n/a**
	Modeled Field (for measured line height on 1/19/2017)	**0.2**	**1.3**	**4.6**	**0.1**	**<0.1**
	Modeled Field (for line height adjusted to peak conditions)	**0.2**	**1.3**	**6.5**	**0.1**	**<0.1**
14	Pre-Project (average line height)	0.2	1.3	5.0	0.1	<0.1
	Pre-Project (minimum line height)	0.1	1.2	7.1	0.1	<0.1
	Measured Field (1/20/2017)	**n/a**	**<0.1**	**2.0**	**0.1**	**n/a**
	Modeled Field (for measured line height on 1/20/2017)	**0.2**	**1.3**	**3.3**	**0.1**	**<0.1**
	Modeled Field (for line height adjusted to peak conditions)	**0.2**	**1.3**	**4.3**	**0.1**	**<0.1**
15	Pre-Project (average line height)	0.2	1.3	5.0	0.1	<0.1
	Pre-Project (minimum line height)	0.1	1.2	7.1	0.1	<0.1
	Measured Field (1/19/2017)	**n/a**	**0.1**	**2.7**	**<0.1**	**n/a**
	Modeled Field (for measured line height on 1/19/2017)	**0.2**	**1.4**	**3.8**	**<0.1**	**<0.1**
	Modeled Field (for line height adjusted to peak conditions)	**0.2**	**1.3**	**5.1**	**0.1**	**<0.1**

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’ model for each individual measurement location.

Results for each of the ten 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 1-3 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 5-50 feet and so generally appear as discrete ‘+’ symbols indicating the measured value. In each figure below three separate models are included. An orange ‘dash-dot’ line shows the peak-loading model submitted in the NHSEC filing (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, below 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, dates, measurement 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	1/12/2017	12:30 to 15:00	2	2	3	3
2	XS-8c	1/16/2017	13:00 to 16:00	3	3	3	2
3	XS-8d	1/13/2017	12:30 to 14:30	1	3	3	3
4	XS-9	1/13/2017	08:00 to 10:00	2	2	3	3
5	XS-10	1/25/2017	09:00 to 12:30	2	2	1	3
6	XS-11	1/27/2017	09:30 to 13:30	2	2	2	3
7	XS-12	1/20/2017	13:00 to 17:00	2	1	2	3
8	XS-13	1/19/2017	14:00 to 17:00	1	3	2	3
9	XS-14	1/20/2017	09:00 to 12:30	1	1	1	3
10	XS-15	1/19/2017	08:30 to 13:00	3	3	2	1
PUC 1	XS-8b	1/12/2017	10:00 to 12:00	n/a	n/a	n/a	n/a
PUC 2	XS-8d	1/13/2017	14:30 to 17:00	n/a	n/a	n/a	n/a
PUC 3	XS-8d	1/13/2017	10:00 to 12:30	n/a	n/a	n/a	n/a
PUC 4	XS-10	1/17/2017	11:00 to 13:30	n/a	n/a	n/a	n/a
PUC 5	XS-11	1/17/2017	14:30 to 17:00	n/a	n/a	n/a	n/a
PUC 6	XS-11	1/25/2017	13:30 to 14:30	n/a	n/a	n/a	n/a

Site 1

Measurements at Site 1 (cross section XS-8b) were performed on January 12, 2017. A graphical summary of results are presented below.

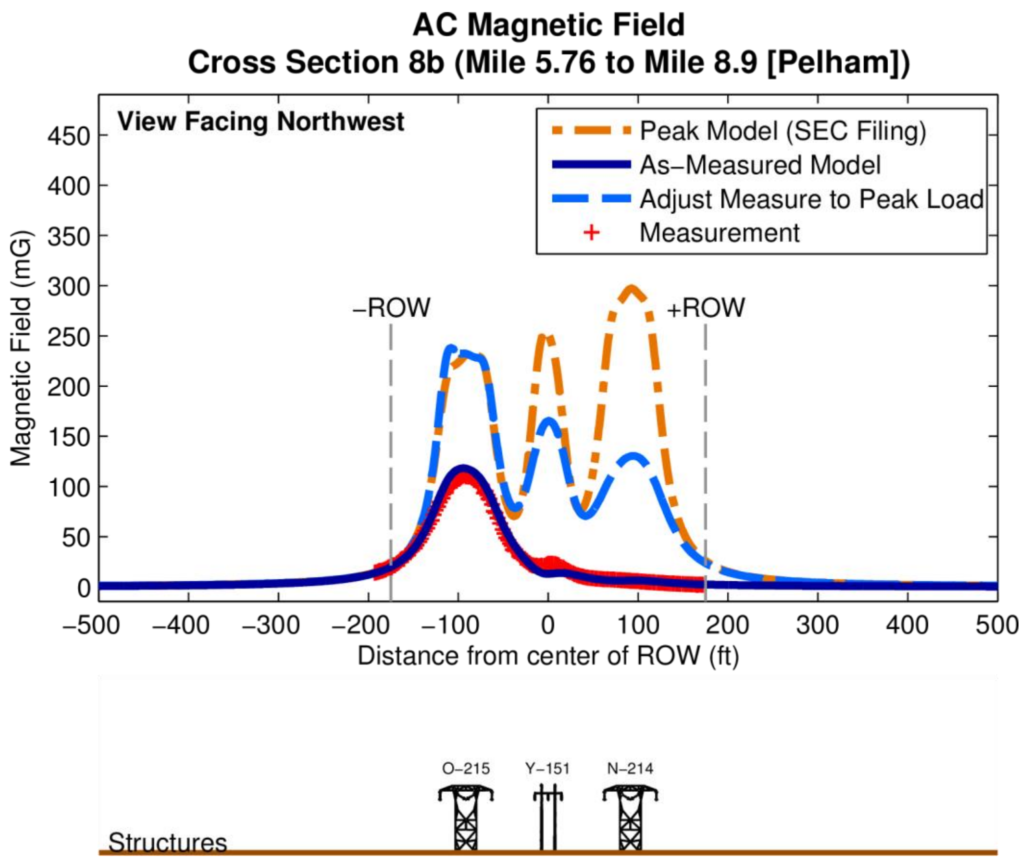


Figure B-1. Measured and modeled magnetic-field levels at Site 1 in XS-8b.

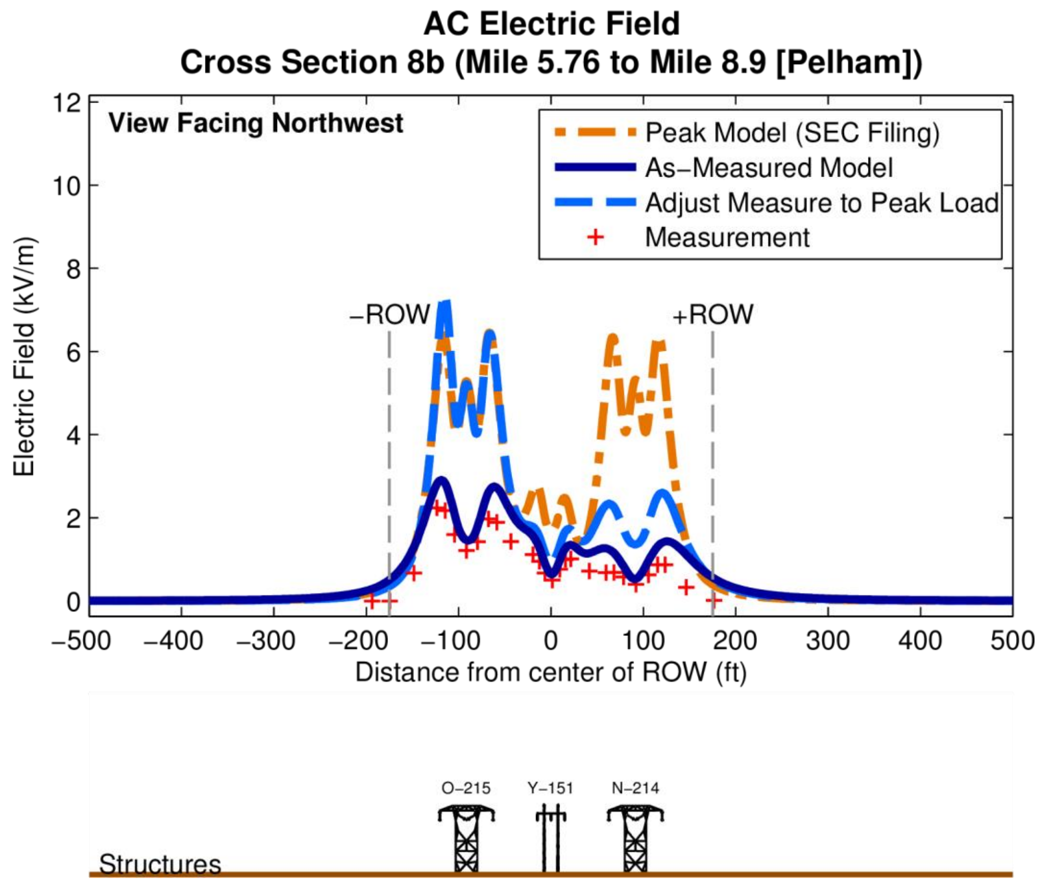


Figure B-2. Measured and modeled electric-field levels at Site 1 in XS-8b.

Site 2

Measurements at Site 2 (cross section XS-8c) were performed on January 16, 2017. A graphical summary of results are presented below.

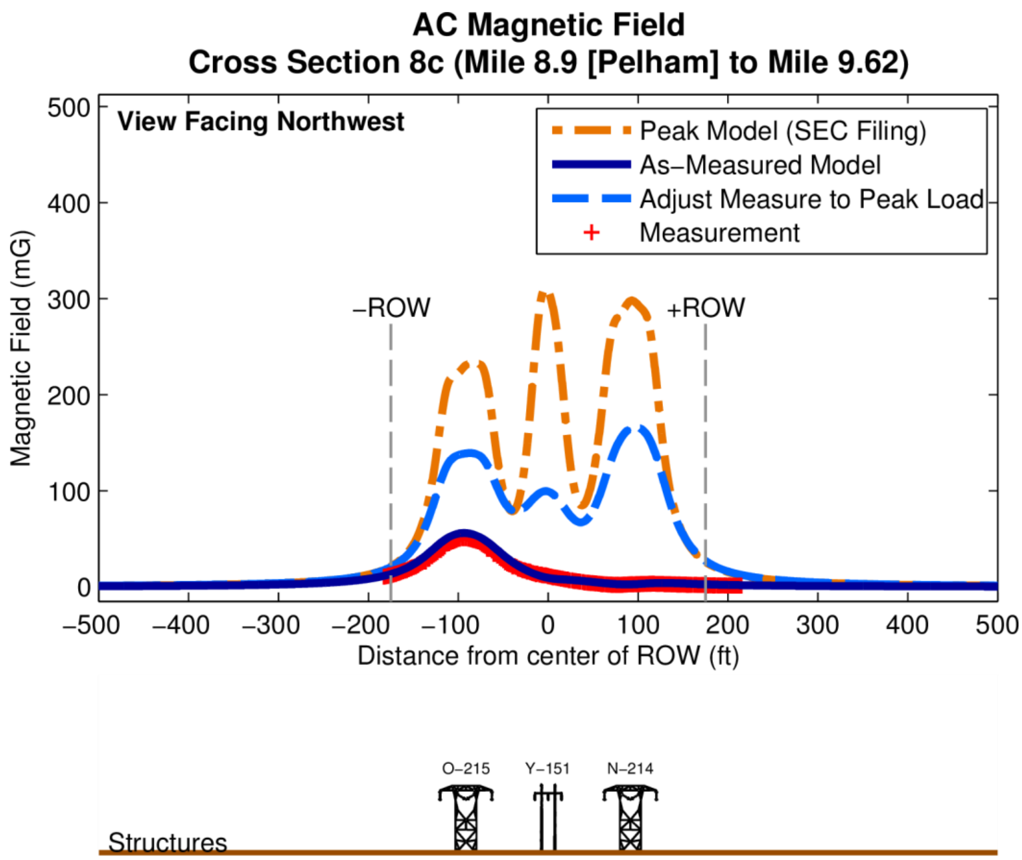


Figure B-3. Measured and modeled magnetic-field levels at Site 2 in XS-8c.

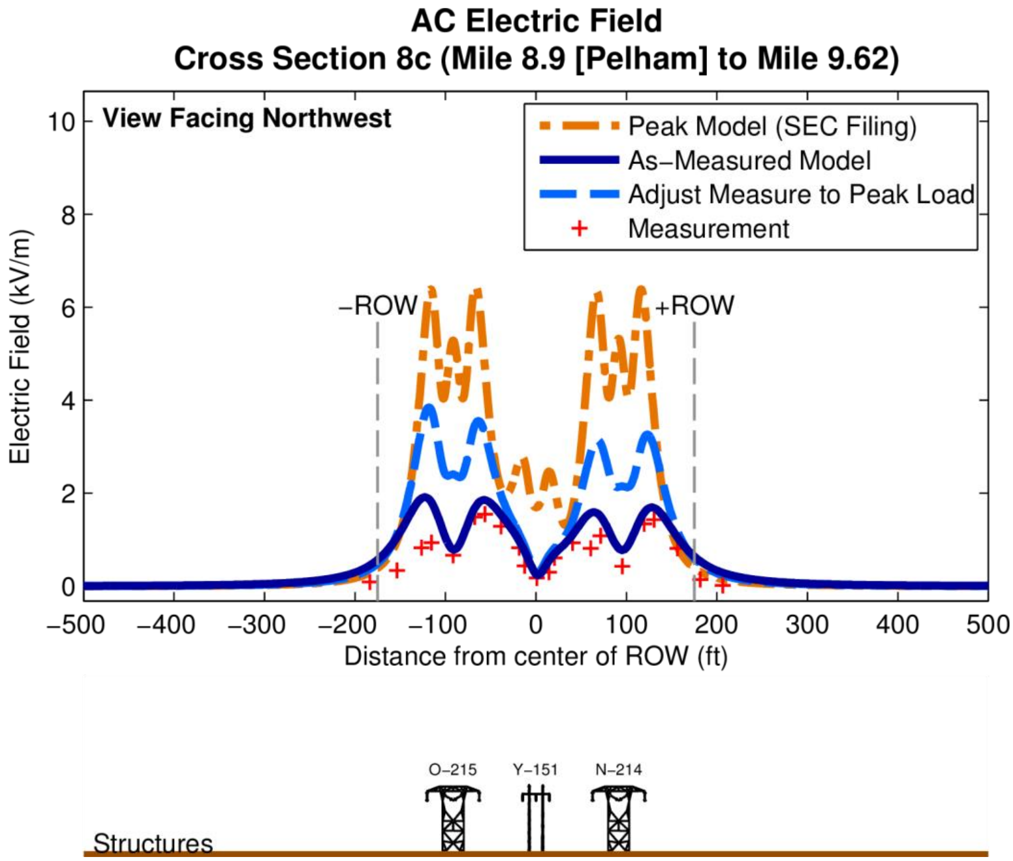


Figure B-4. Measured and modeled electric-field levels at Site 2 in XS-8c.

Site 3

Measurements at Site 3 (cross section XS-8d) were performed on January 13, 2017. A graphical summary of results are presented below.

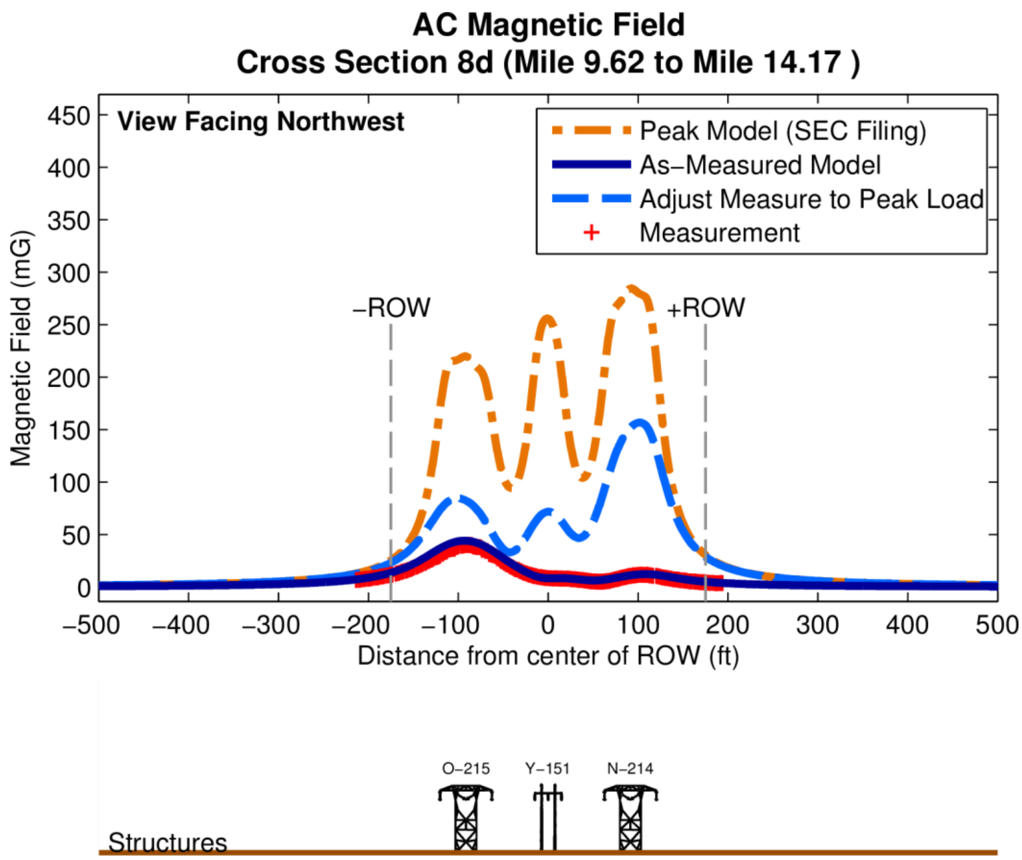


Figure B-5. Measured and modeled magnetic-field levels at Site 3 in XS-8d.

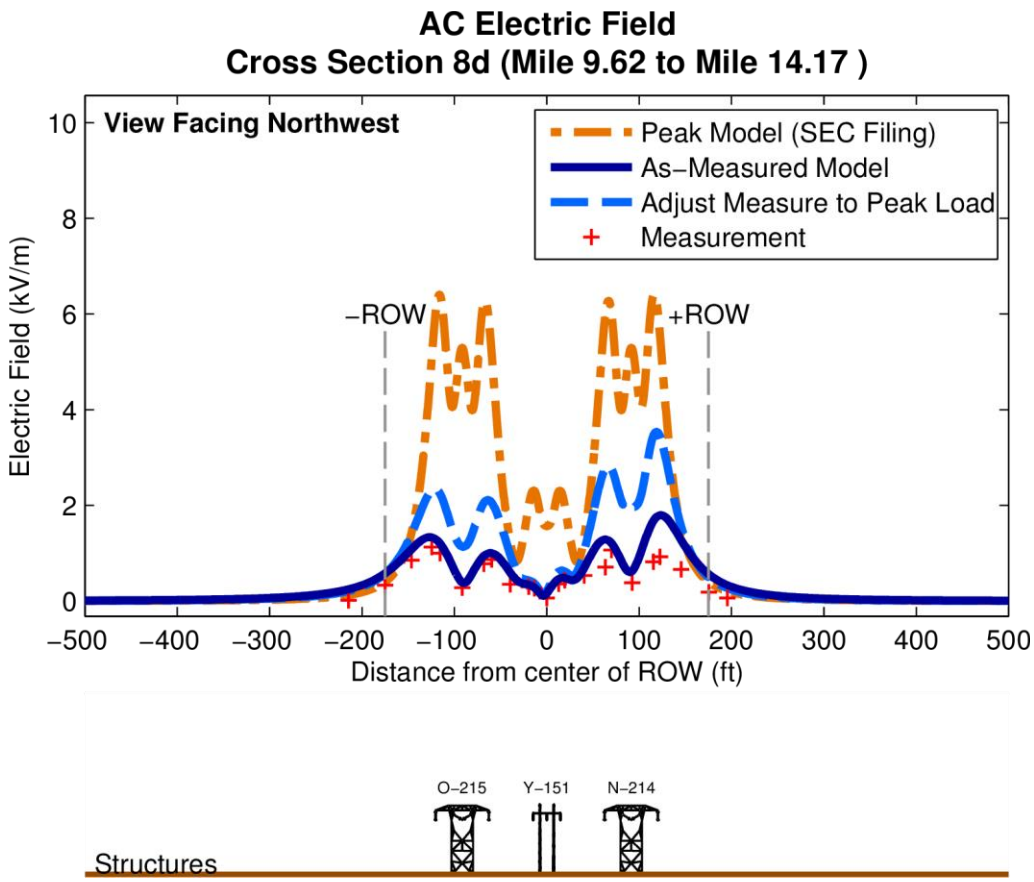


Figure B-6. Measured and modeled electric-field levels at Site 3 in XS-8d.

Site 4

Measurements at Site 4 (cross section XS-9) were performed on January 13, 2017. A graphical summary of results are presented below.

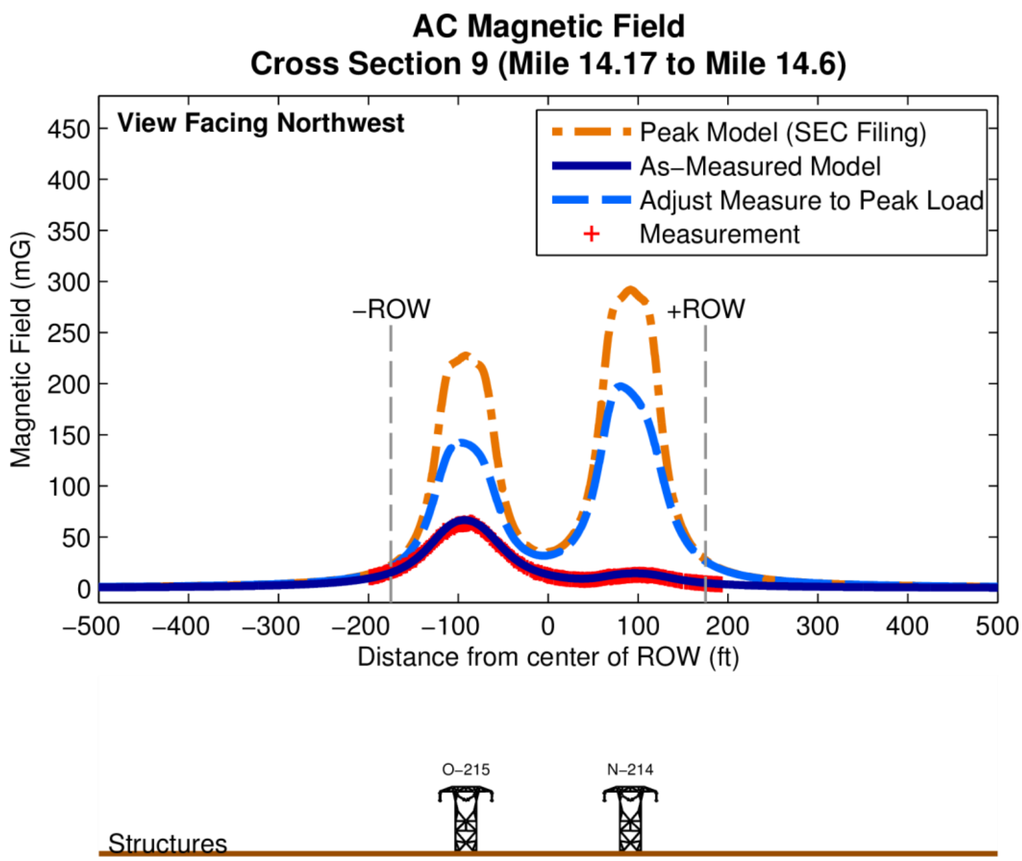


Figure B-7. Measured and modeled magnetic-field levels at Site 4 in XS-9.

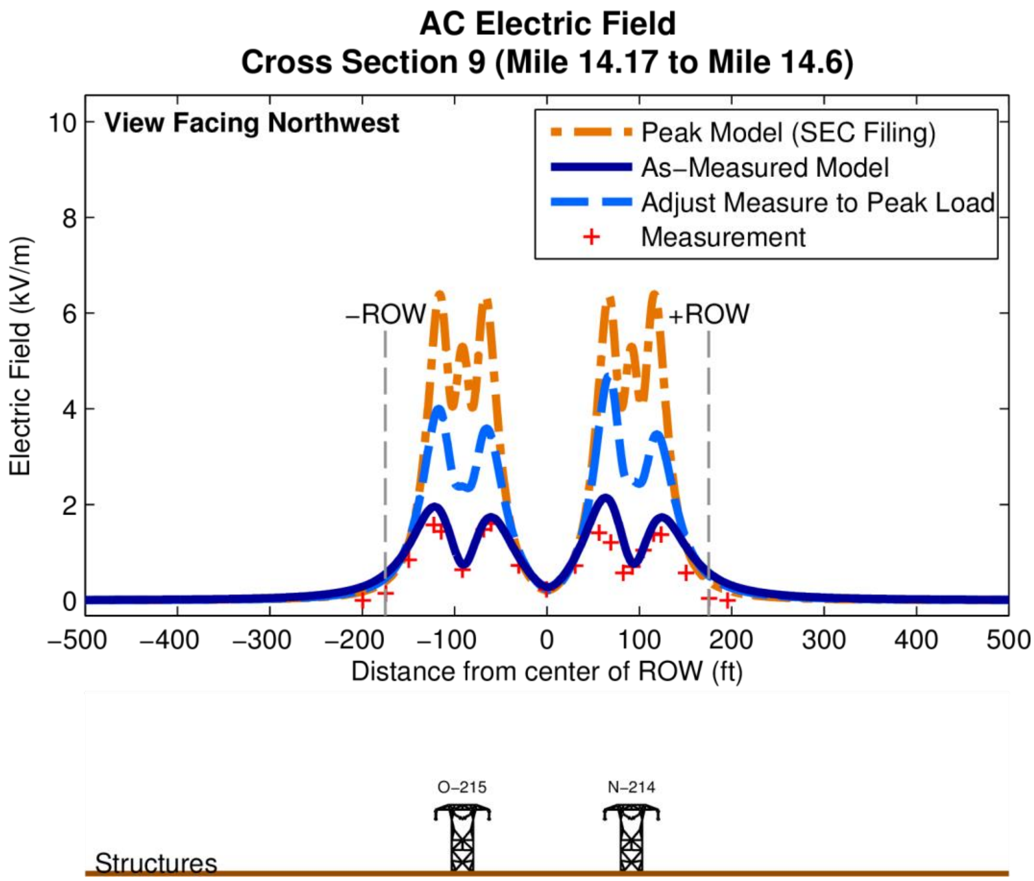


Figure B-8. Measured and modeled electric-field levels at Site 4 in XS-9.

Site 5

Measurements at Site 5 (cross section XS-10) were performed on January 25, 2017. A graphical summary of results are presented below.

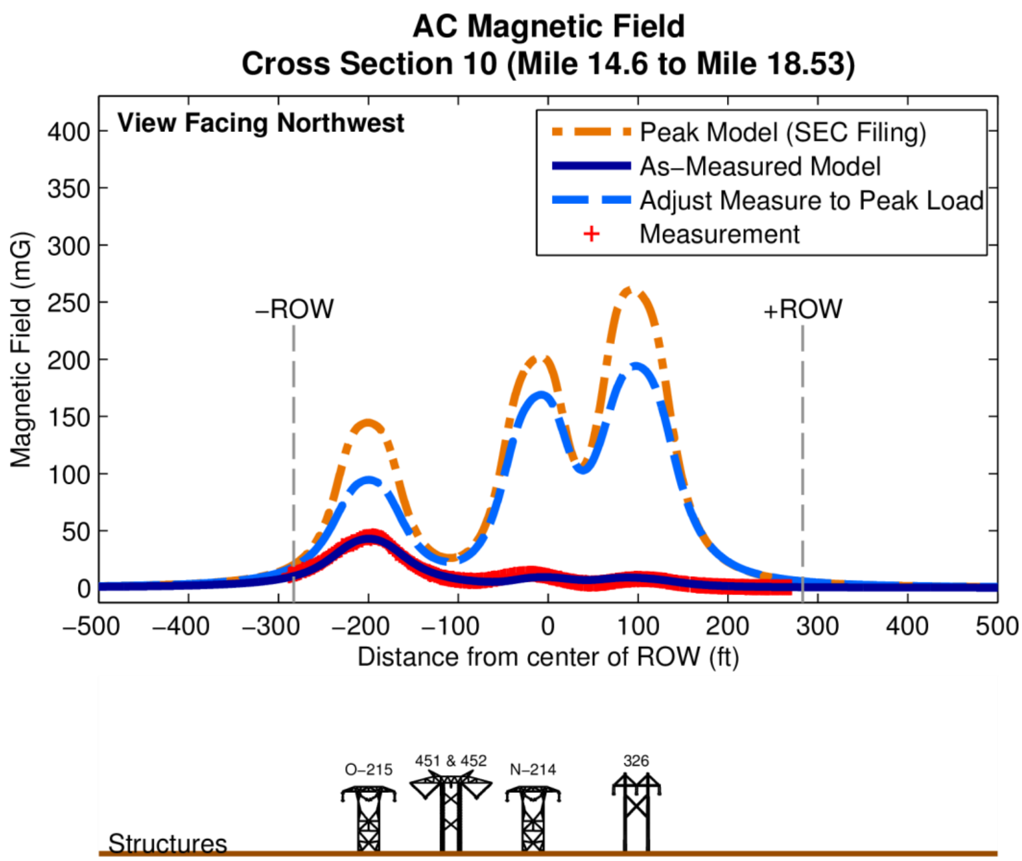


Figure B-9. Measured and modeled magnetic-field levels at Site 5 in XS-10.

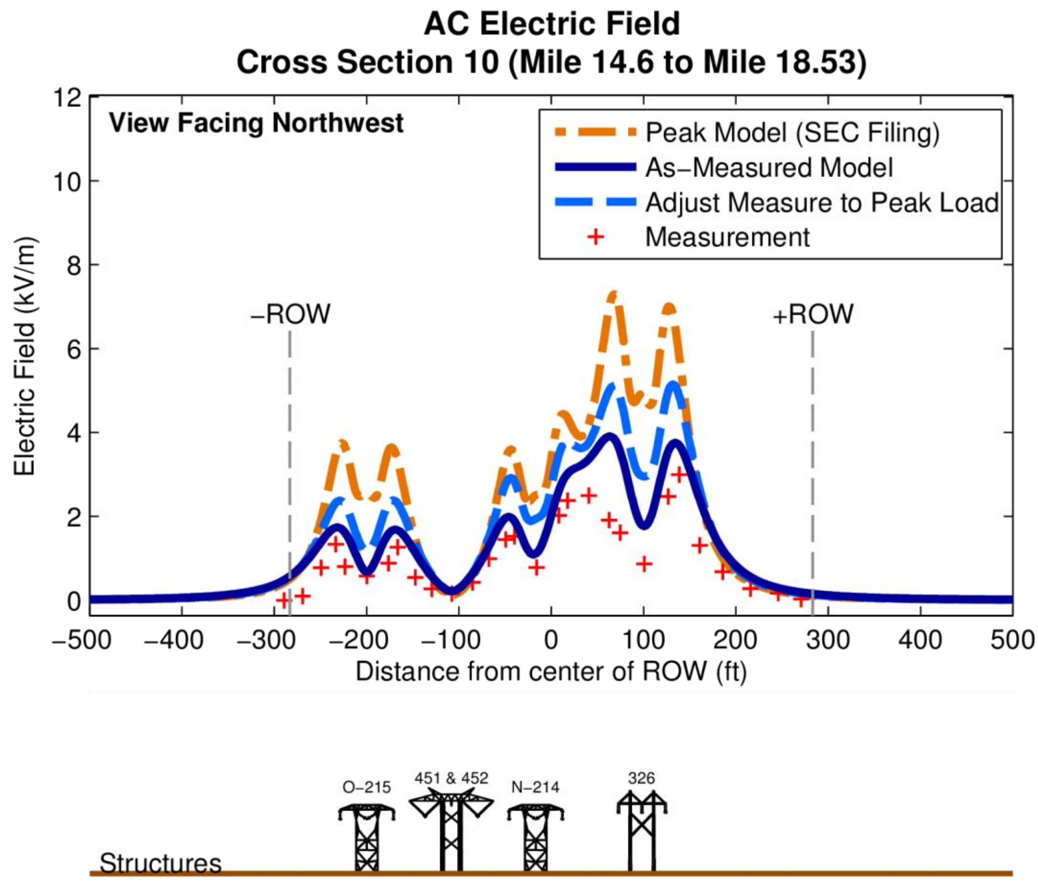


Figure B-10. Measured and modeled electric-field levels at Site 5 in XS-10.

Site 6

Measurements at Site 6 (cross section XS-11) were performed on January 27, 2017. A graphical summary of results are presented below.

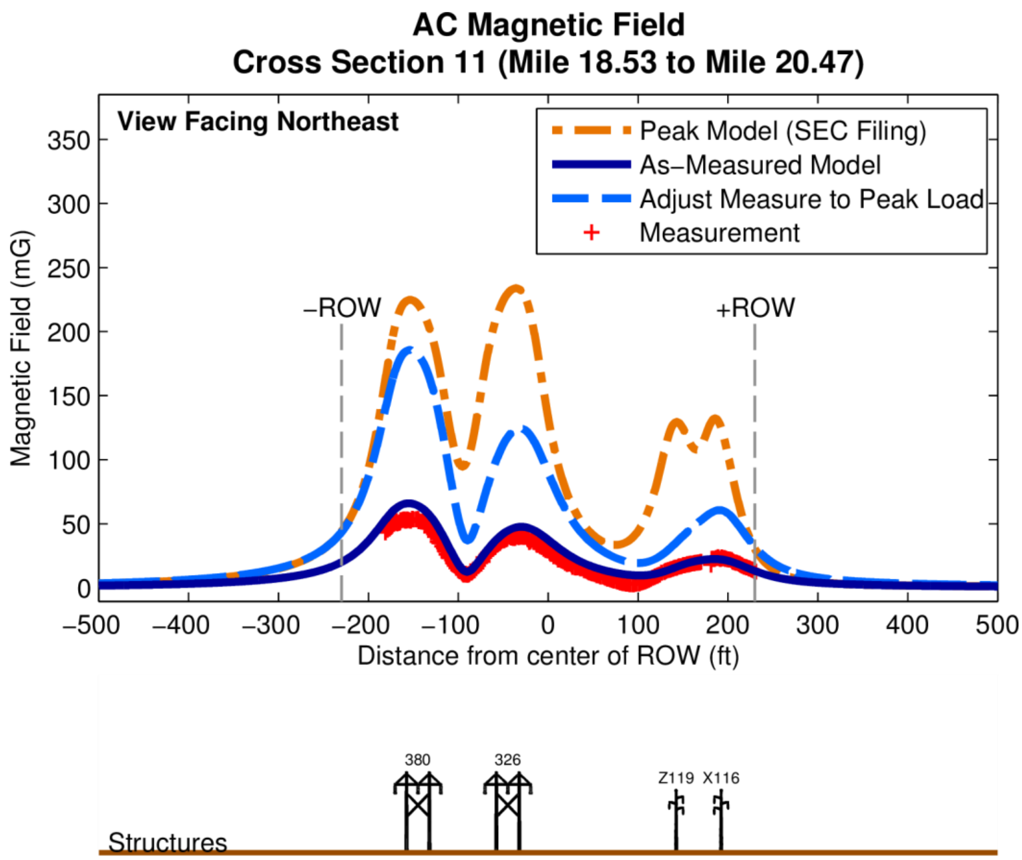


Figure B-11. Measured and modeled magnetic-field levels at Site 6 in XS-11.

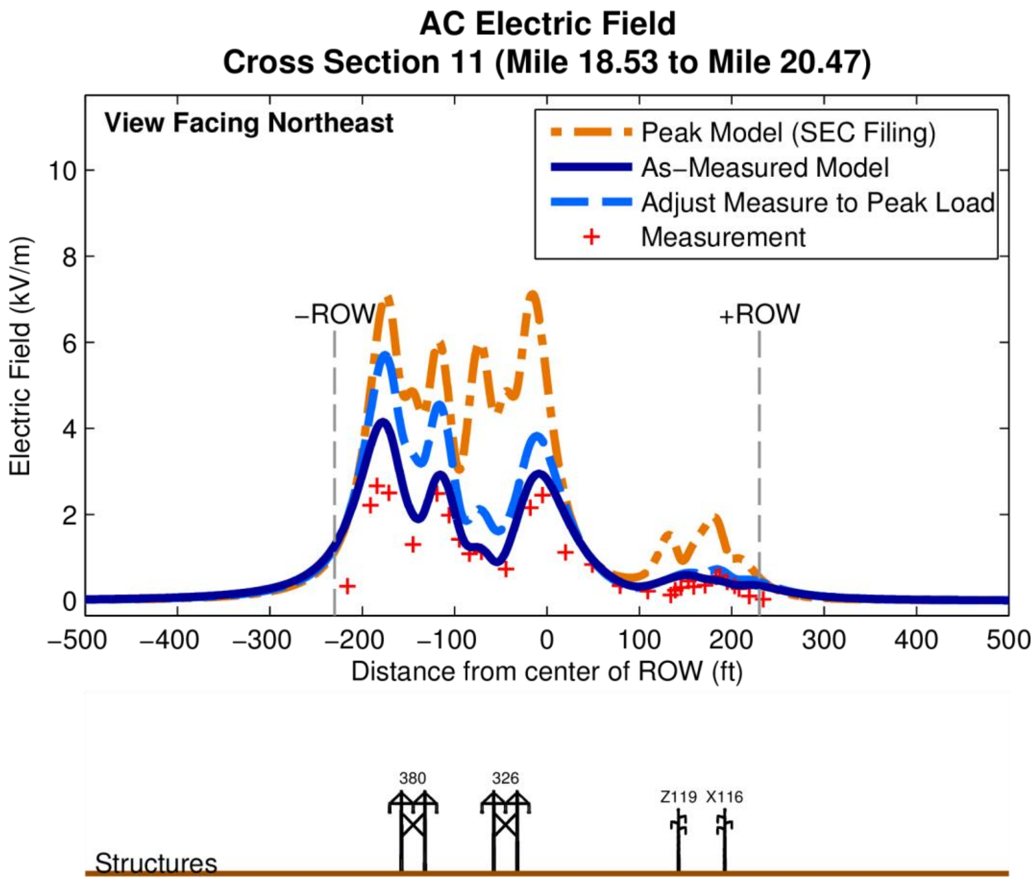


Figure B-12. Measured and modeled electric-field levels at Site 6 in XS-11.

Site 7

Measurements at Site 7 (cross section XS-12) were performed on January 20, 2017. A graphical summary of results are presented below.

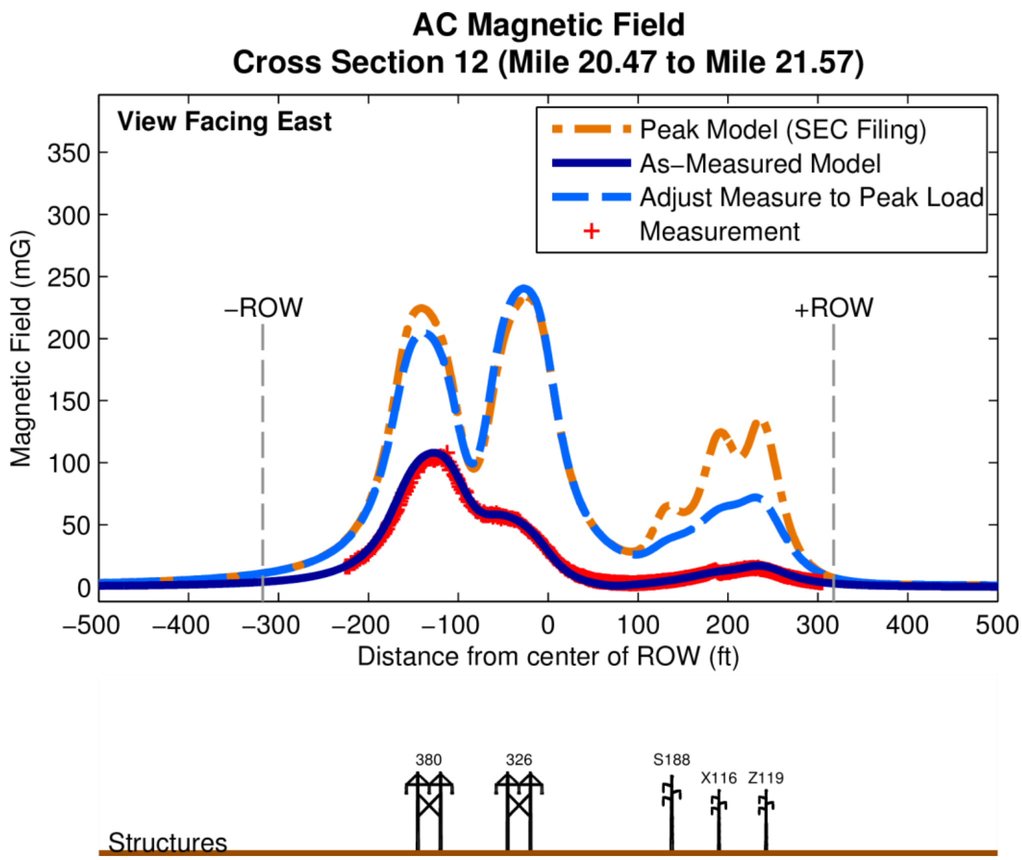


Figure B-13. Measured and modeled magnetic-field levels at Site 7 in XS-12.

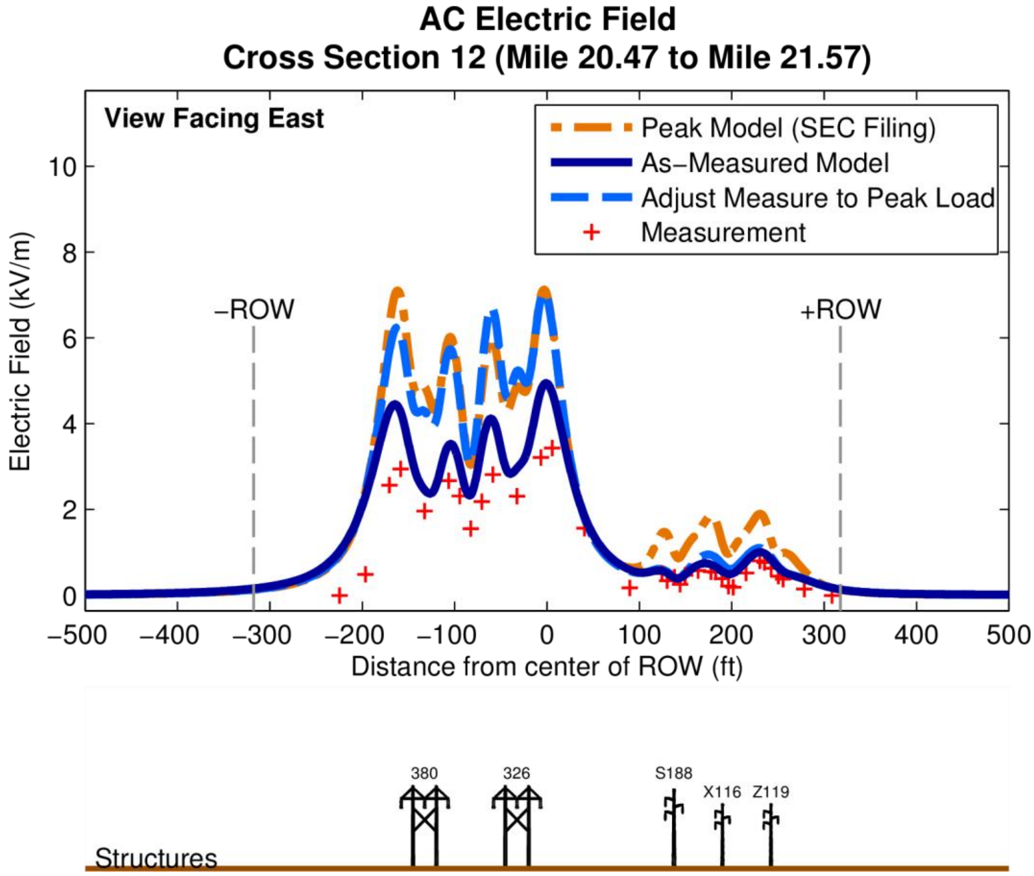


Figure B-14. Measured and modeled electric-field levels at Site 7 in XS-12.

Site 8

Measurements at Site 8 (cross section XS-13) were performed on January 19, 2017. A graphical summary of results are presented below.

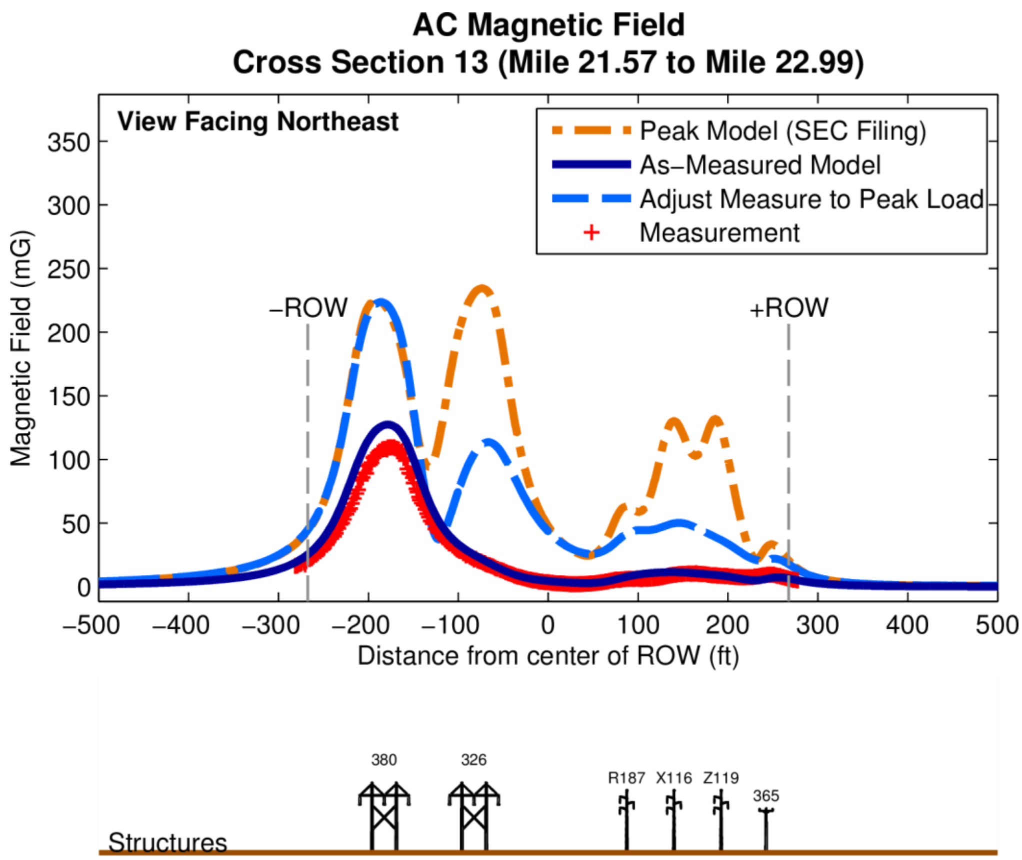


Figure B-15. Measured and modeled magnetic-field levels at Site 8 in XS-13.

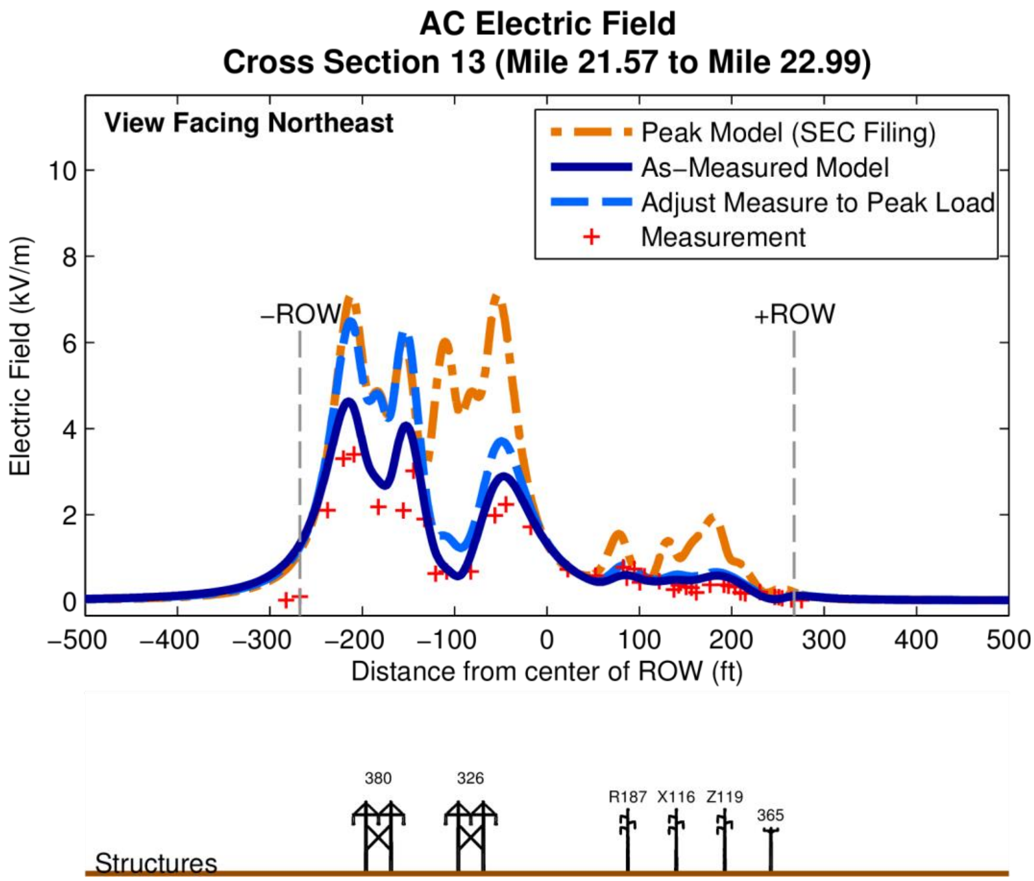


Figure B-16. Measured and modeled magnetic-field levels at Site 8 in XS-13.

Site 9

Measurements at Site 9 (cross section 14) were performed on January 20, 2017. A graphical summary of results are presented below.

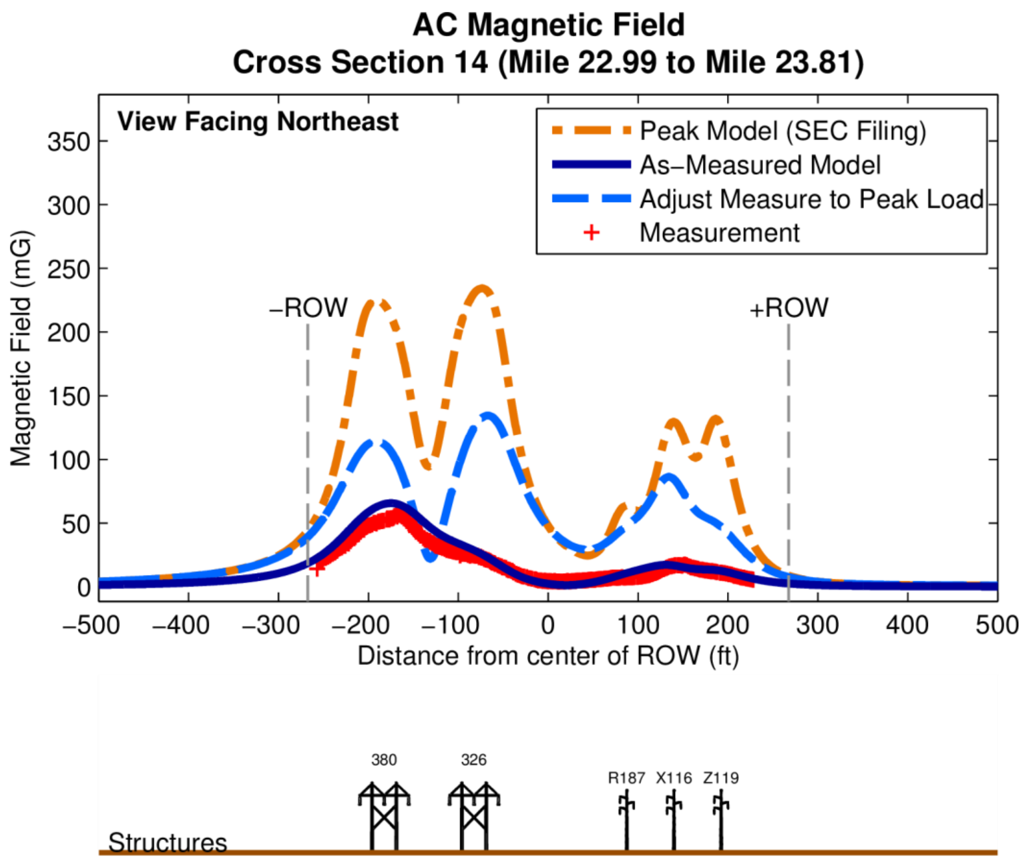


Figure B-17. Measured and modeled magnetic-field levels at Site 9 in XS-14.

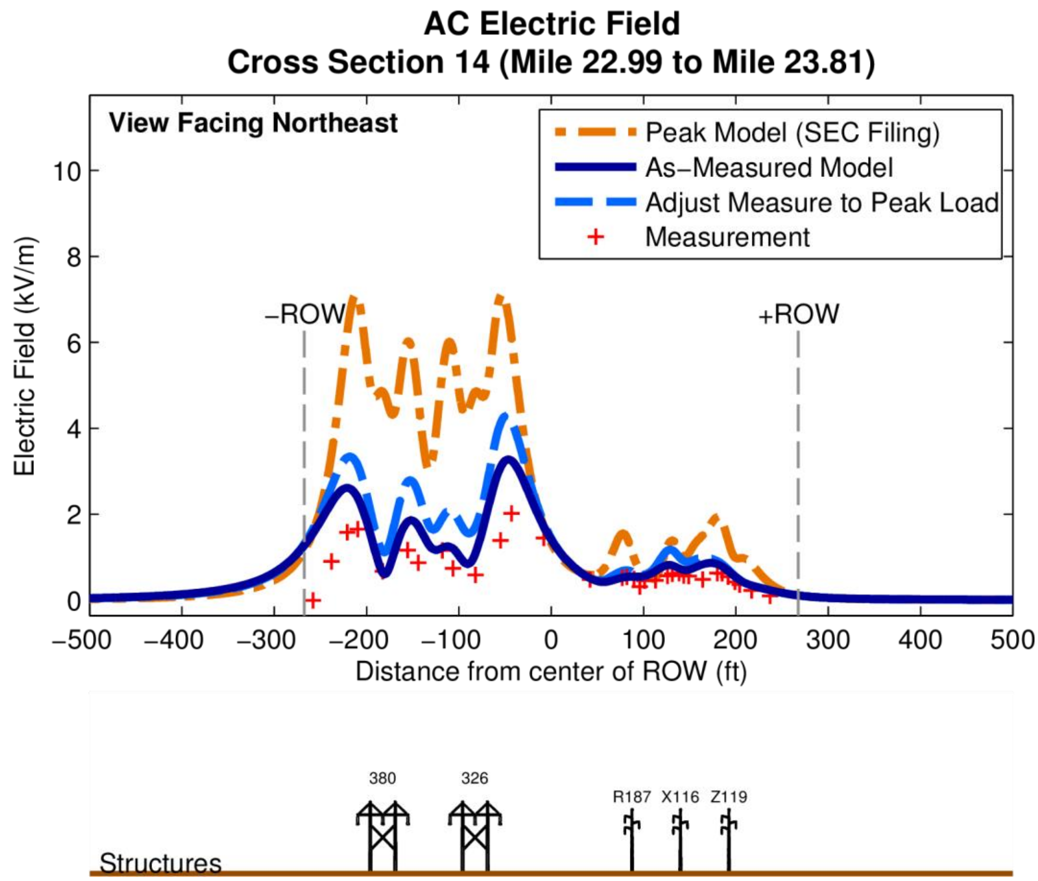


Figure B-18. Measured and modeled electric-field levels at Site 9 in XS-14.

Site 10

Measurements at Site 10 (cross section XS-15) were performed on January 19, 2017. A graphical summary of results are presented below.

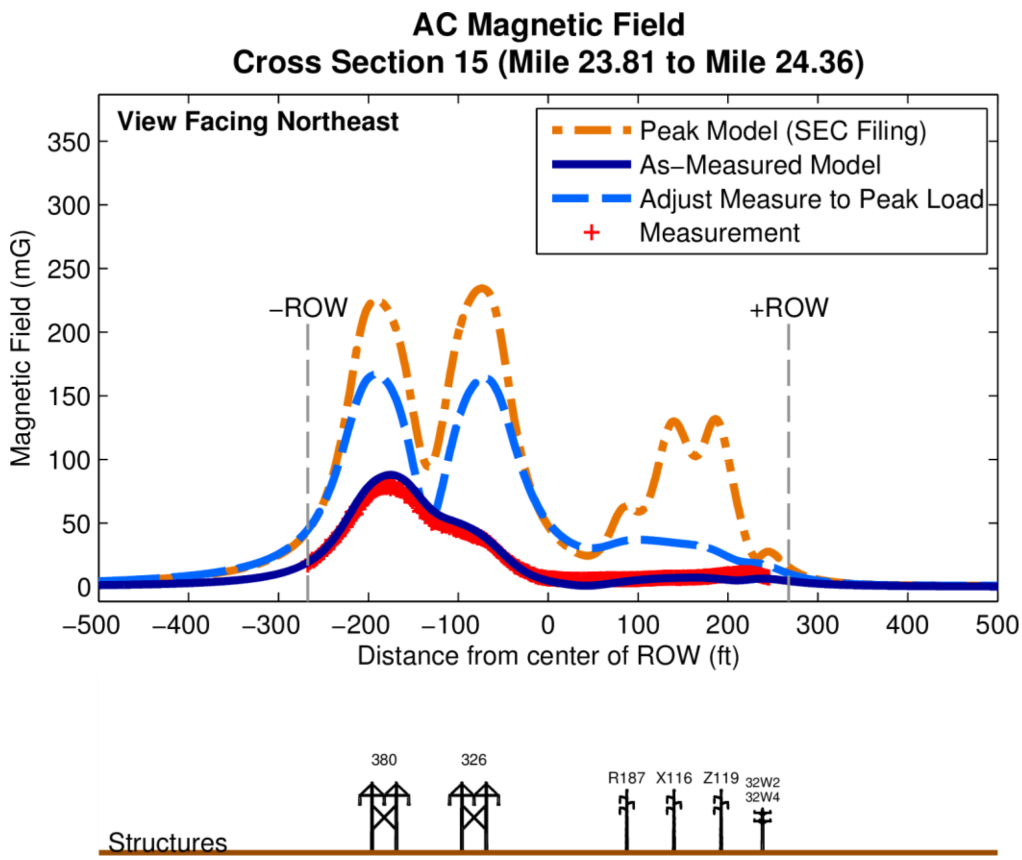


Figure B-19. Measured and modeled magnetic-field levels at Site 10 in XS-15.

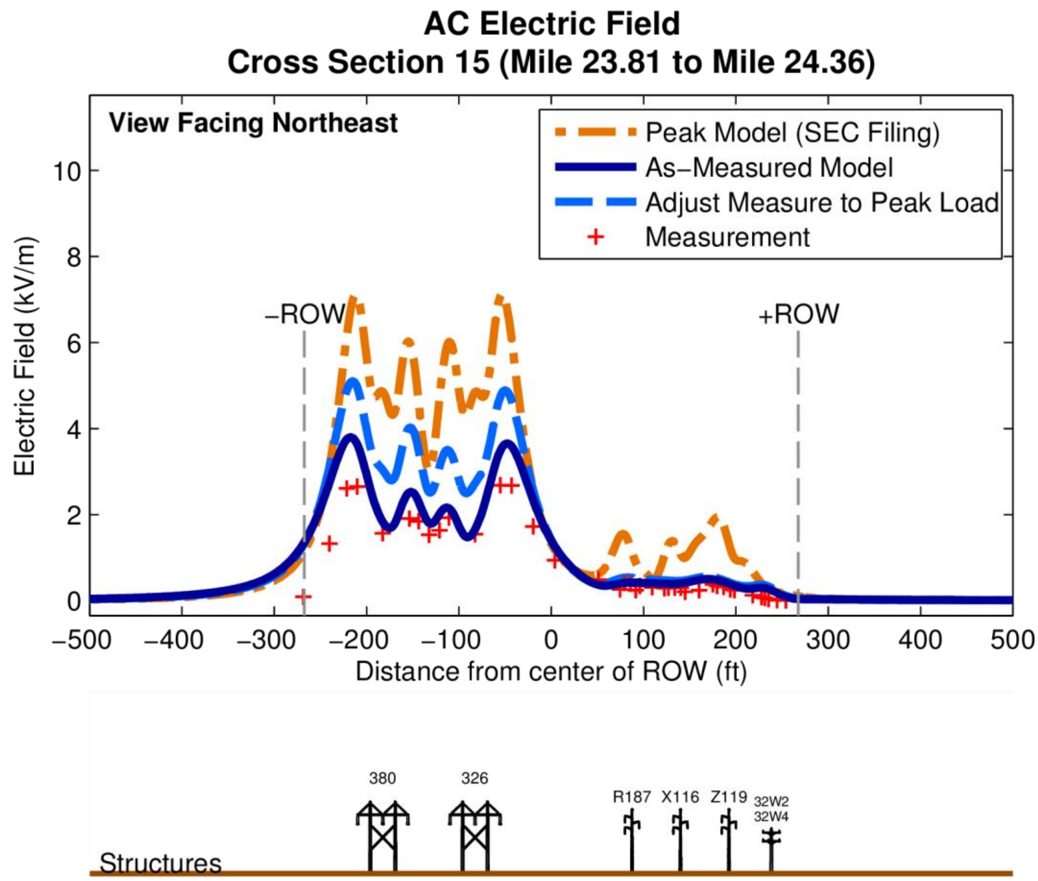


Figure B-20. Measured and modeled electric-field levels at Site 10 in XS-15.

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.

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.

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

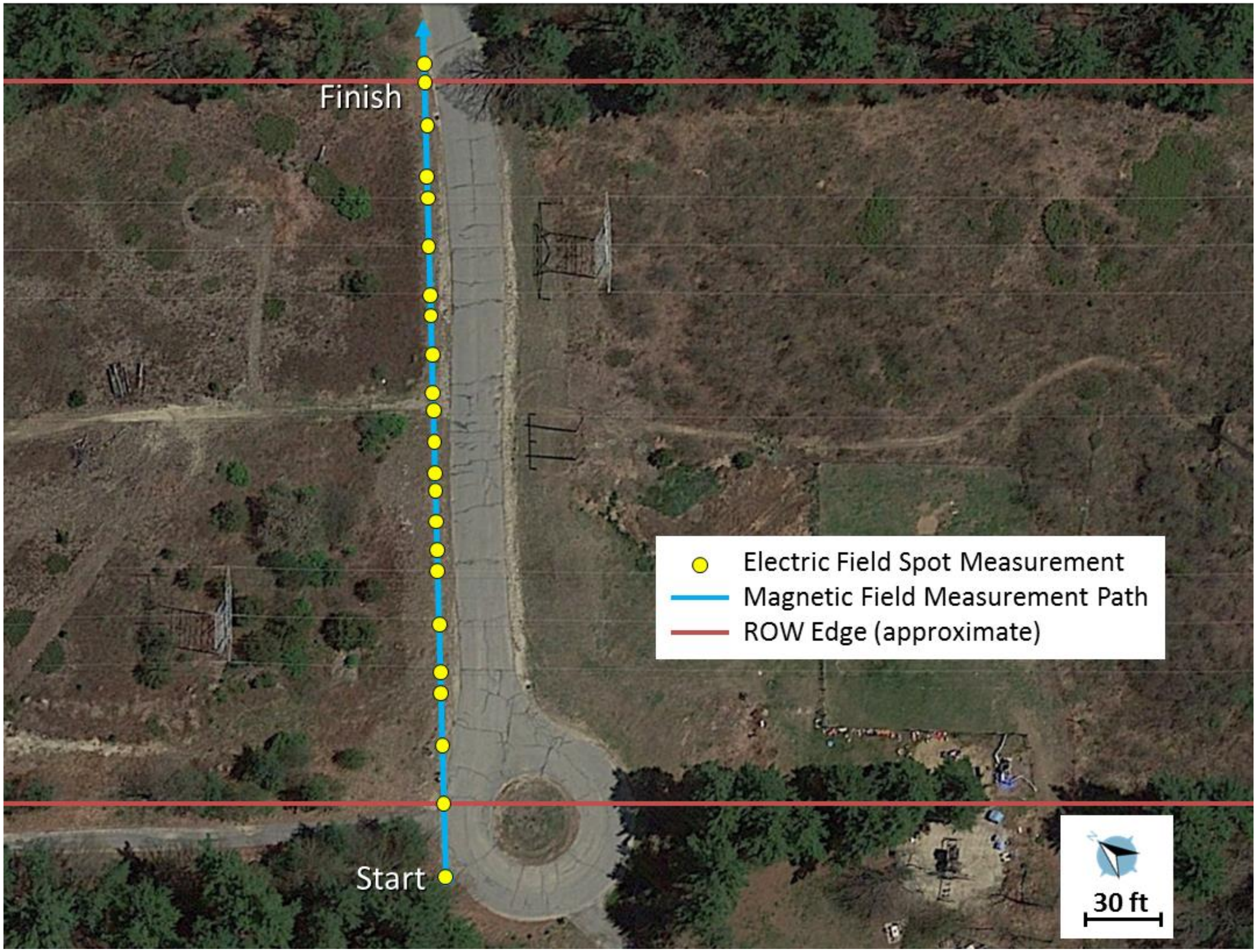


Figure C-3. Aerial photo of measurement Site 3 (in XS-8d) showing the approximate location of the magnetic field measurement path and electric field spot measurements.

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

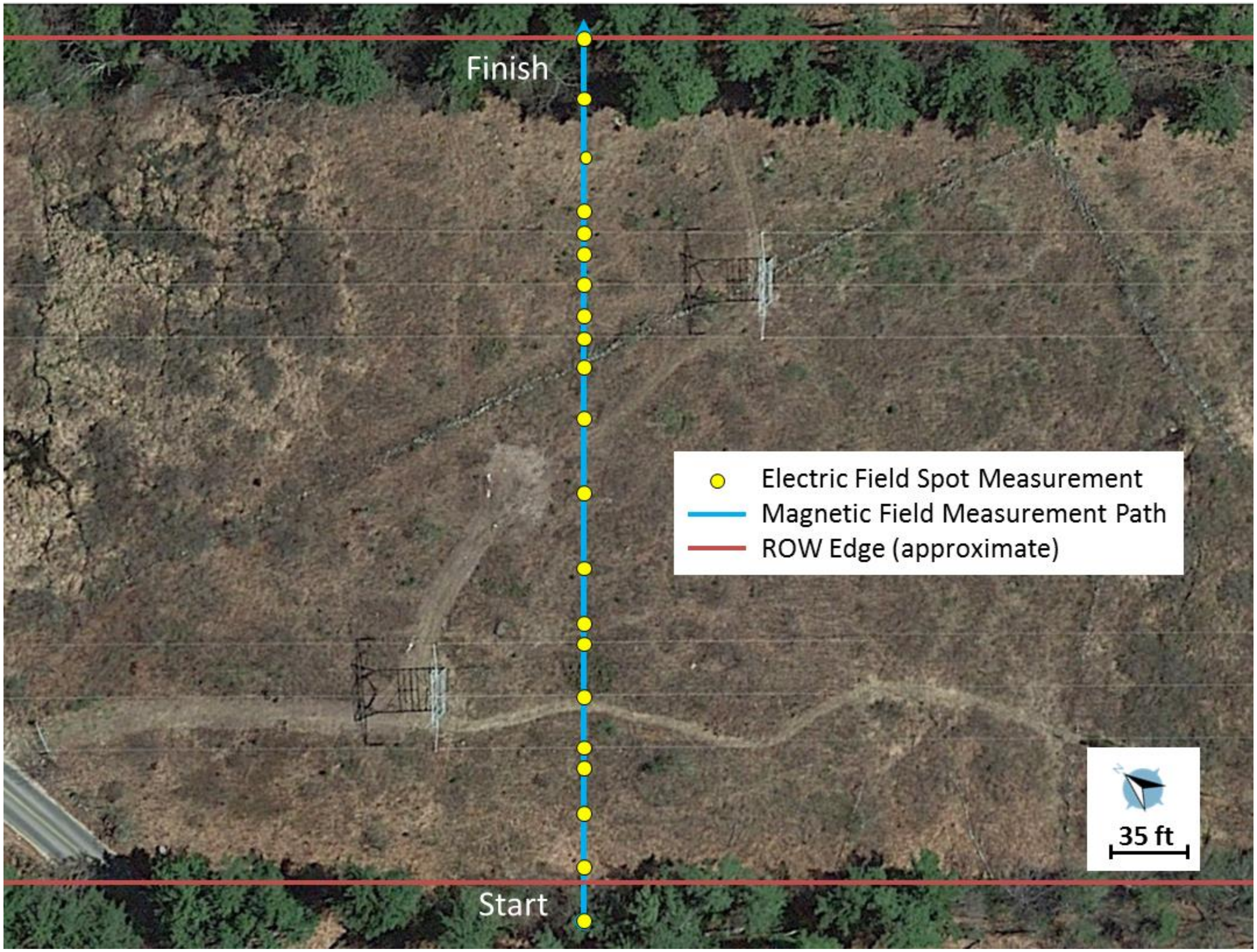


Figure C-4. Aerial photo of measurement Site 4 (in XS-9) showing the approximate location of the magnetic field measurement path and electric field spot measurements.

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

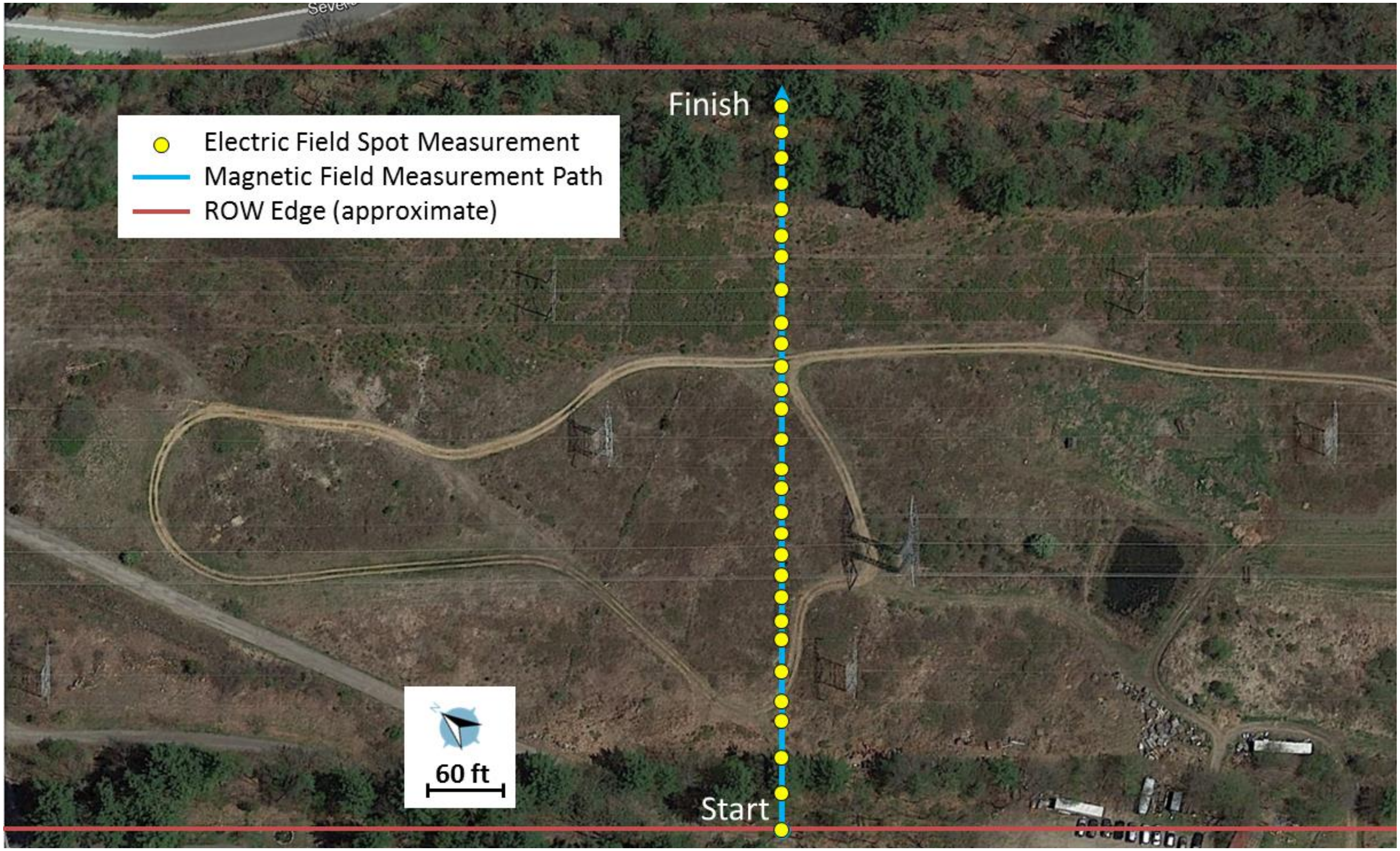


Figure C-5. Aerial photo of measurement Site 5 (in XS-10) showing the approximate location of the magnetic field measurement path and electric field spot measurements.

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

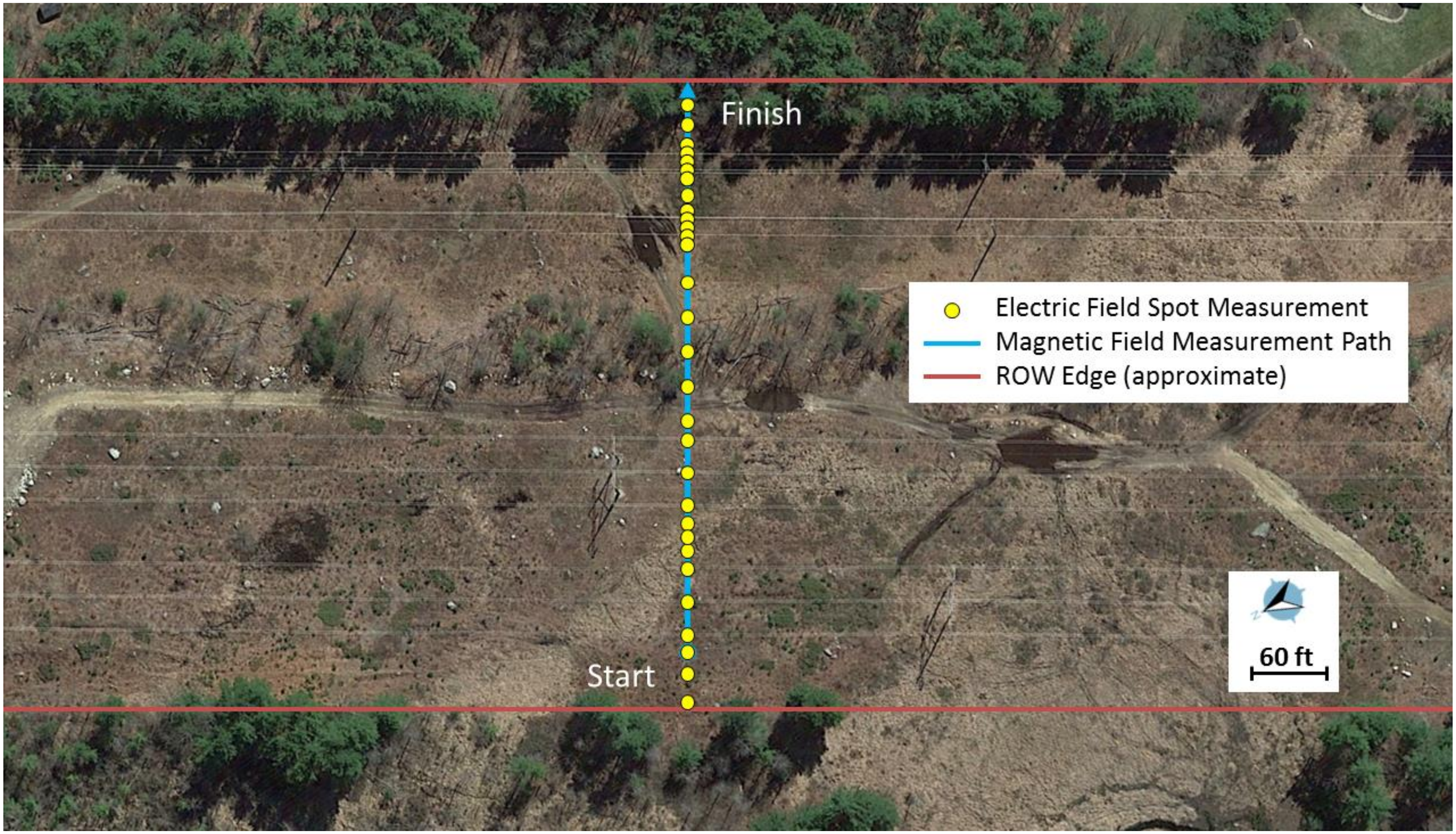


Figure C-6. Aerial photo of measurement Site 6 (in XS-11) showing the approximate location of the magnetic field measurement path and electric field spot measurements.

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

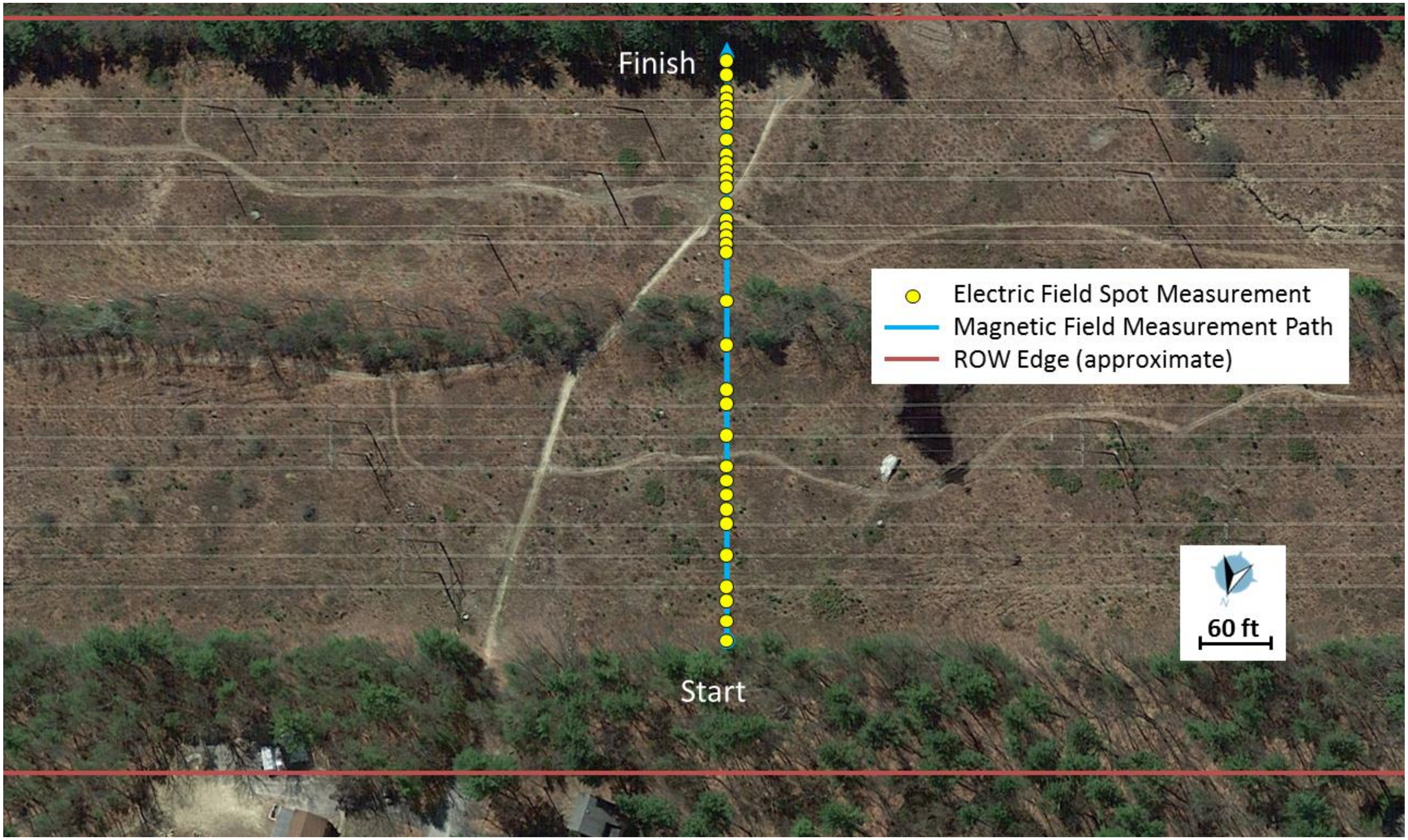


Figure C-7. Aerial photo of measurement Site 7 (in XS-12) showing the approximate location of the magnetic field measurement path and electric field spot measurements.

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

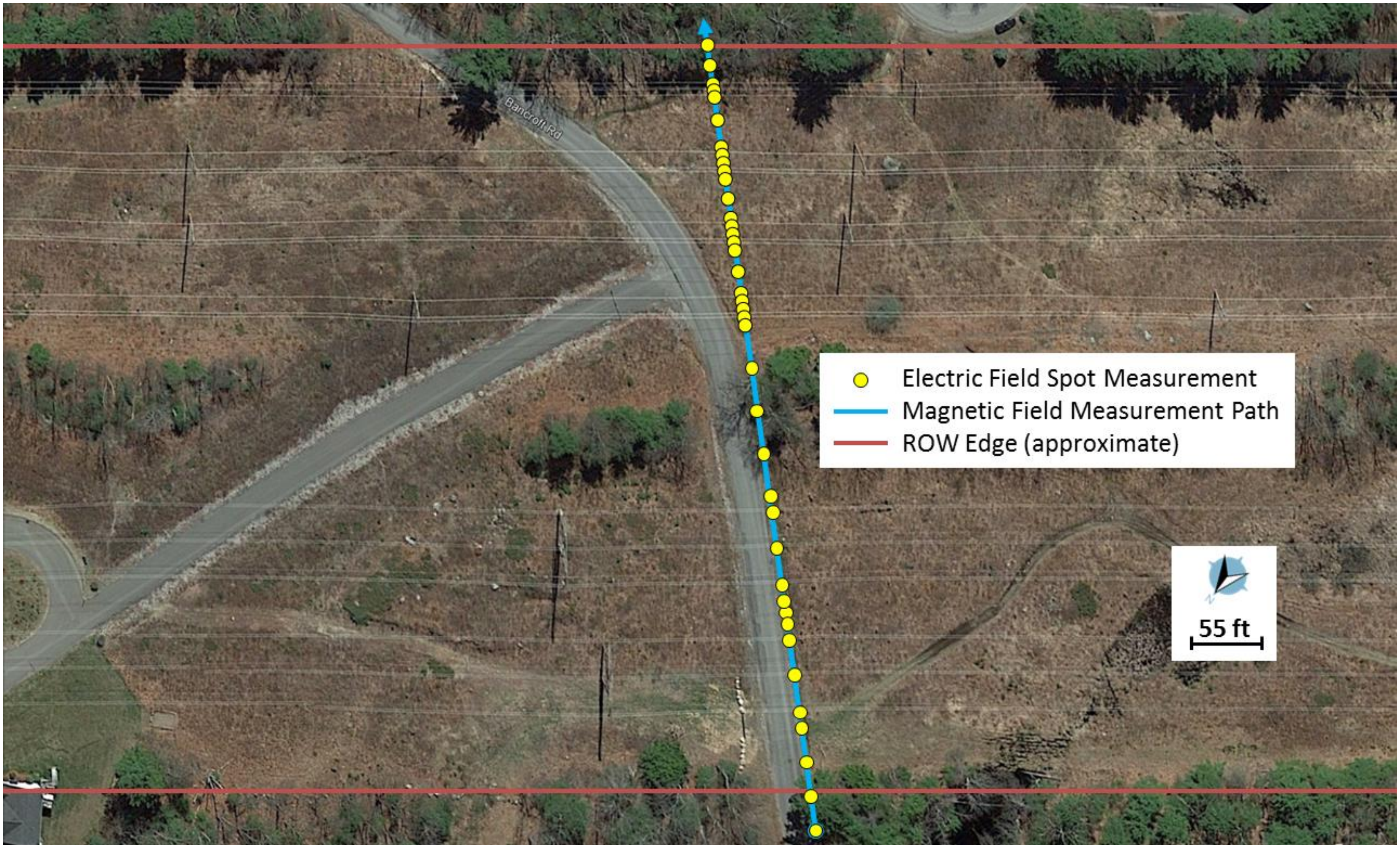


Figure C-8. Aerial photo of measurement Site 8 (in XS-13) showing the approximate location of the magnetic field measurement path and electric field spot measurements.

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

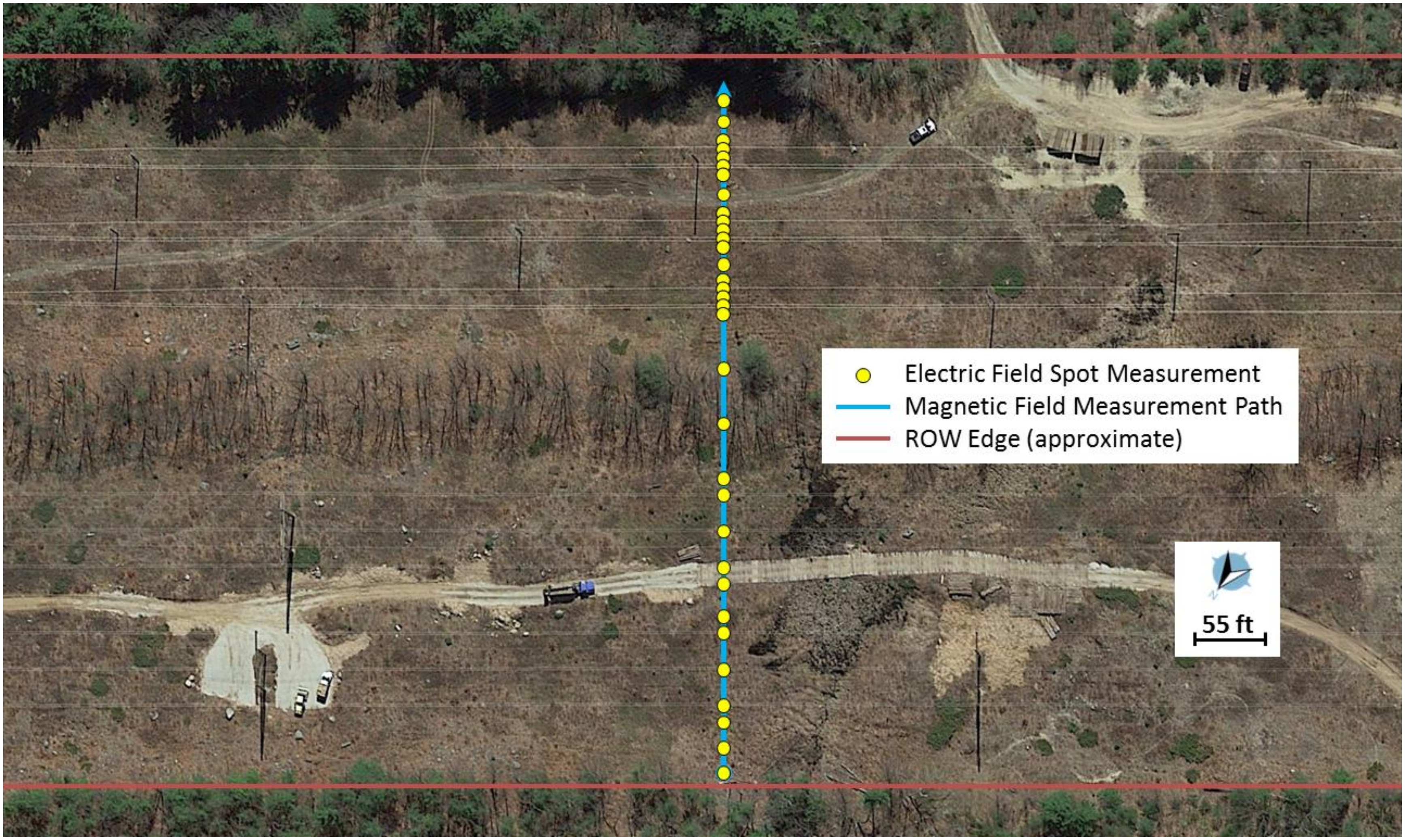


Figure C-9. Aerial photo of measurement Site 9 (in XS-14) showing the approximate location of the magnetic field measurement path and electric field spot measurements.

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

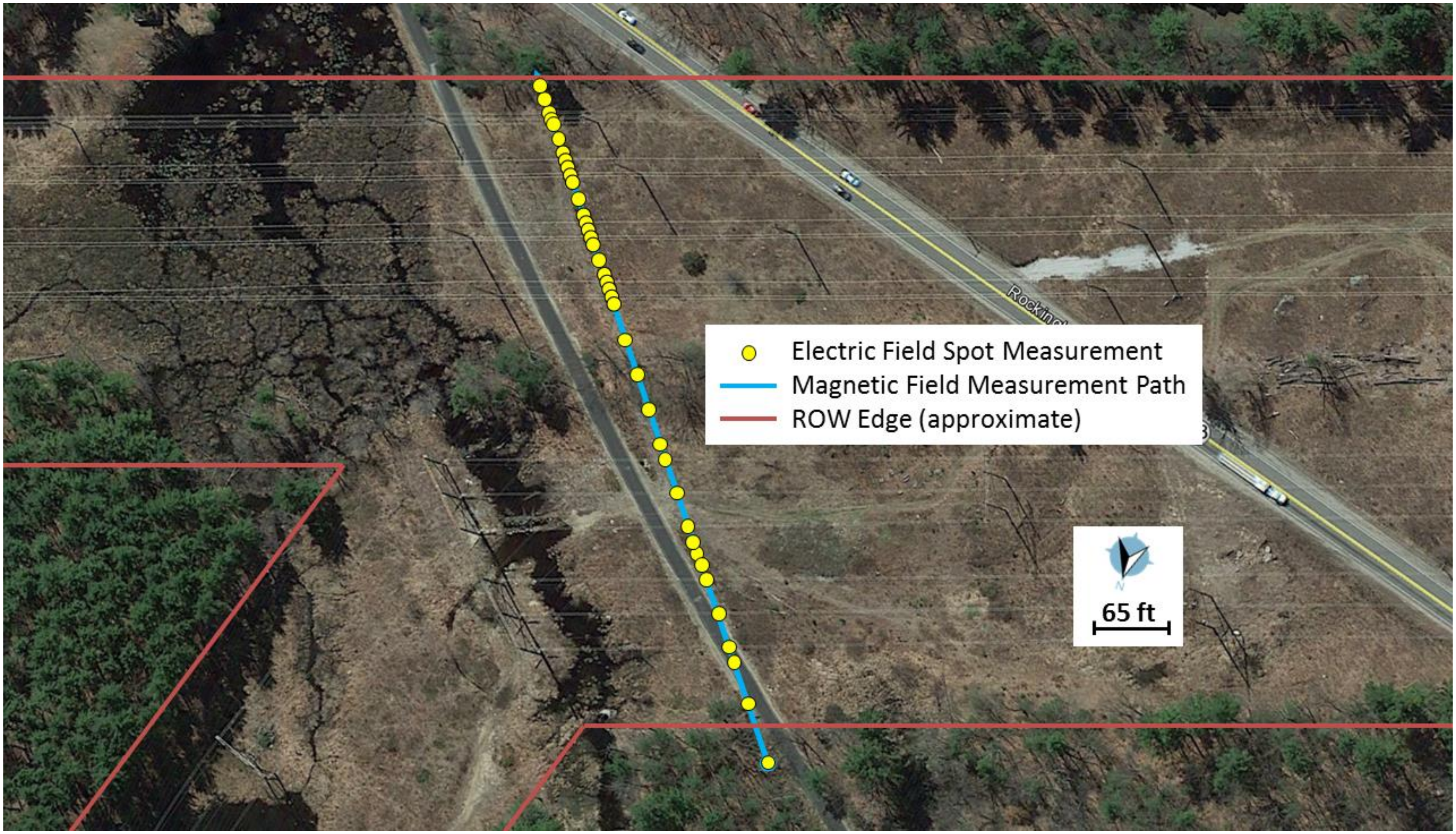


Figure C-10. Aerial photo of measurement Site 10 (in XS-15) showing the approximate location of the magnetic field measurement path and electric field spot measurements.

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	99.8	-13.1	-5.8	3.6	20.8	26.0
		N-214	230	254.0	1.2	-1.3	14.0	32.0	46.3
		O-215	230	199.1	6.9	214.9	7.1	32.0	30.3
Site 2 (XS-8c)	Off Tina Avenue	Y-151	115	126.6	-4.9	0.0	6.0	20.8	39.3
		N-214	230	254.0	1.2	12.5	-4.4	32.0	42.1
		O-215	230	199.1	6.9	148.7	19.9	32.0	39.3
Site 3 (XS-8d)	Along Winter Street	Y-151	115	126.6	-4.9	7.3	1.1	20.8	34.2
		N-214	230	254.0	1.2	41.6	-1.8	32.0	40.5
		O-215	230	199.1	6.9	166.5	11.1	32.0	48.2
Site 4 (XS-9)	Southeast of Griffin Road	N-214	230	254.0	1.2	43.5	-2.8	32.0	36.1
		O-215	230	199.1	6.9	176.7	9.5	32.0	38.5
Site 5 (XS-10)	South of Dan Hill Road	N-214	230	254.0	1.2	23.3	n/a	33.0	36.1
		O-215	230	199.1	6.9	121.2	n/a	33.0	40.6
		326	345	543.1	-107.3	14.7	-29.8	35.0	40.9
		451/452	DC	n/a	n/a	n/a	n/a	37.5	69.5
Site 6 (XS-11)	North of Wiley Hill Road	X116	115	127.6	23.4	64.0	-2.0	30.0	41.4
		Z119	115	127.7	23.4	63.6	-2.1	24.0	47.2
		326	345	543.1	-107.3	275.6	-39.2	35.0	48.2
		380	345	536.0	-29.5	257.3	-42.4	35.0	39.2
Site 7 (XS-12)	Off Davis Drive	Z119	115	127.7	23.4	35.6	0.8	24.0	34.8
		X116	115	127.6	23.4	36.0	1.1	30.0	42.8
		S188	115	-75.8	18.3	1.3	-2.0	24.0	36.4
		326	345	543.1	-107.3	-116.3	-3.0	35.0	33.5
		380	345	536.0	-29.5	334.8	-43.1	35.0	35.8

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 8 (XS-13)	Along Bancroft Road	365	34.1	19.6	0.4	9.1	-0.9	25.0	32.8
		Z119	115	127.7	23.4	38.8	3.8	24.0	53.1
		X116	115	127.6	23.4	39.1	3.9	30.0	46.9
		R187	115	-14.7	33.7	-15.1	0.7	30.0	40.7
		326	345	543.1	-107.3	-36.9	-9.3	35.0	49.2
		380	345	536.0	-29.5	390.5	-55.9	35.0	34.7
Site 9 (XS-14)	Off Snow Flake Lane	Z119	115	127.7	23.4	38.5	1.6	24.0	42.3
		X116	115	127.6	23.4	39.0	1.7	30.0	34.8
		R187	115	-14.7	33.7	-25.7	0.3	30.0	45.1
		326	345	543.1	-107.3	-81.4	-4.7	35.0	45.8
		380	345	536.0	-29.5	338.7	-35.5	35.0	47.8
Site 10 (XS-15)	Along Londonderry Rail Trail	32W4	12.7	5.4	-0.2	2.4	0.4	25.0	39.3
		32W3	12.7	n/a	n/a	3.2	-0.3	n/a	50.8
		Z119	115	127.7	23.4	37.2	3.2	24.0	55.3
		X116	115	127.6	23.4	37.5	3.5	30.0	58.0
		R187	115	-14.7	33.7	-14.4	-0.7	30.0	52.3
		326	345	543.1	-107.3	-129.6	-7.2	35.0	42.7
		380	345	536.0	-29.5	317.4	-49	35.0	40.8

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	99.8	-13.1	6.6	0.8
		N-214	230	254.0	1.2	-2.8	13.4
		O-215	230	199.1	6.9	221.7	6.0
PUC 2 (XS-8d)	Shelly Drive	Y-151	115	126.6	-4.9	5.2	2.4
		N-214	230	254.0	1.2	36.7	0.5
		O-215	230	199.1	6.9	169.2	9.5
PUC 3 (XS-8d)	Glance Road	Y-151	115	126.6	-4.9	4.9	2.3
		N-214	230	254.0	1.2	44.9	-2.8
		O-215	230	199.1	6.9	186.8	11.1
PUC 4 (XS-10)	David Drive	N-214	230	254.0	1.2	14.9	n/a
		O-215	230	199.1	6.9	205.5	n/a
		326	345	543.1	-107.3	11.5	-6.8
		451/452	DC	n/a	n/a	n/a	n/a
PUC 5 (XS-11)	Wiley Hill Road	X116	115	127.6	23.4	37.5	-1.3
		Z119	115	127.7	23.4	36.9	-1.4
		326	345	543.1	-107.3	93.5	-4.5
		380	345	536.0	-29.5	200.7	-35.9
PUC 6 (XS-11)	Mayflower Drive	X116	115	127.6	23.4	52.6	-1.3
		Z119	115	127.7	23.4	52.0	-1.4
		326	345	543.1	-107.3	8.7	-5.5
		380	345	536.0	-29.5	416.2	-50.9

Appendix E

Aerial Maps and Measured EMF Levels from of Road Crossing Measurement Sites

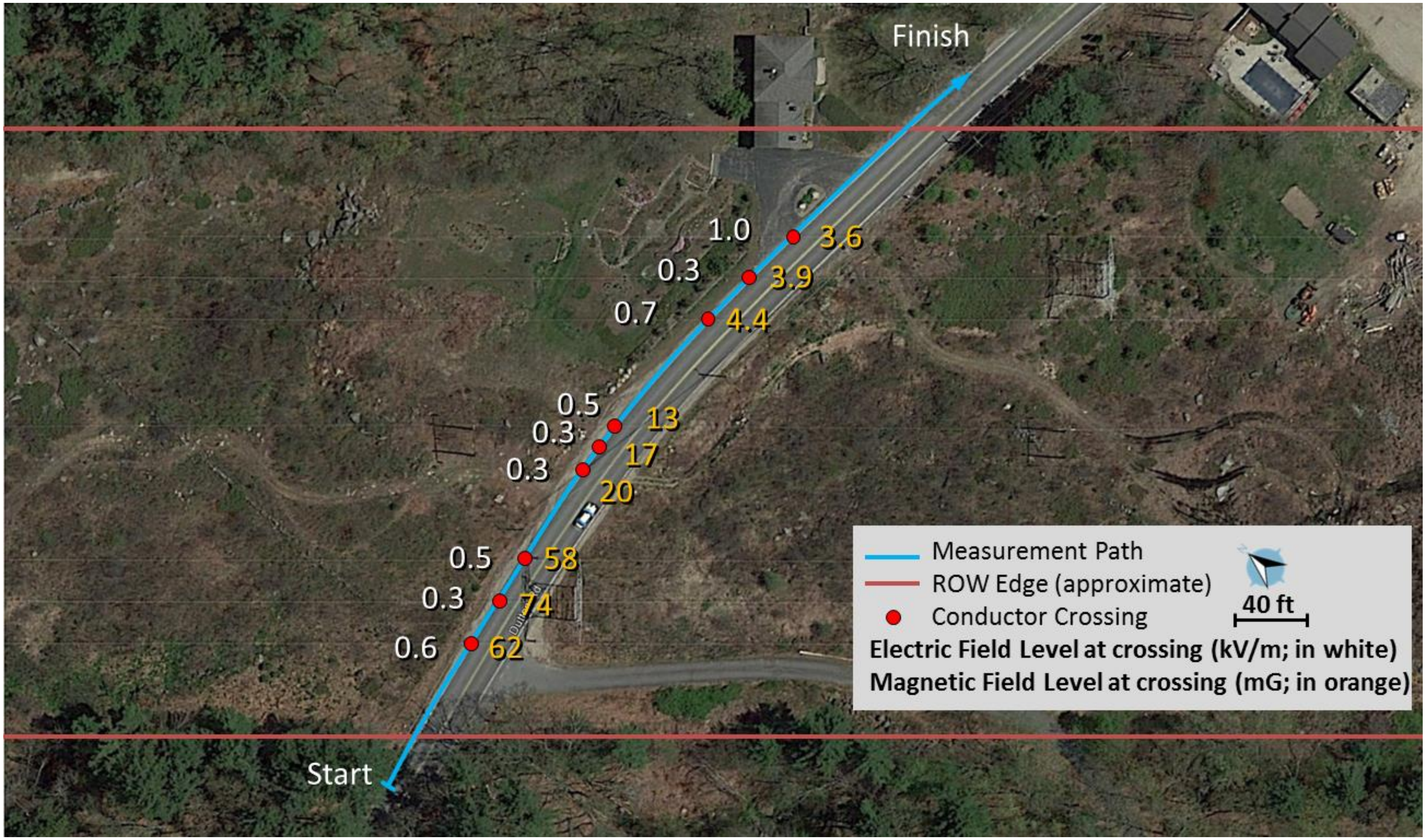


Figure E-1. Aerial photo of measurement at PUC Site 1(Dutton Road in XS-8b) showing the path along which EMF measurements were performed.

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

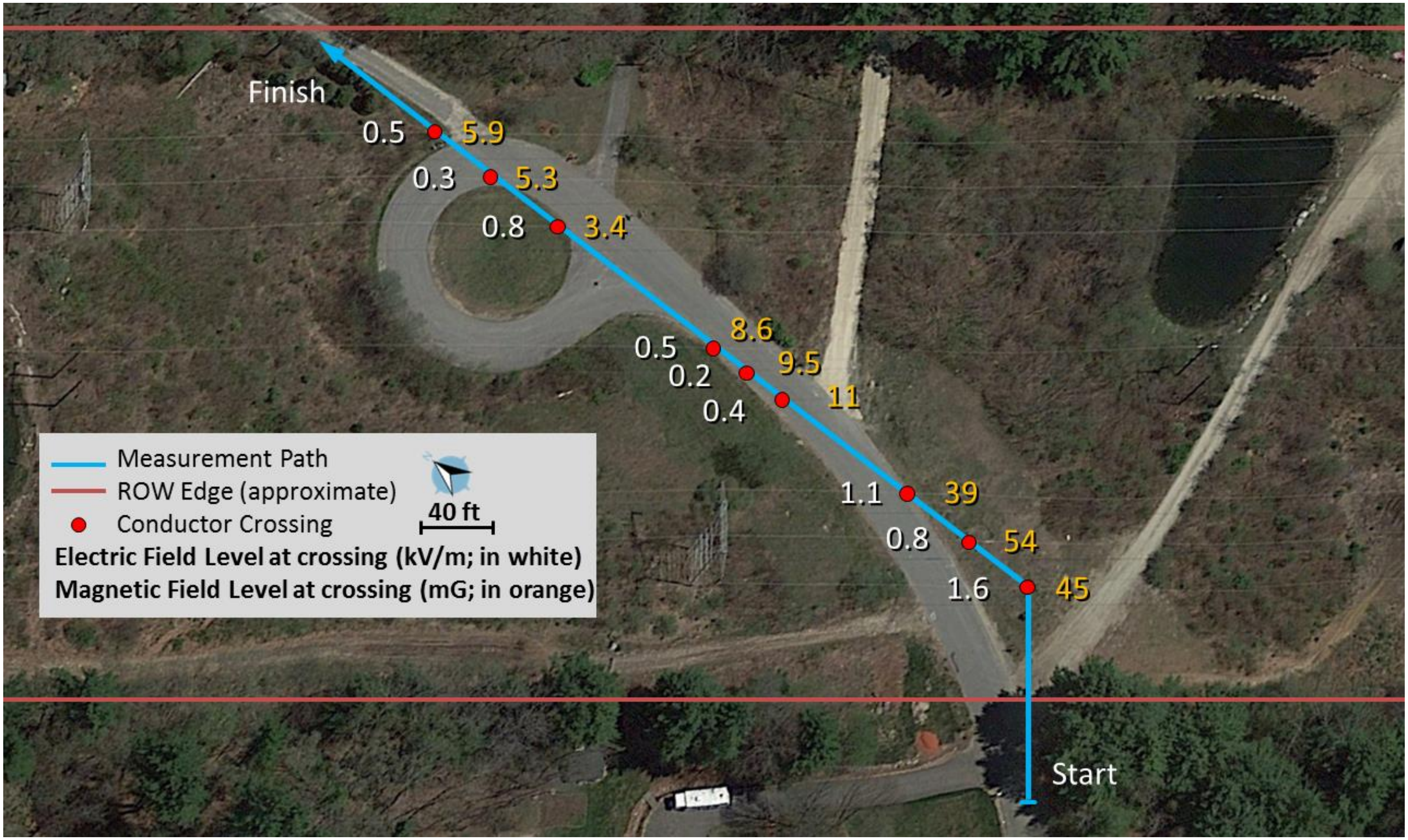


Figure E-2. Aerial photo of measurement at PUC Site 2 (Shelly Drive Road in XS-8d) showing the path along which EMF measurements were performed.

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

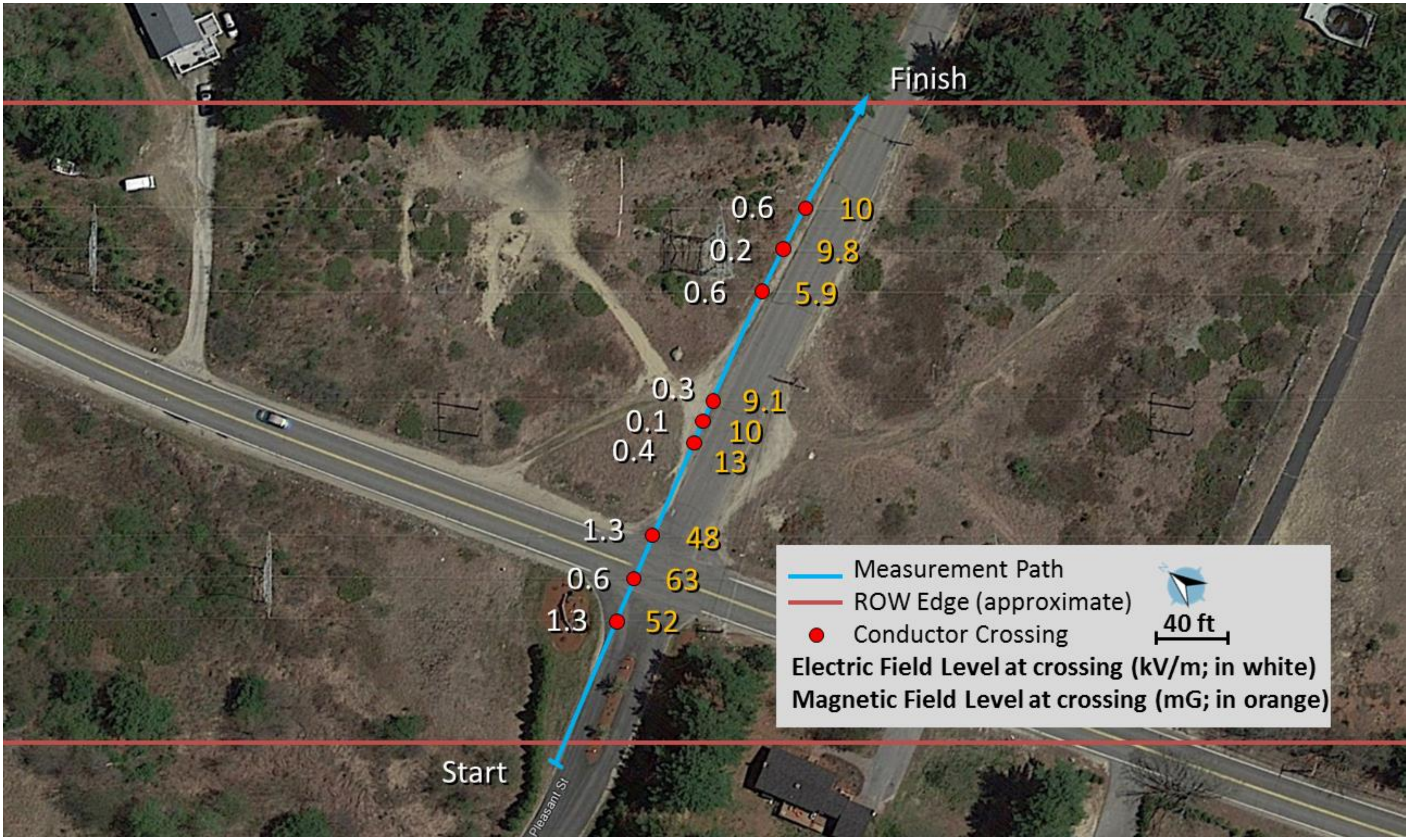


Figure E-3. Aerial photo of measurement at PUC Site 3 (Glance Road Drive Road in XS-8d) showing the path along which EMF measurements were performed.

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

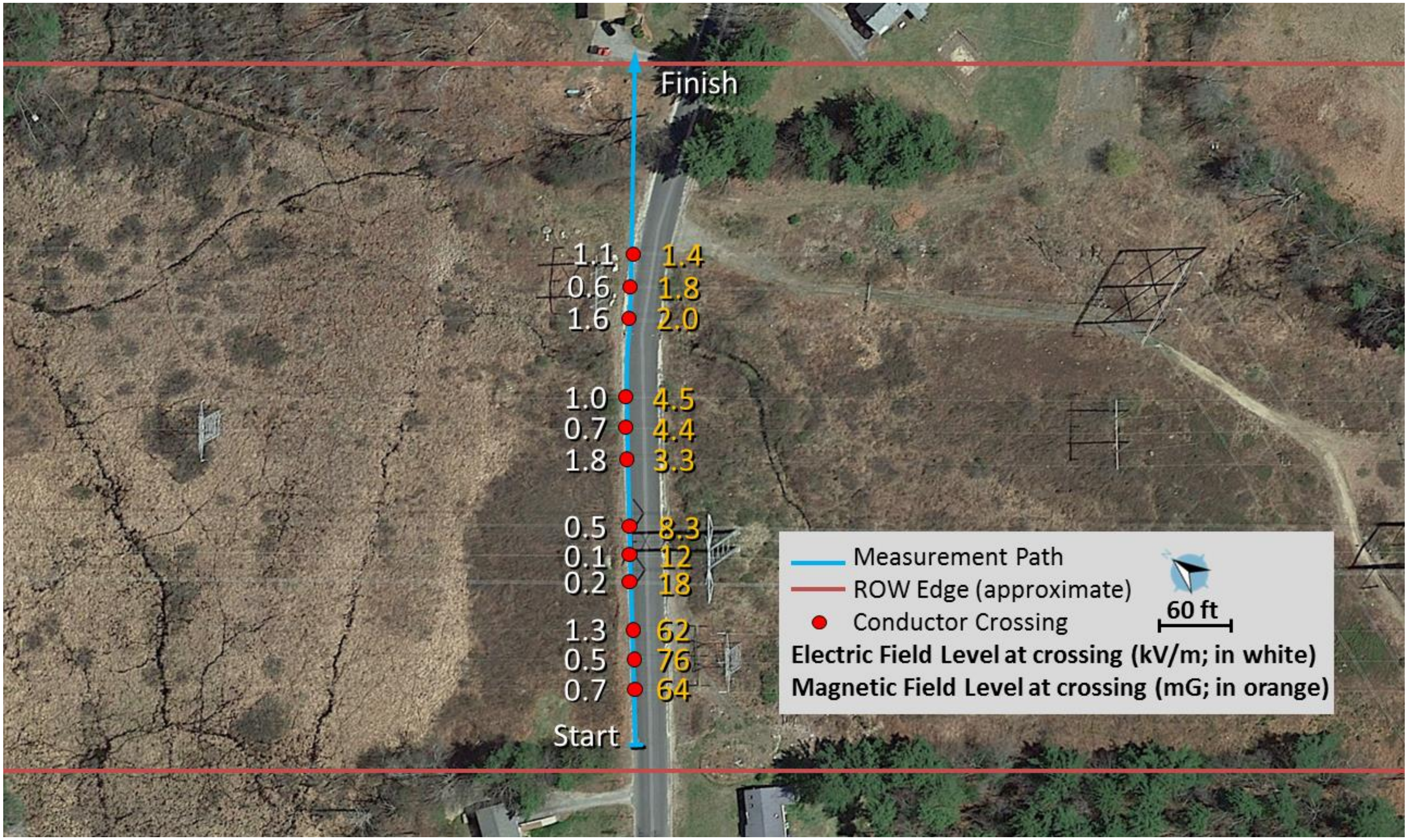


Figure E-4. Aerial photo of measurement at PUC Site 4 (David Drive in XS-10) showing the path along which EMF measurements were performed.

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

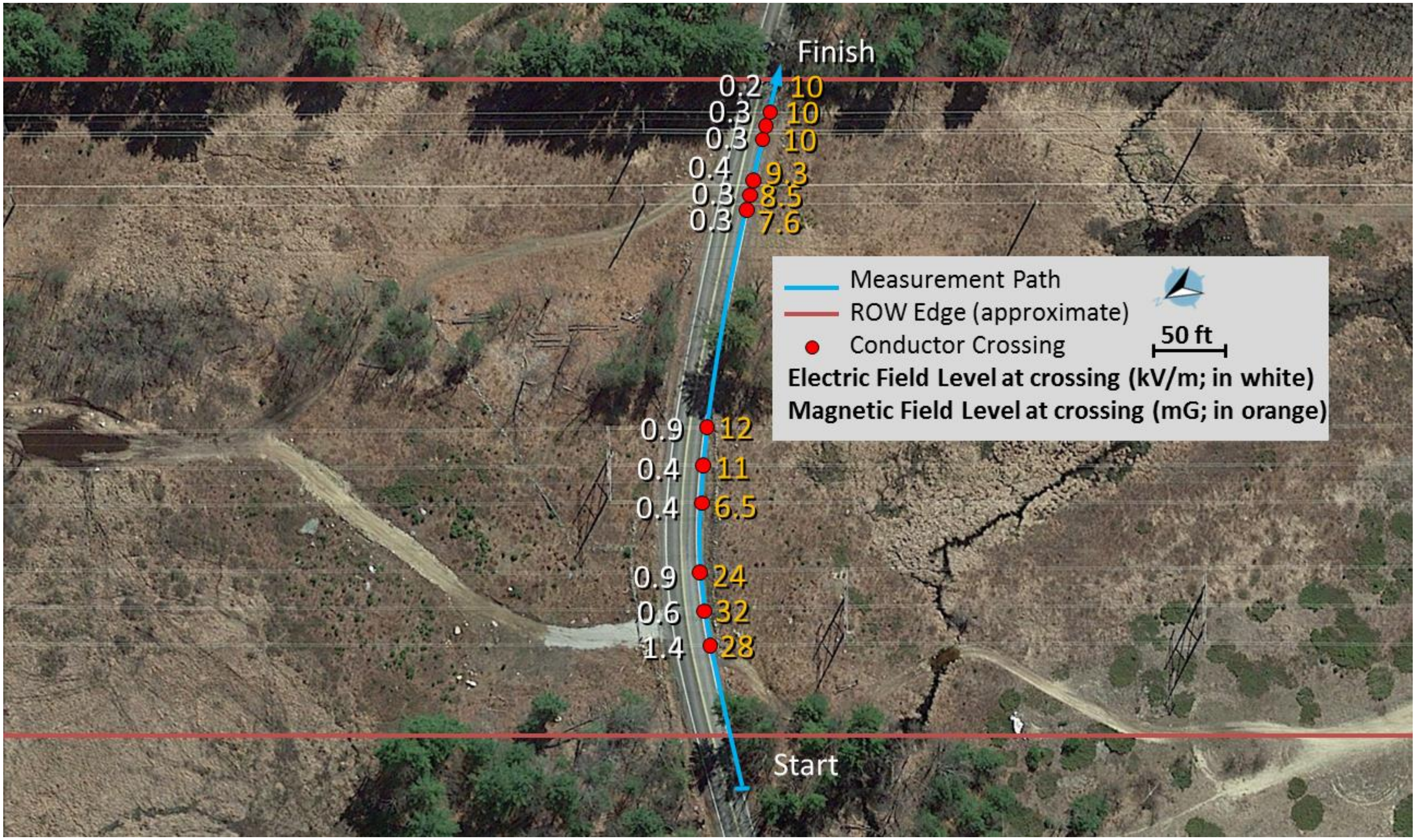


Figure E-5. Aerial photo of measurement at PUC Site 5 (Wiley Hill Road in XS-11) showing the path along which EMF measurements were performed.

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

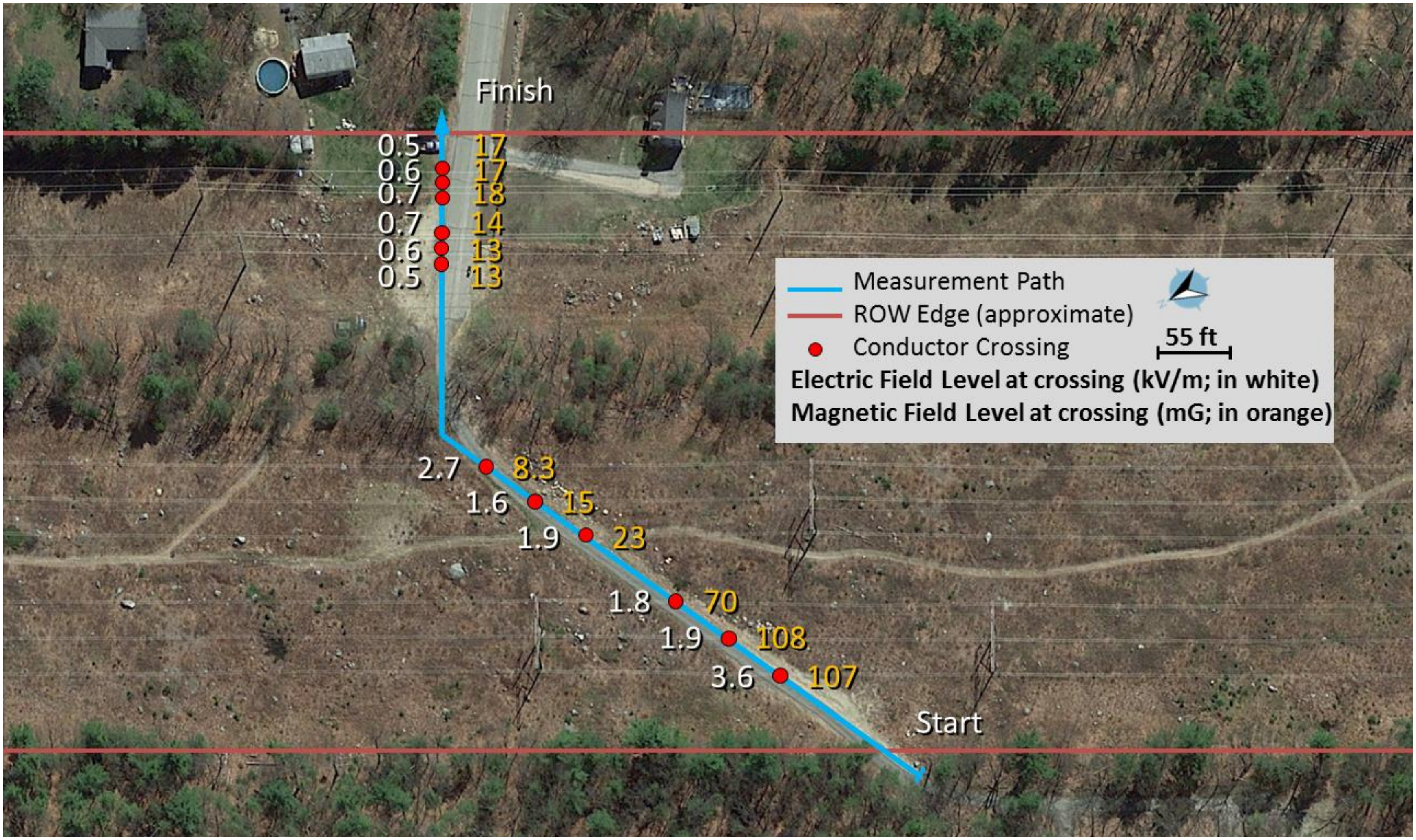


Figure C-6. Aerial photo of measurement at PUC Site 6 (Mayflower Drive in XS-11) showing the path along which EMF measurements were performed.

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

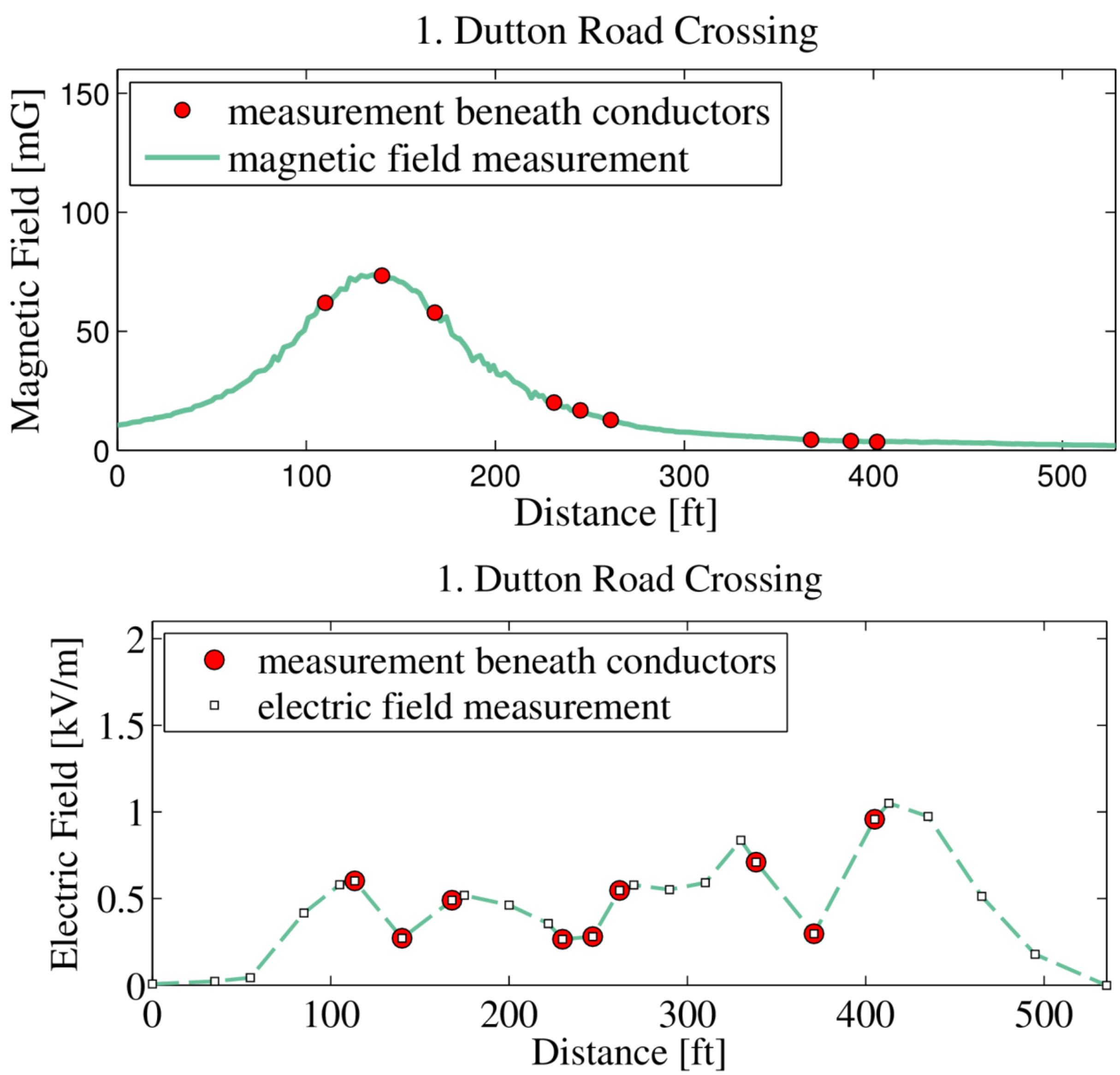


Figure E-7. Detailed EMF measurements performed at PUC Site 1 (Dutton Road in XS-8b)

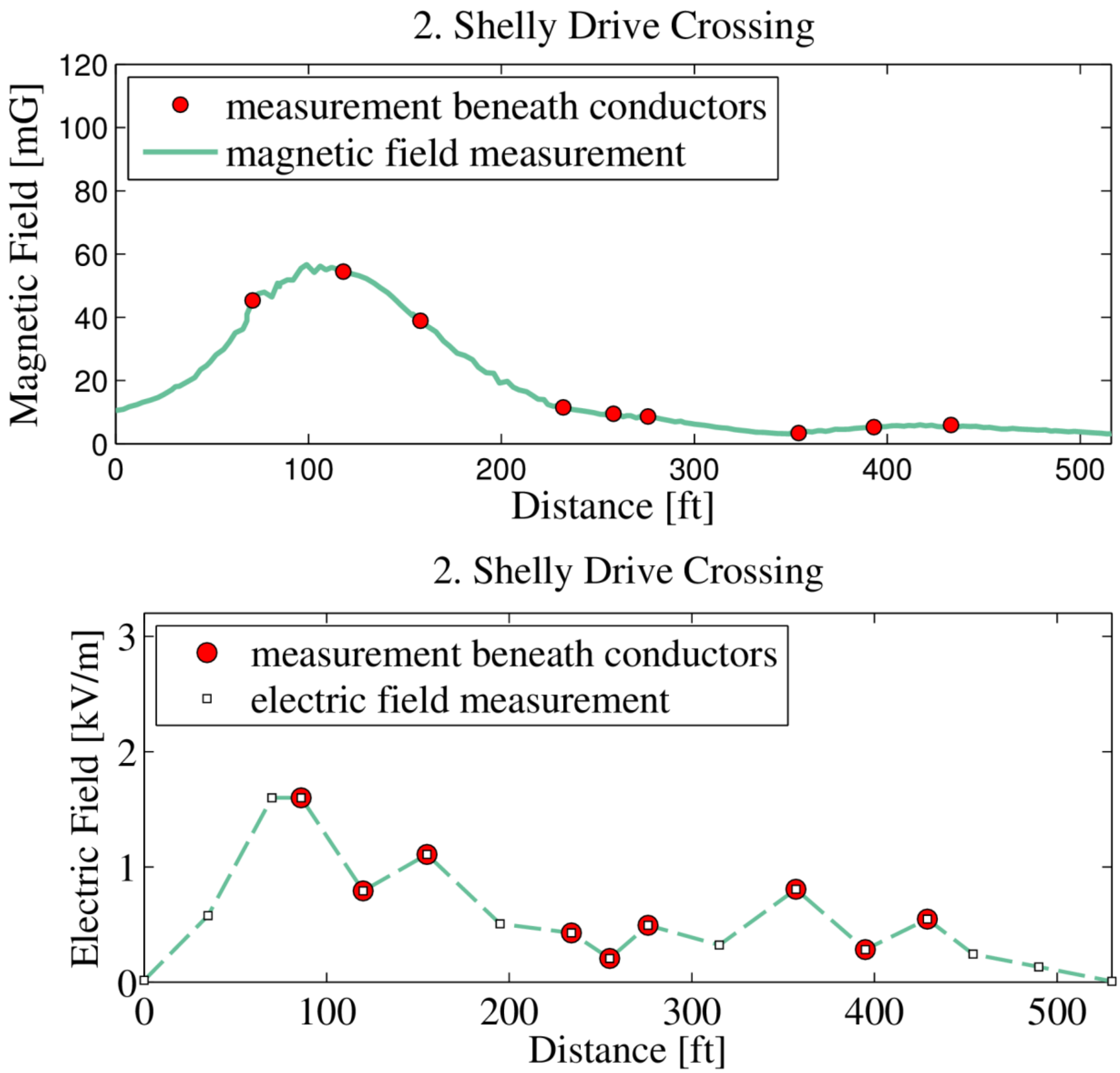


Figure E-8. Detailed EMF measurements performed at PUC Site 2 (Shelly Drive in XS-8d)

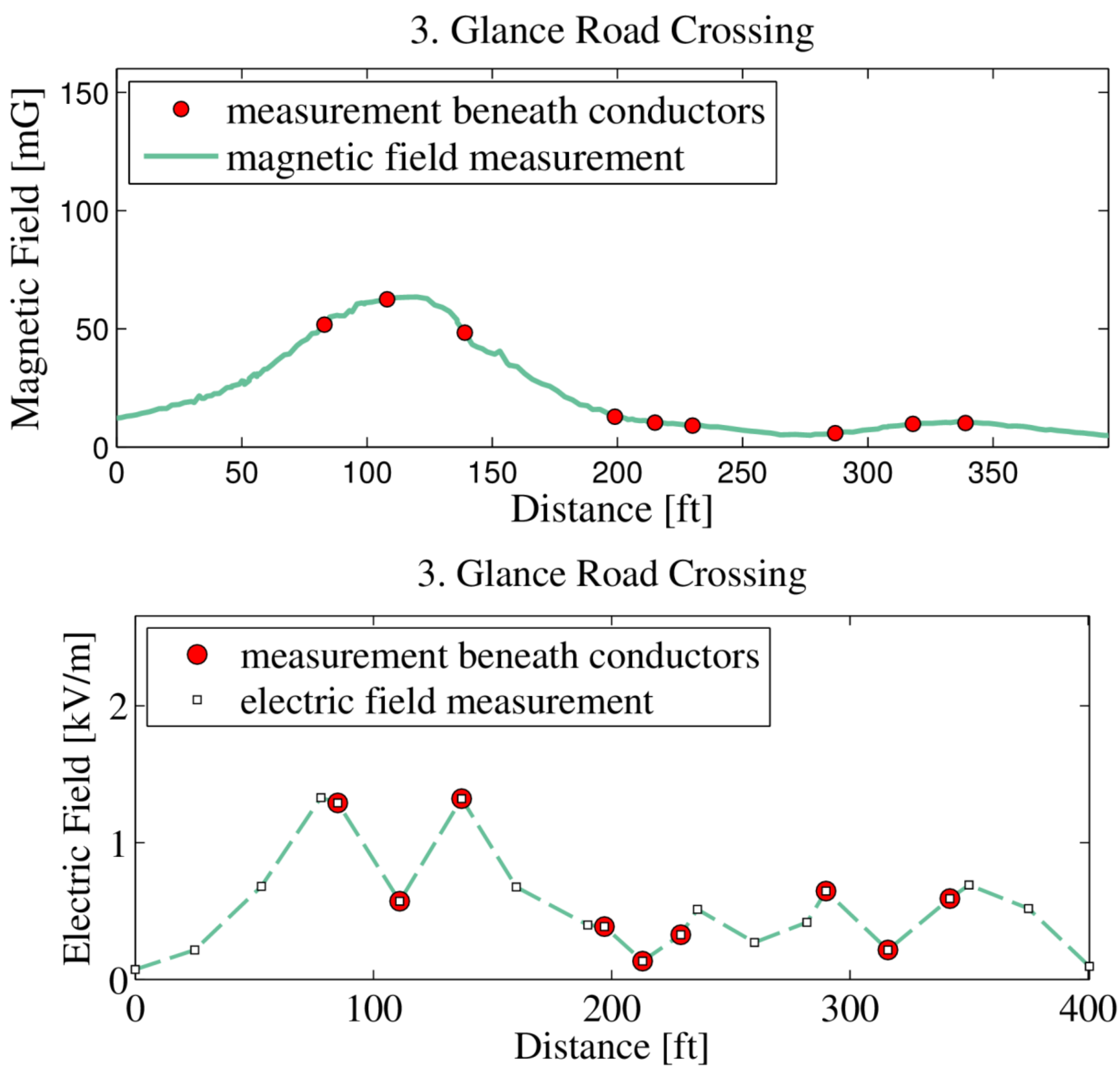


Figure E-9. Detailed EMF measurements performed at PUC Site 3 (Glance Road in XS-8d)

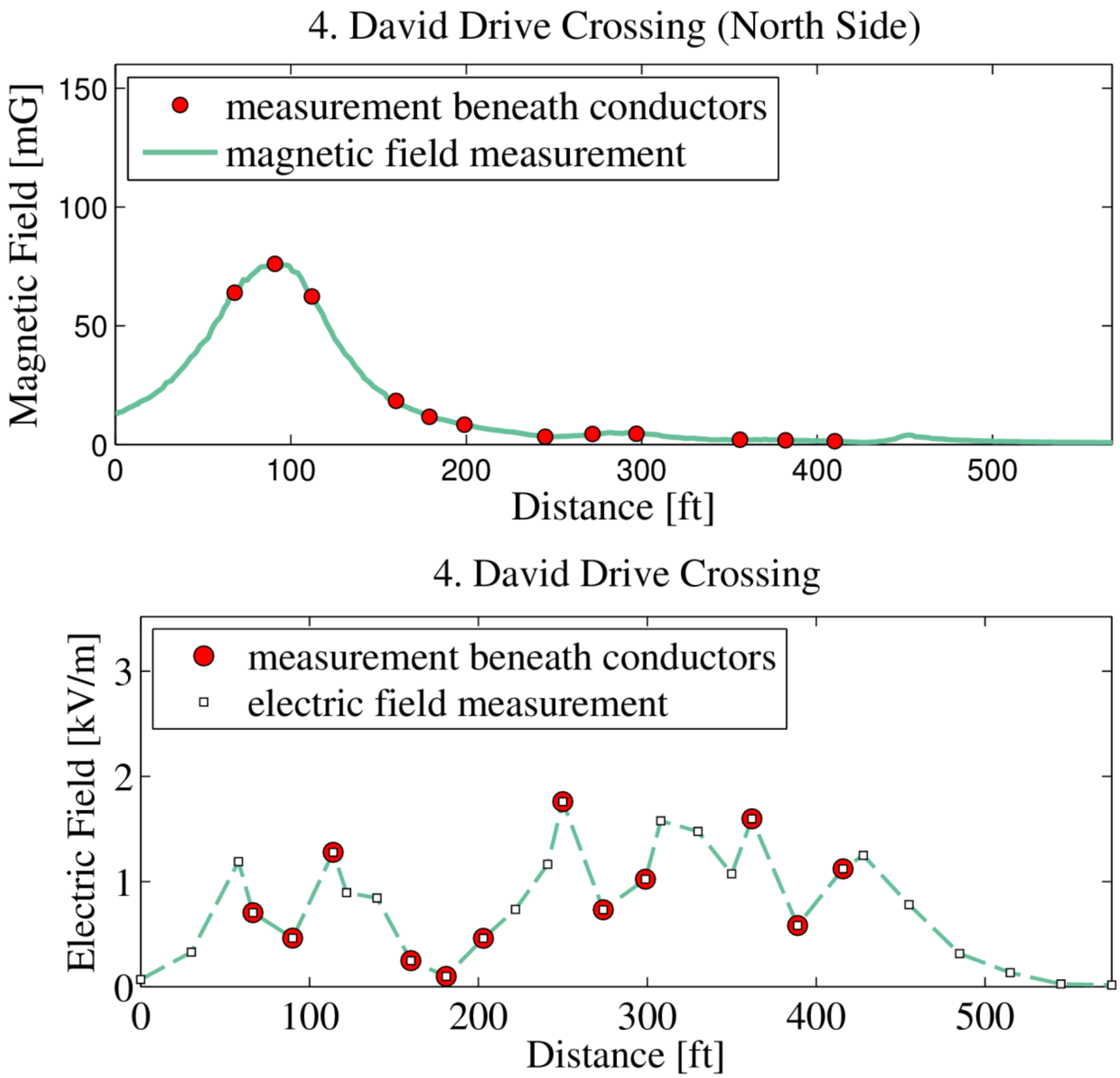


Figure E-10. Detailed EMF measurements performed at PUC Site 4 (David Drive in XS-10)

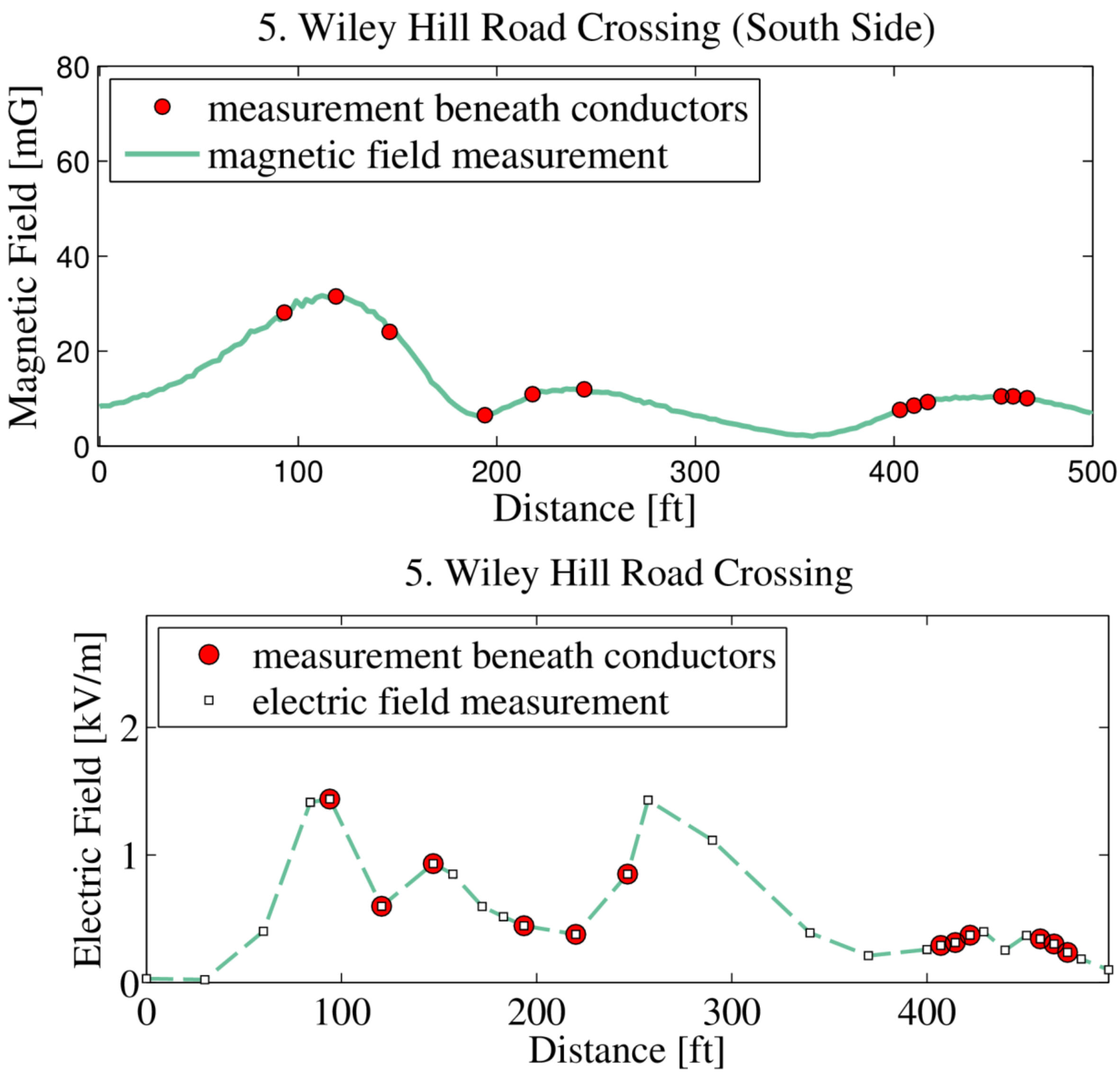


Figure E-11. Detailed EMF measurements performed at PUC Site 5 (Wiley Hill Road in XS-11)

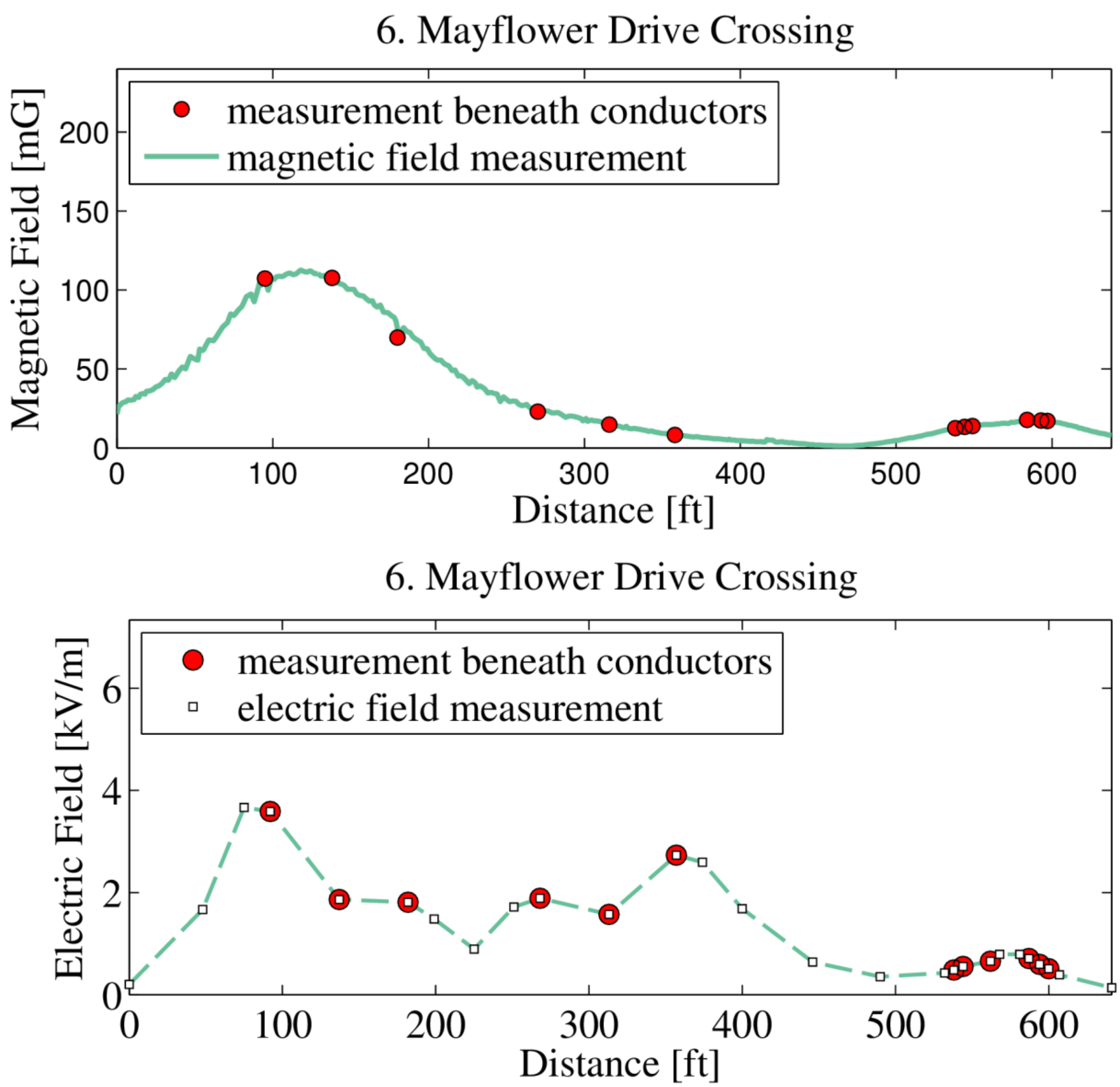


Figure E-12. Detailed EMF measurements performed at PUC Site 6 (Mayflower Drive in XS-11)

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: 3363

Date of Calibration: 6/27/2016

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

Lonsdale 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	***600E***
Serial No.	***A44142***
Date of Calibration	***31st March 2016***
CHM Calibration Due Date	***31st March 2017***

Equipment used:

Model	Serial No.	Control No.	Calibration Due Date
SupaRule T30 Thermometer	8310412	CAL ID 041	28th April 2016

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: 22.0°C
Temperature reading before adjustment: 22.2°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.

Eoin O'Loughlin

Approved Signatory
Eoin O'Loughlin

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

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 11/11/2016

Exponent®

M E M O R A N D U M

TO: Randall Knepper, Director, Safety and Security, NH PUC

Pamela Monroe, Administrator, NH SEC

FROM: Jessica T. Farrell, P.E.
David L. Plante, P.E.
Benjamin Cotts, Ph.D., P.E.
Gary Johnson, Ph.D.

DATE: November 11, 2016

PROJECT: Merrimack Valley Reliability Project (NH SEC Docket 2015-05)

SUBJECT: Measurements of Electric and Magnetic Fields

To comply with the Order and Certificate of Site and Facility with Conditions issued by the New Hampshire Site Evaluation Committee (NHSEC) for the Merrimack Valley Reliability Project on October 4, 2016, National Grid and Eversource, through Exponent, provide a proposed protocol for performing measurements of electric and magnetic fields (EMF) both before and after the Project is placed into service in consultation with the Safety Division of the New Hampshire Public Utilities Commission (PUC).

Order and Certificate of Site and Facility Condition:

> . . . that the Applicant, in consultation with the PUC's Safety Division, shall measure actual electric and magnetic field levels along the Project ROW 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 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.

Proposed Measurement Protocol

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

Measurement Preparation and Location Identification

National Grid and Eversource will identify at least one location (preferably with at least one alternate location), which is anticipated to be appropriate for measurements both before and after the Project is placed into service, in each of the 10 cross sections specified in Tables A-1 and A-2 in the Application, at Appendix AG. These locations should have the characteristics as close as possible to the following:

1) Free from other sources of EMF which may affect measured levels (e.g., overhead/underground distribution lines) or other facilities which can alter measured EMF levels (e.g., water or sewer pipes, gas or oil pipelines).
2) Flat, level surface beneath the transmission lines that is away from transmission line structures (ideally near midspan of lines).
3) Free of underbrush, trees or other conductive objects which is necessary in order to match the conditions for which Exponent modeled the electric field.

Additionally, foul weather, particularly precipitation, will interfere with the function of instruments and the valid measurement of electric field levels. Exponent will therefore coordinate with utility personnel and the Safety Division to identify a time-frame with anticipated favorable weather conditions. This timeframe (or timeframes) will be 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., loading information of all transmission lines at the measurement locations) can be logged and available during the proposed measurement period. Post-construction measurements will be made during summer peak loading season.

Measurement Procedure

At each identified measurement location, the utility 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 in 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.1308-1994). All meters and measurement accessories will be calibrated by the manufacturer using methods like those described in IEEE Std. 644-1994. If measurements before the Project is placed into service are taken at line loadings lower than peak levels, field levels will be adjusted for peak loading conditions on existing lines and the new MVRP line for comparisons to values in Table A-1 and A-2 in the Petition.

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.

[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.