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December 14, 2016



Mr. Robert Stein, Chairman
Connecticut Siting Council
Ten Franklin Square
New Britain, CT 06051

RE: Docket No. 424: Interstate Reliability Project
Post-Construction EMF Monitoring Report

Dear Chairman Stein:

Per the Connecticut Siting Council's ("Council") September 20, 2013 approval of Eversource Energy's ("Eversource") Development and Management Plan ("D&M Plan") for Interstate Reliability Project, enclosed are an original and fifteen copies of the Post-Construction Electric and Magnetic Fields Monitoring Report.

Should you or other Council members have any questions regarding this submission, please do not hesitate to contact me via e-mail at kathleen.shanley@eversource.com or telephone at (860) 728-4527.

Sincerely,

Kathleen M. Shanley
Manager, Transmission Siting

Enclosures

# INTERSTATE RELIABILITY PROJECT
# POST-CONSTRUCTION EMF MONITORING REPORT

## December 13, 2016

Measurements and Report By:

Exponent, Inc.
17000 Science Drive, Suite 200
Bowie, MD 20715

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# Introduction

In 2011, the Connecticut Light & Power Company (CL&P) filed its Application for Certificate of Environmental Compatibility and Public Need for the construction and operation of the Connecticut portion of the Interstate Reliability Transmission Project in Docket 424. The Application included detailed modeling to project future levels of electric and magnetic fields (EMF) associated with the existing and proposed lines along each segment of the Proposed Route.[1] The Decision and Order issued by the Connecticut Siting Council (CSC) at the conclusion of the proceeding requires: *"3. The Certificate Holder shall prepare a Development and Management (D&M) Plan, whole or in parts, for this project…and shall include:… j. A post-construction electric and magnetic field monitoring plan."*[2] Pursuant to this requirement, a Post-Construction Electric and Magnetic Field Monitoring Plan ("the Plan") was included in *Appendix F to the Development and Management Plan for Construction of The Interstate Reliability Project New 345-kV Transmission Lines and Related Minor Modifications to Adjacent Lines* that was filed with the CSC in August, 2013.

The Plan calls for measurements of EMF (twice) at each of nine route sections of the transmission line between the Card Street Substation and the Connecticut/Rhode Island border as well as a perimeter magnetic-field measurement around the Card Street Substation. The monitoring locations were selected to capture each newly-constructed overhead line type including several locations in which the 3271 line is constructed on the base-case H-frame structures as well as portions of the line that are constructed on delta and vertical structures. Other sections of the route were also selected for measurements where 69- or 115-kilovolt (kV) lines share the right of way (ROW). Upon completion of the Project, each of these potential sites was reviewed and slight modifications were made to the specific location of some measurement sites due to terrain, undergrowth, or accessibility.

The Project was completed and energized on December 14, 2015. Pursuant to the Plan, an Exponent engineer visited each of nine sites and the Card Street Substation (detailed below) on October 4 and October 5, 2016 (Measurement 1), and again on October 11 and November 2, 2016 (Measurement 2) to take EMF measurements. As required by the CSC, this report includes:

- "true-up" comparisons between field measurements taken after completion of the Project; and calculated field values using actual line conditions at the time these measurements were taken (Appendix C);

- aerial maps on a scale of 1 inch equals 100 feet to mark each measurement location (Appendix B);

1 Application of CL&P to the CSC in Docket No. 424, Vol. 1, Section 7, 2011.

2 CSC Decision and Order, Docket No. 424, December 27, 2012. Several pages of the decision pertaining to EMF were later corrected. See http://www.ct.gov/csc/lib/csc/pendingproceeds/docket_424/final_decision_documents/424-20130109-clericalcorrections.pdf

- coincident transmission line currents as recorded by the SCADA system (Appendix D); and,

- the size of the transmission line conductors for each measurement location (Appendix D).

The EMF measurements in this report show that the calculations presented in the Application provide a reasonable estimate of the actual EMF levels measured after the Project was placed into operation.  The loadings of the transmission lines at the time of measurements were generally far less than the annual average loading (AAL) assumed for calculations during the siting proceedings and so the measured magnetic-field levels also were generally less than those calculated.  The measured electric-field levels were generally lower than those calculated during the siting proceedings because heights of the conductors above ground at the measurement locations were generally higher than those that had been assumed for modeling.  To facilitate a direct comparison of measured and modeled field levels, true-up modeling was performed based upon the loadings and line heights encountered at each section of the route where measurements were performed.  These true-up comparisons show excellent agreement with measured results and demonstrate the accuracy of EMF modeling methods used during the siting proceedings.

# Sources of Electric and Magnetic Fields

**Electric fields** result from the voltages applied to electrical conductors and equipment. They are generally expressed in measurement units of volts per meter (V/m) or kilovolts per meter (kV/m) where 1 kV/m is equal to 1,000 V/m. Most conductive materials—including fences, shrubbery, trees, and buildings—block electric fields. In addition, electric-field levels diminish rapidly with increasing distance from the source; in the case of overhead transmission lines the decrease is typically in proportion to the square of the distance from the lines. The electric-field levels from a transmission line depend on the line's voltage, its height above ground, and the position of the conductors relative to one another. Electric fields from utility sources such as transmission lines also generally are very stable over time since the elements of the electrical infrastructure are held within tight voltage tolerance levels for improved performance.

**Magnetic fields** are produced by the flow of electric currents and typically are measured in units of Gauss (G) or milligauss (mG) where 1 G = 1,000 mG. Similar to electric fields, magnetic fields from transmission lines depend on the conductor height above ground and relative spacing of transmission line conductors, but also depend on the current flowing through the conductor at any given time. For this reason magnetic fields from transmission lines can vary substantially over time as the demand for electric power fluctuates. Magnetic fields are not blocked by conductive objects; however, similar to electric fields, magnetic-field levels diminish rapidly with increasing distance from the source. In the case of transmission lines, magnetic fields also generally decrease with distance from the lines in proportion to the square of that distance.

Magnetic-field measurements present a snapshot of the conditions at a single point in time. As the demand for energy changes within the state and surrounding region so too will the measured magnetic-field levels. There are daily load patterns where demand increases during the daytime and decreases during the nighttime, as well as seasonal patterns with higher demand during summer months than in winter months. The measurements performed on October 4, 5, 11, and November 2, 2016, occurred at various times throughout the day and so the recorded field levels also vary as a result of the variations in loading at the particular time of measurements.

The newly-constructed 3271 and 341 transmission lines associated with the Project are sources of both electric fields and magnetic fields on the ROW, with the level of those fields diminishing with distance from the transmission lines. In addition to these new lines, existing transmission and distribution lines on portions of the ROW also are sources of EMF in those sections.

# Measurement and Modeling Methods

## Measurement Methods

EMF measurements and modeling were performed at a height of 1meter (3.28 feet) above ground in accordance with standard methods for measuring EMF near power lines (Institute of Electrical and Electronics Engineers, IEEE Std. 644-1994a). Both electric fields and magnetic fields were expressed as the total field computed as the resultant of field vectors measured along vertical, transverse, and longitudinal axes.[3] The magnetic field was measured in units of mG by orthogonally-mounted sensing coils whose output was recorded by a digital meter (Emdex II) manufactured by Enertech Consultants. In addition, at each measurement location, an additional magnetic field meter (EMDEX LITE) was placed at ground level beneath the center conductor of the new transmission line and set to continuously record the magnetic-field fluctuation and was used to evaluate if there was a large change in loading during the time that measurements were taken.

Electric-field levels were measured in units of kV/m at 5- to 50-foot intervals along the ROW with a minimum of five equally-spaced measurement locations performed beneath each transmission line in accordance with IEEE 644-1994-R2008.[4] The electric field was measured with a single-axis field sensor (oriented sequentially along each of the three orthogonal axes) and the output was logged by the same EMDEX II meter manufactured by Enertech Consultants. These instruments meet the IEEE instrumentation standard for obtaining accurate field measurements at power-line frequencies (IEEE Std.1308-1994). The meters and the electric field probes were calibrated by the manufacturer by methods like those described in IEEE Std. 644-1994-R2008.

A SupaRule T30 cable-height meter was used to measure the height of the conductors. In addition, a Kestrel 4000 weather meter was used to record temperature, relative humidity, barometric pressure, and wind speed. The calibration certificates for each piece of equipment are included in Appendix E.

## Modeling Methods

CL&P reported power flows and voltage on the transmission lines at the time measurements were taken. Exponent used these monitored conditions to assess the stability of readings, and included the monitored loads in calculations of site-specific magnetic-field levels for true-up calculations. Measurements of conductor height were used to true-up the calculated electric-

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[3] Magnetic field measurements along the vertical, transverse, and longitudinal axes were recorded as root-mean-square magnitudes. Root mean square refers to the common mathematical method of defining the effective voltage, current, or field of an alternating current system.

[4] 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).

field levels. The horizontal distance between the transmission line conductors was measured to confirm as-built construction records. These data were combined with other data provided by CL&P regarding the voltage, circuit phasing, conductor type, and conductor bundle spacing. The EMF levels for true-up models were calculated using computer algorithms developed by the Bonneville Power Administration (BPA, 1991) as was used for the modeling of EMF levels in the Application. The inputs to the Bonneville Power Administration program included the voltage, current flow, circuit phasing, and conductor positions measured on-site at each location. The resultant electric fields and magnetic fields were calculated along transects perpendicular to the transmission line conductors at four of the nine measurement sites. At the remaining sites measurements are compared to EMF levels calculated in the Application for AAL.

# Measurement Locations

The new overhead 345-kV line (3271 line) was constructed primarily in a horizontal configuration on H-frame structures. There several exceptions to this configuration including a portion on the property of the Highland Ridge Golf Range (measured at Site 2), crossing over Hawthorne Lane alternative (measured at Site 4) as well as areas of the federally-owned Mansfield Hollow property.

The new 345-kV transmission line was constructed in two segments. The first segment was on a 29.3-mile route between the Card Street Substation and the Lake Road Switching Station where the line is designated 3271. In the second segment, the new 345-kV transmission line (designated the 341 line) was constructed on a 7.5-mile route from the Lake Road Switching Station, through the Killingly Substation, to the Connecticut/Rhode Island border in Thompson.

As described above, the Plan in Appendix F to the Development and Management Plan calls for measurements of EMF (twice) at each of nine cross sections of the transmission line route as well as a perimeter magnetic-field measurement around the Card Street Substation. The monitoring locations were selected to capture each newly-constructed overhead line type that is part of the line design including several locations in which the 3271 line is constructed on the base-case H-frame structures as well as portions of the line that are constructed on delta and vertical structures. Other sections of the route also were selected for site measurements where 69- or 115-kilovolt (kV) lines share the right of way (ROW). Upon completion of the Project, each of the potential measurement sites was reevaluated and the locations changed slightly to obtain better conditions for measurements if the terrain, undergrowth, or accessibility at the initial site was deemed less suitable. The configurations of the transmission lines, however, in the shifted locations remained the same as in the original plan. The locations where all measurements were performed are shown in Figure 1.

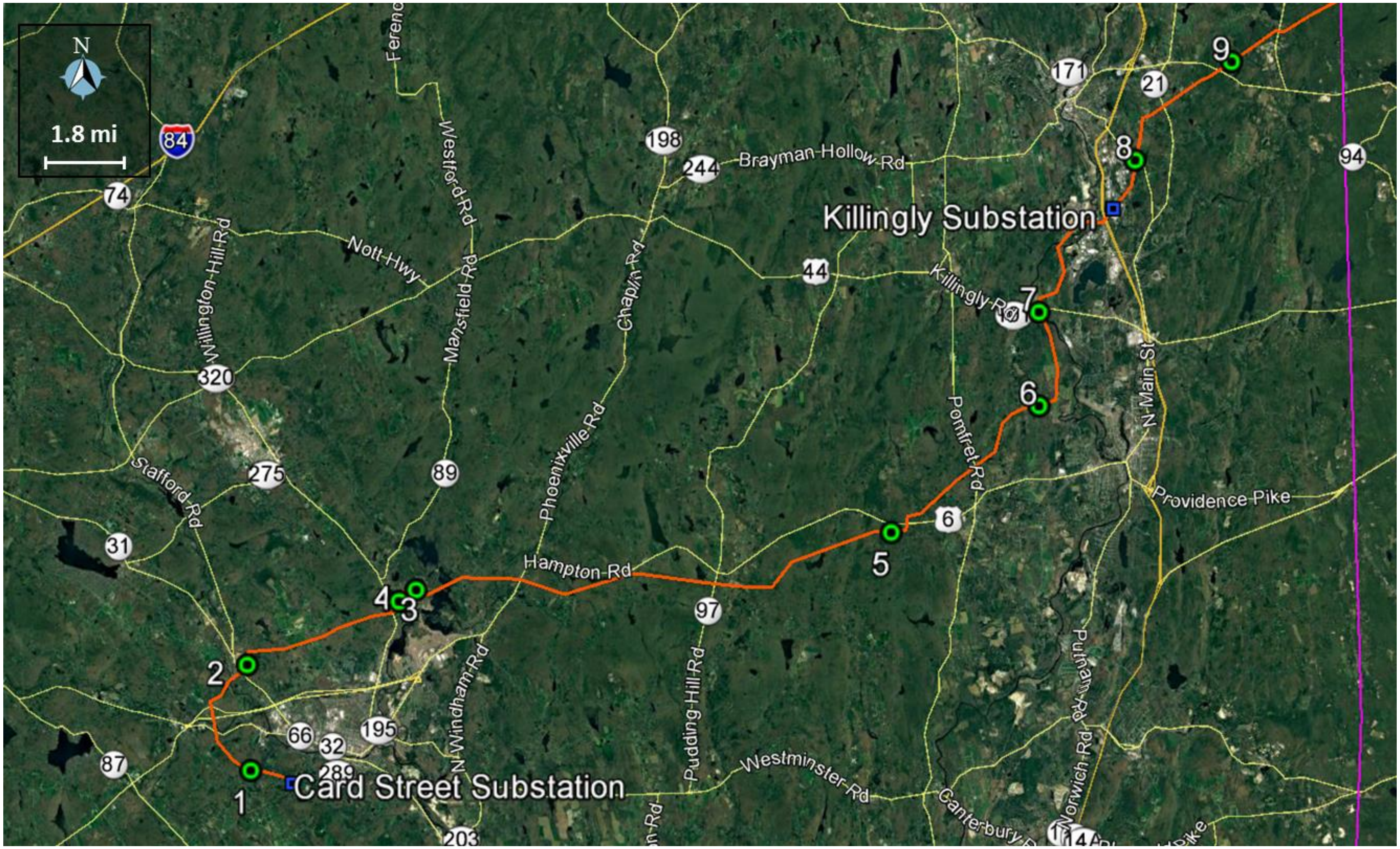



Figure 1. Route of the transmission line and measurement sites.

A summary of the locations where EMF measurements were made is shown in Table 1. Locations that were shifted slightly from the original location (and so remain on the same D&M Map originally proposed) are denoted with a '†' symbol, those locations that were shifted sufficiently to appear on a different D&M Map are denoted with a '‡' symbol. Finally, those locations for which true-up modeling was performed are identified by green shading.

**Table 1. Electric- and magnetic-field monitoring locations**

| Site | Cross Section Number | Municipality | Monitoring Location | D&M Map Number |
|---|---|---|---|---|
| 1 | XS-1 | Columbia | Cards Mill Road | 2 |
| 2 | XS-2 | Mansfield | Off East Stratford Road | 8 |
| 3 | XS-2 | Mansfield | South of Bassetts Bridge Road | 14 |
| 4 | HL-1 | Mansfield | Hawthorne Lane | 15 |
| 5 | XS-6 | Brooklyn | West of Windham Road | 34 |
| 6 | XS-6 | Brooklyn | East of Church Street | 43 |
| 7 | XS-7 | Pomfret | Hartford Pike | 47 |
| 8 | XS-11 | Killingly | East of Killingly Avenue | 56 |
| 9 | XS-12 | Putnam | Behind Elvira Heights | 62 |

Details regarding the line configurations at each measurement location are provided below.

**Site 1** is located in XS-1 where the ROW width is 350 feet; measurements were performed along the west side of Cards Mill Road in Columbia. This measurement site was moved approximately 400 feet west from the original site (east of Cards Mill Road) due to the presence of a fence on the ROW at the original location which would have precluded measurements over a large portion of the ROW width. In XS-1, a pair of 115-kV transmission lines (800 and 900 lines) is located on a double-circuit structure on the south side of the ROW, approximately 85 feet from the centerline of the new 3271 line. In addition, the 345-kV transmission line (330 line) is supported on H-frame structures approximately 85 feet north of the 3271 line's centerline. Cards Mill Road runs approximately 10 degrees from perpendicular to the transmission line ROW at this location. A local distribution circuit also runs along the east side of Cards Mill Road and crosses over Cards Mill Road near the intersection of Baker Hill Road. In order to quantify the contribution of the distribution line, measurements were performed on both sides of Cards Mill Road at distances >200 feet from the transmission ROW. The magnetic field level was measured to be relatively small at the location of measurements on the west side of the street, small enough that it is not discernable in the data where the line crossed over the measurement path beneath the 330 line. This site was not selected for true-up measurements due to the presence of other sources of EMF.

**Site 2** is located in the small portion of XS-2 (referred to in the Application as XS-2 BMP) east of Stafford Road in Mansfield where the new 3271 line is supported on vertical delta structures (rather than the baseline configuration of H-frame structures), on a 300-foot wide ROW approximately 75 feet from the 330 line. This measurement site is on Highland Ridge Golf Range property and was moved from the originally-proposed site (just east of Stafford Road) due to the presence of a fence running through the ROW, which, similar to Site 1, would have precluded measurements over a large portion of the ROW width. The revised location near the far end of the driving range of the golf course was open and free of other sources of EMF; however, the terrain beneath the transmission lines sloped upwards from west to east and so it was not selected as a location for true-up measurements

**Site 3** is located south of Bassetts Bridge Road in Mansfield on a typical portion of XS-2 where the new 3271 line is supported on H-frame structures approximately 85 east of the existing 330 line on a 300-foot wide ROW. This measurement site was shifted by one span to the north from the original measurement site because it was more open than the originally-proposed site and was also free of other sources of EMF. While the terrain was somewhat rough (measurements performed in a corn field—post harvest), there was no significant slope to the ground level beneath the lines. This location therefore was selected for true-up measurements.

**Site 4** is located in Focus Area C along Hawthorne Lane in Mansfield, and was designated HL-1 in the Plan and is situated on a 300-foot wide ROW. In this portion of the route, the existing 330 line was rebuilt on monopole structures and the new 3271 line was also constructed on vertical monopole structures, approximately 65 feet north of the 330 line. The measurement site was not moved from that originally proposed. The majority of this measurement path was performed along the paved cul-de-sac at the end of Hawthorne Lane, which provided a smooth and flat area free of other sources of EMF. This location therefore was selected for true-up measurements.

**Site 5** is located on a portion of XS-6, on a 300-foot wide ROW west of Windham Road in Brooklyn, and is the same location originally identified in the Plan. The lines constructed on this portion of the ROW are physically the same as those at Site 3. The new 3271 line was constructed on H-frame structures 85 feet north of the existing 330 line. The terrain at this location sloped upward from north to south and in addition there was tall brush on portions of the ROW, so this location was not selected for true-up measurements.

**Site 6** is also located on a portion of XS-6, (referred to in the Application as XS-6 BMP) east of Church Street in Brooklyn. Similar to the configuration at Site 5, the new 3271 line was constructed on H-frame structures 85 feet north of the existing 330 line on a 300-foot wide ROW. The terrain at this location was relatively flat, smooth, and good for measurements; however, a sheep pen located on the ROW necessitated performing measurements relatively near to the structures (far from midspan where conductors are far higher than typical), so this location was not selected for true-up measurements.

**Site 7** is located on a portion of XS-7 along the south side of Hartford Pike in Pomfret (near the Quinebaug River crossing). This site was moved from the originally-proposed measurement site (shown on D&M Map Sheet 45) due to accessibility of this location without crossing private property (> 1 mile from the nearest road crossing). Along this portion of the route, the new 3271 line was constructed on H-frame structures on the north side of a 360-foot ROW. The existing 330 line is 85 feet south with two 115-kV transmission lines (1607 and 1505 lines) also supported on H-frame structures 170-feet and 230-feet south of the 3271 line, respectively. While the shoulder of Hartford Pike provided a smooth measurement path, the ground level sloped down from west to east approaching the Quinebaug River. In addition, a local distribution line runs along the north side of Hartford Pike. For these reasons, this location was not selected for true-up measurements.

**Site 8** is located on a portion of XS-11, east of Killingly Avenue in Killingly. This cross section is also east of the Killingly Substation, where the new transmission line is designated 341, and was constructed 85 feet west of an existing 345-kV transmission line (347 line) on a 340-foot wide ROW. On this portion of the route, existing 23-kV distribution lines (14M22 and 14M28) are supported on single wooden pole structures approximately 110 feet west of the new 341 line. This measurement site was located on a relatively flat open area and while measurements needed to be made relatively near to the transmission line structures (far from midspan) due to terrain variation on other portions of the ROW, this location was selected for true-up measurements because of the different line designation (341) and hence different loading in this Cross Section.

**Site 9** is located in XS-12 (referred to in the Application as XS-12 BMP) on a portion of the route northwest of and behind Elvira Heights in Putnam. In this cross section, the new 341 line is constructed on H-frame structures 85 feet north of the existing 347 line on a 300-foot wide ROW. The terrain slopes down gradually from southeast to northwest at this location, and on the far northwest portion of the ROW at this location (approximately 45 feet from the 347 line), the terrain drops off precipitously, so measurements were not possible on this portion of the route. The conductor height of the 341 and 347 lines were found to be lower on this portion of the route than in other portions (approximately 34 feet); in addition, the loading on the respective lines at the time of measurements were among the highest observed during any of the performed measurements. Therefore, despite assessment that the measurement location was not ideal, it was selected for true-up measurements.

# Results

EMF measurements were performed on October 4 and 5 (Measurement 1), and October 10 and November 2, 2016 (Measurement 2). The following section presents a summary of the measurement results at each location, as well as a comparison with calculations in Application. The section also presents an analysis of the true-up model at each of four measurement locations (Sites 3, 4, 8, and 9). Detailed measurements taken at each site are presented in Appendix C along with a direct comparison to the modeling levels provided in the Application.

The purpose of this section is to compare EMF calculations provided in the Application to EMF measurements taken during operation after completion of the Project. In addition, true-up comparisons of calculated EMF levels are provided to show the accuracy of the modeling methods.

Differences between post-construction EMF measurements at the edge of the ROW and EMF calculations provided to the CSC during the siting proceedings are attributable to differences between the assumptions underlying the calculations made in 2011 and actual conditions at the time the measurements were taken. These include:

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

(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.

## Magnetic Field Variation with Loading

As described above, magnetic-field levels will change as the loading on the lines varies with time. The performed measurements therefore represent a load-dependent snapshot of the magnetic-field levels at the time of measurements. As shown in Table D-2 in Appendix D, the loading on the transmission lines was generally higher during the first set of measurements taken on October 4 and 5, 2016, than on the second set of measurements, taken on October 11 and November 2, 2016. As a result, measured magnetic-field levels for the second set of measurements are lower.

Figure 2 shows three separate plots. The top-left plot shows the magnetic-field levels measured nearest the –ROW edge, while the top-right plot shows magnetic field nearest the +ROW edge.[5] This figure demonstrates that the magnetic-field levels were generally lower near the –ROW

[5] In cases such as Site 6 where the available clearing was insufficient to perform measurements out to the edge of the ROW, measurement results are provided at the point nearest to the ROW edge that was measured. At sites for which true-up modeling was performed (3, ,4, 8, and 9) *and* at which measurements did not reach the edge of the ROW, the electric or magnetic field level calculated at the ROW edge in the true-up model is used instead of the measurement closest to the ROW edge.

edge than the +ROW edge. This is primarily because the 345-kV transmission lines tend to be nearer to the +ROW edge than the –ROW edge. This figure also shows that magnetic-field levels for the first set of measurements were generally higher than the second set of measurements. In the bottom plot of Figure 2, a bar graph shows the loading on each transmission line (sorted left-to-right at each Site so that lines on the left are near the –ROW edge and lines near the right are near the +ROW edge) at the time of measurements, separated by site. This subplot, detailing loading of each transmission line illustrates why measurements were generally higher for the first set of measurements than for the second. In nearly all cases, the blue bar (representing the loading during the first set of measurements) is higher than for the second set of measurements.

An interesting case is shown at Site 7 where the measured magnetic field nearest the –ROW edge was noticeably higher during the first measurement visit than the second. Conversely, nearest the +ROW edge the measured magnetic-field level was just slightly higher for the second set of measurements than for the first. The loading data, summarized in the bottom of Figure 2, explain this apparent discrepancy. The 345-kV 3271and 330 lines are nearer to the –ROW edge, while the 115-kV 1607 and 1505 lines are nearer to the +ROW edge. During the first measurement trip, the 3271 and 330 lines were more heavily loaded than during the second trip, resulting in a higher measured magnetic-field level near the –ROW edge. Conversely, the 1505 and 1607 lines were more heavily loaded during the second measurement trip than the first, resulting in higher measured magnetic-field levels near the +ROW edge.

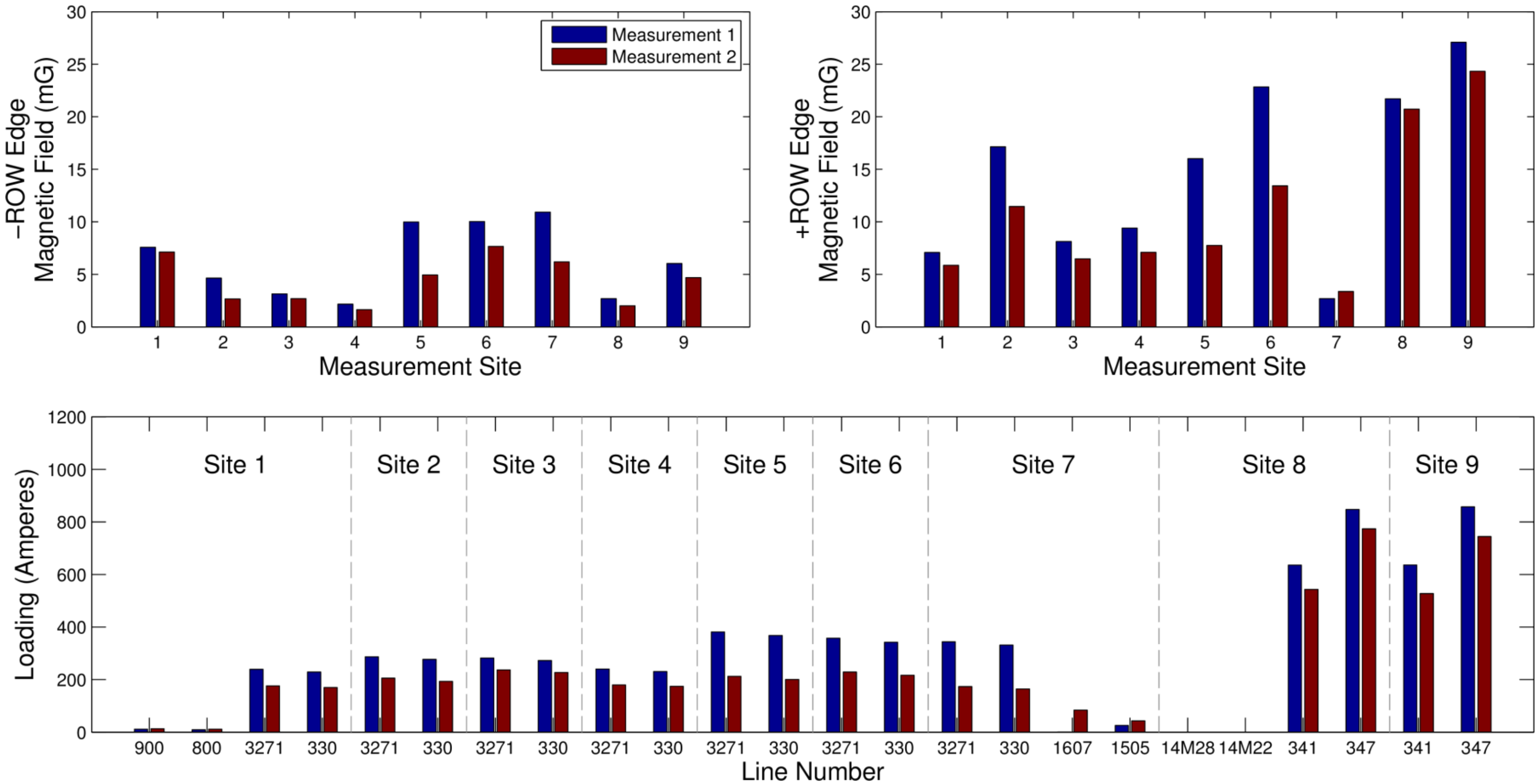



Figure 2. Comparison of measured magnetic-field levels at the ROW edges with changes in loading. In the bottom plot the lines at the left of the plot at each site are closest to the -ROW edge and those at the right are closest to the +ROW edge.

## Comparison of Calculated EMF Levels Provided during the Siting Proceedings and Measured EMF Levels

The projected electric and magnetic fields associated with the transmission line configurations ultimately selected by the CSC were provided in the CL&P 2011 Application.

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 C where either true-up modeling or the results presented in the Application (for AAL) are superimposed on the same graph as measurements. Measurements locations where true-up modeling was not performed (Sites 1, 2, 5, 6, and 7) generally show similar trends with lower measured EMF levels compared to those modeled in the application. One example (Site 5) is presented below in Figure 3 for reference and discussion while the results for the remaining sites are presented in Appendix C.

Figure 3 shows electric-field levels (right side) and magnetic-field levels (left side) separately. Actual measurement values are shown by a series of '+' markers while the modeling performed in the Application is superimposed as a dashed brown line. Two sets of measurements were performed for magnetic-field levels and the levels were measured every 1-3 feet using a survey wheel in conjunction with the magnetic-field meter. Due to the close spacing of these measurements the '+' markers sometimes appear as a thick, jagged line. In contrast, electric-field measurements were performed once at each site and individual measurement locations were separated by 5-50 feet and so generally appear as discrete '+' symbols indicating the measured value.[6] As shown in Figure 3, measured electric field levels are lower than those calculated in the application. This is due both to the greater conductor height above ground at the location of measurements (approximately 43-47 feet) than was conservatively assumed in the Application (35 feet) and to differences in assumed loading in the Application compared to the date of measurements. Measured magnetic field levels also are far lower than those calculated at AAL in the Application due to greater conductor height above ground. The loading on the 3271 and 330 lines at the time of measurements was approximately one-third that of the projected AAL assumed in the Application. Corresponding magnetic field levels are therefore much lower than those presented in the Application. Even after accounting for differences between projected loadings in the Application and those recorded during magnetic field measurements, the measured magnetic field levels are lower than those presented in the Application due to the greater conductor height above ground.

Results at Sites 1, 2, 6, and 7 also show similar trends to those presented here, for similar reasons (i.e., greater conductor heights and lower line loadings at the location/time of measurements), compared to those presented in the Application.

[6] Electric-field measurements were performed at closer spacing near the transmission lines and at greater spacing on more distant portions of the ROW.

EMF levels at the ROW edge are reasonably consistent with the calculations in the 2011 Application; however, a better comparison between measured and calculated EMF levels can be made using the true-up modeling detailed in the following section for sites 3, 4, 8 and 9.

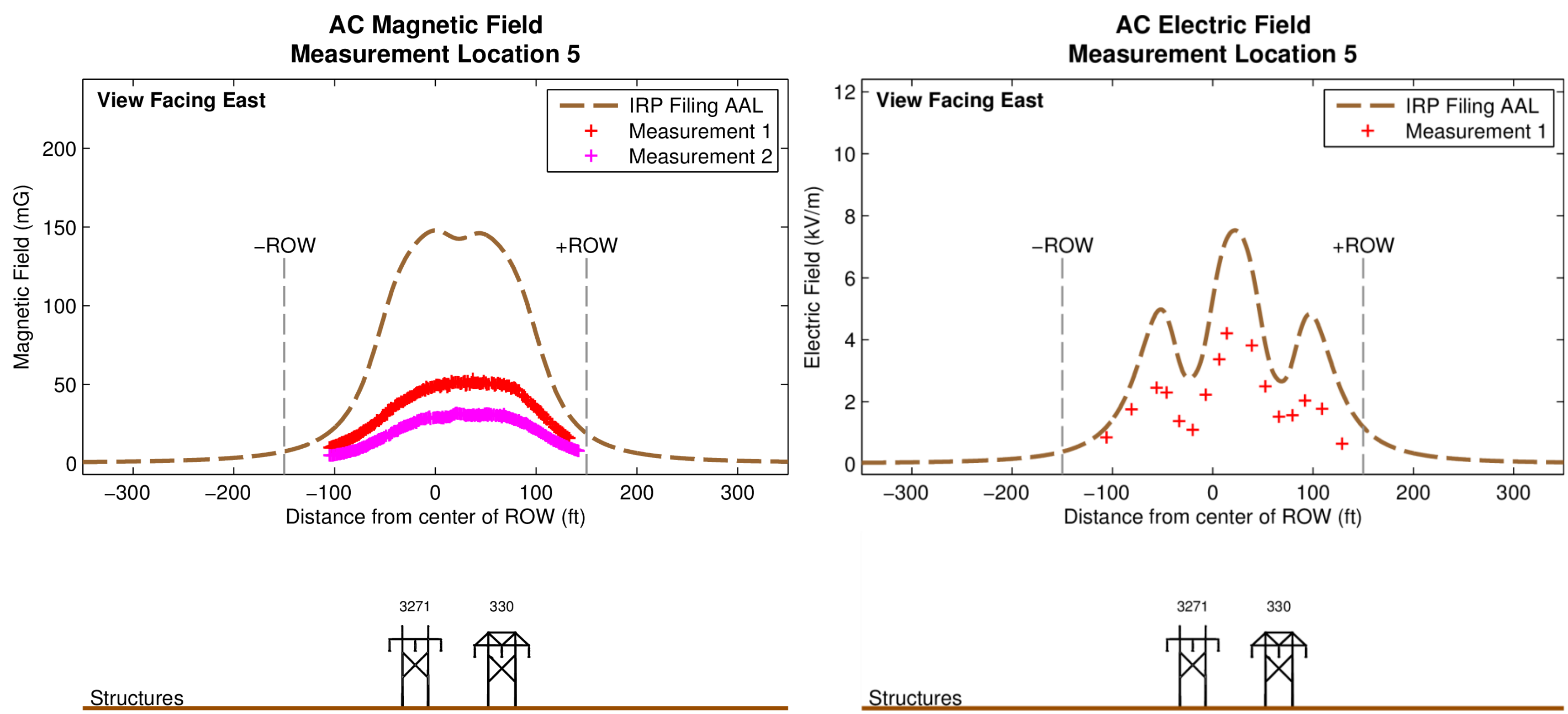



Figure 3. Comparison of measurements at Site 5 with calculations (at AAL) provided in the Application.

Magnetic field levels (left) and electric field levels (right) are shown

## Comparison of Calculated Magnetic Field Levels Using Actual Line Loading Data (True-Ups) and Measured Magnetic-Field Levels

The most accurate comparison between modeling and measurements is when the measured levels are compared to a model constructed from data reflective of the conditions present at the time and place of measurements. In order to confirm the accuracy of modeling methods, the Plan calls for a comparison of measured magnetic-field values with calculated values at a couple of monitoring sites.[7] These true-up 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 the measurements are made, and the magnetic fields are calculated from contemporaneous recorded line currents. True-up comparisons for four measurement locations are presented below:[8]

- Monitoring Site 3: South of Bassetts Bridge Road, Mansfield
- Monitoring Site 4: Hawthorne Lane, Mansfield
- Monitoring Site 8: East of Killingly Avenue, Killingly
- Monitoring Site 9: Behind Elvira Heights, Putnam

As discussed above, these sites were chosen for true up comparisons between calculated and measured fields for several reasons. At these sites, the terrain is relatively flat, conductor configurations are longitudinally uniform, and there are no extraneous sources of EMF. The measurements were performed as described above for Figure 3.[9] As shown by the profiles below, the agreement between the calculated and measured field profiles at these locations is very good (with a mean deviation of less than 13% for all cases, and generally less than 10%) and demonstrates the accuracy of the modeling methods. Calculated field values for the conditions observed on the Measurement 1 and Measurement 2 visits are identified in the figures as True-up Model 1 and True-up Model 2, respectively.

Each of the figures below details measurements at one of the four true-up locations.

[7] In addition, when we compared the maximum magnetic field measured on the ROW to the level adjusted for that expected at AAL, the magnetic fields were lower, and often substantially lower, than those presented in the Application for the same section of the ROW.

[8] Note that the figures presented below for each Site show the same view from the perspective of a person on the ROW as presented in the Application.

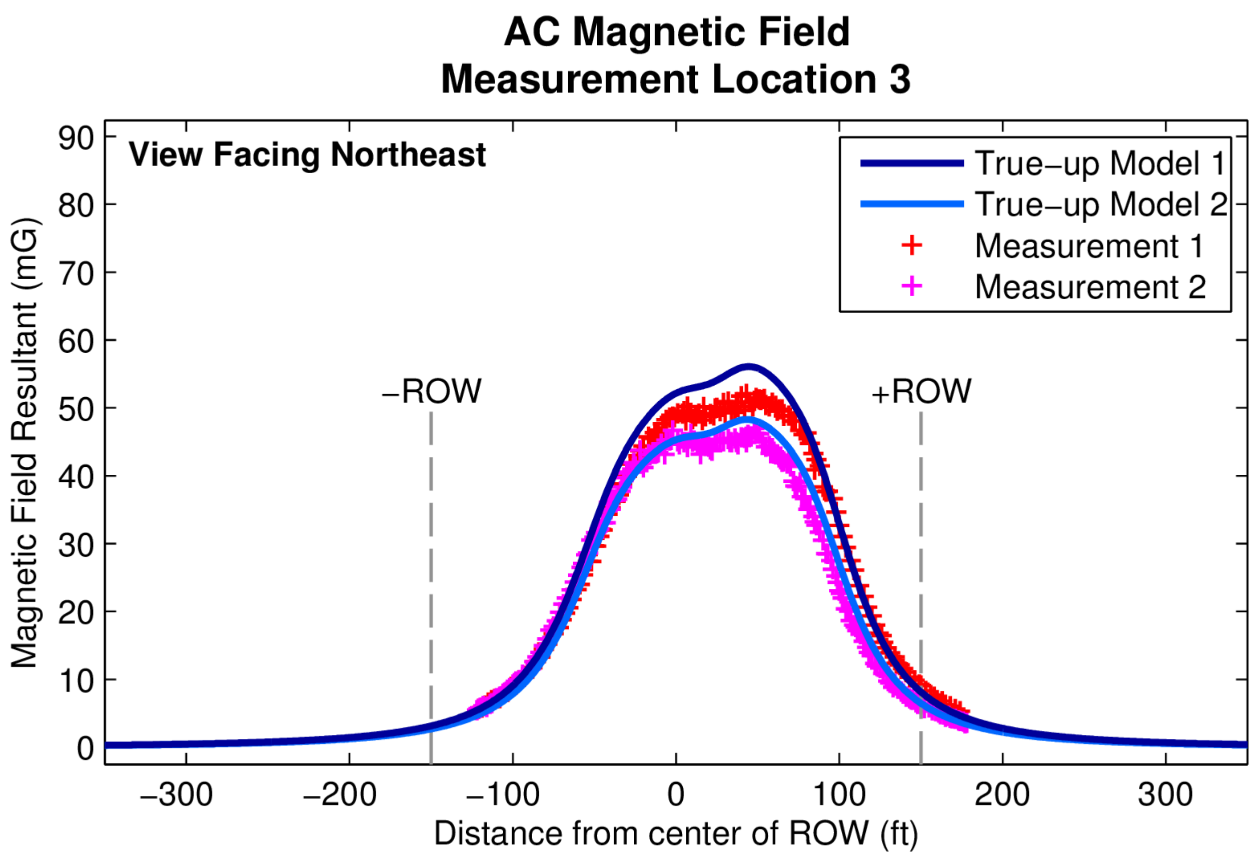
[9] Electric-field measurements were performed at closer spacing near the transmission lines themselves and at greater spacing on more distant portions of the ROW.

## Site 3: South of Bassetts Bridge Rd in XS-2

In this portion of the route, the new 3271 line is supported on H-frame structures approximately 85 feet west of the existing 330 line on a 300-foot wide ROW. Figure 4 and Figure 5 depict calculated and measured magnetic- and electric-field levels at Site 3, respectively. The figures are shown depicting the ROW transect from the vantage point of an observer standing in the ROW looking north.

The two sets of magnetic-field measurements were performed on October 4 and November 2, 2016, with a single set of electric-field measurements performed on November 2, 2016.[10] The mean deviation between the calculated and measured magnetic-field profiles is 6.5% and 7.8%, respectively. The electric-field deviation is 9.3%. Most all calculated magnetic-field values are higher or similar to the measured values. Magnetic-field levels calculated near the lines are all higher than corresponding measurements, while near the ROW edge where field levels are quite low, the measured levels may be slightly higher or lower due to induced currents on the transmission line shieldwires, which are not accounted for in the model or terrain irregularities. The electric-field measurements are at or below calculated values.

[10] Electric-field measurements were performed only once because the voltage and conductor height above ground remain relatively constant with time. This results in electric field levels that are also relatively constant in time, in contrast to magnetic-field levels which, even for very similar physical configuration, can vary significantly due to the variation in the loading levels on the transmission lines.



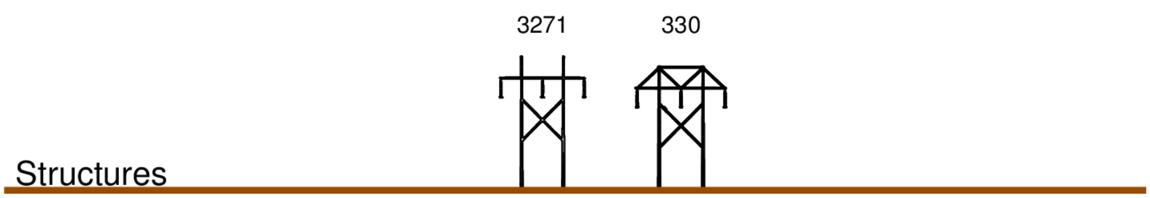
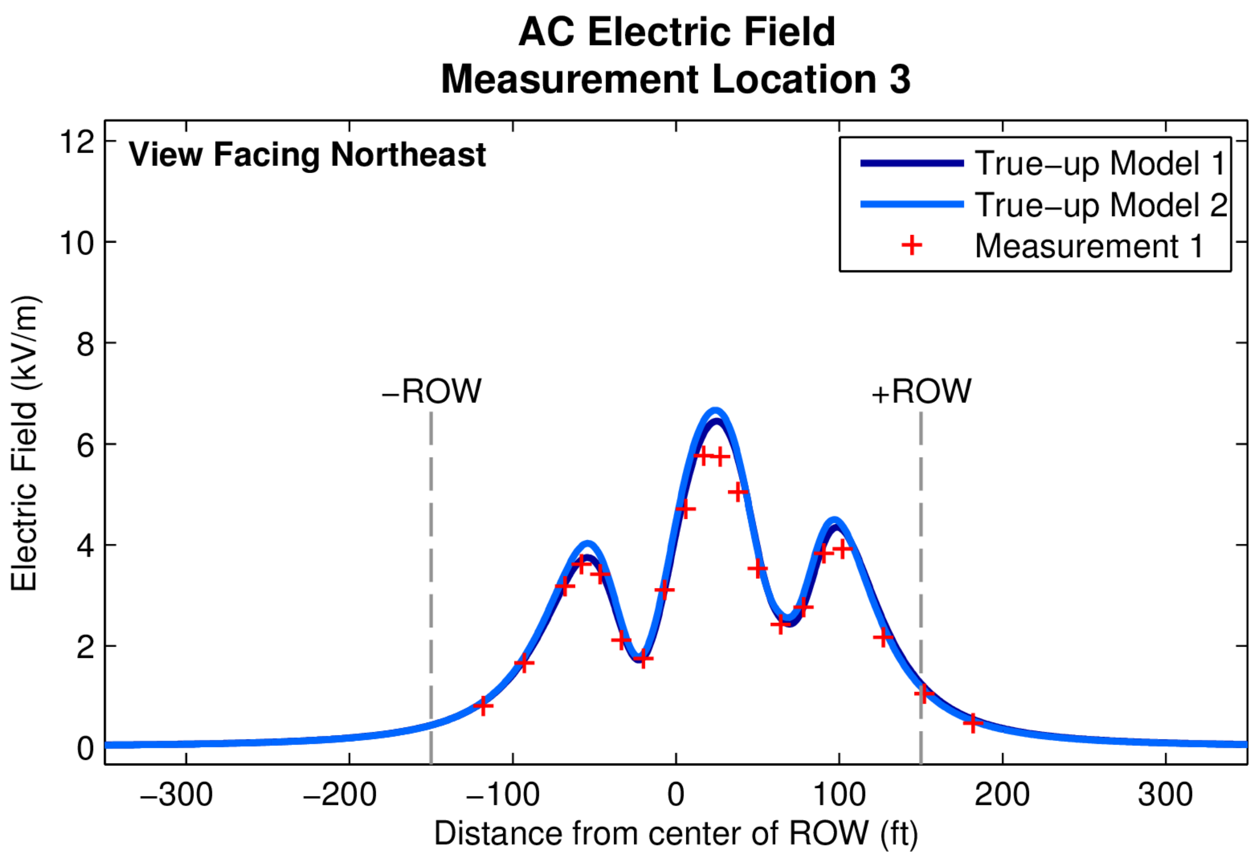




Figure 4. Comparison of calculated and measured magnetic-field levels at Site 3, south of Bassetts Bridge Road in Mansfield.



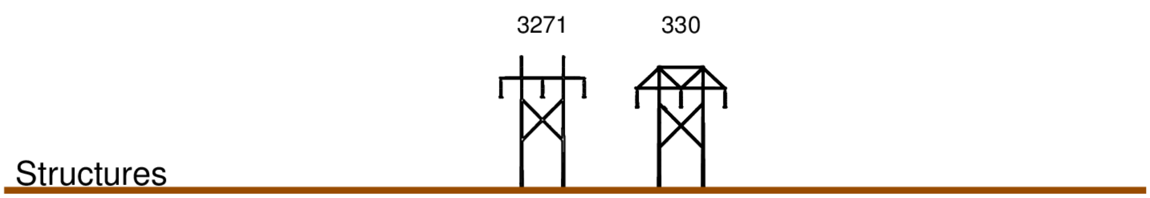




Figure 5. Comparison of calculated and measured electric field levels at Site 3, south of Bassetts Bridge Road in Mansfield.

## Site 4: Hawthorne Lane (HL-1) in Mansfield

This portion of the route is located in Focus Area C along Hawthorne Lane in Mansfield, and was designated HL-1 in the Plan. In this portion of the route, both the 330 line and the new 3271 line are constructed on vertical monopole structures on a 300-foot ROW. Figure 6 and Figure 7 depict calculated and measured magnetic- and electric-field levels at Site 4, respectively. The figures are shown depicting the ROW transect from the vantage point of an observer standing in the ROW looking east.

The two sets of magnetic-field measurements were performed October 4 and November 2, 2016, with a single set of electric-field measurements performed on October 4, 2016. The mean deviation between the calculated and measured magnetic-field profiles is 7.8% and 6.4%, respectively. The electric-field deviation is 9.9%. Measured magnetic-field levels are lower than calculated magnetic-field levels except for a small portion between the two transmission lines where terrain changes may have produced deviations between the idealized model and actual measurements.

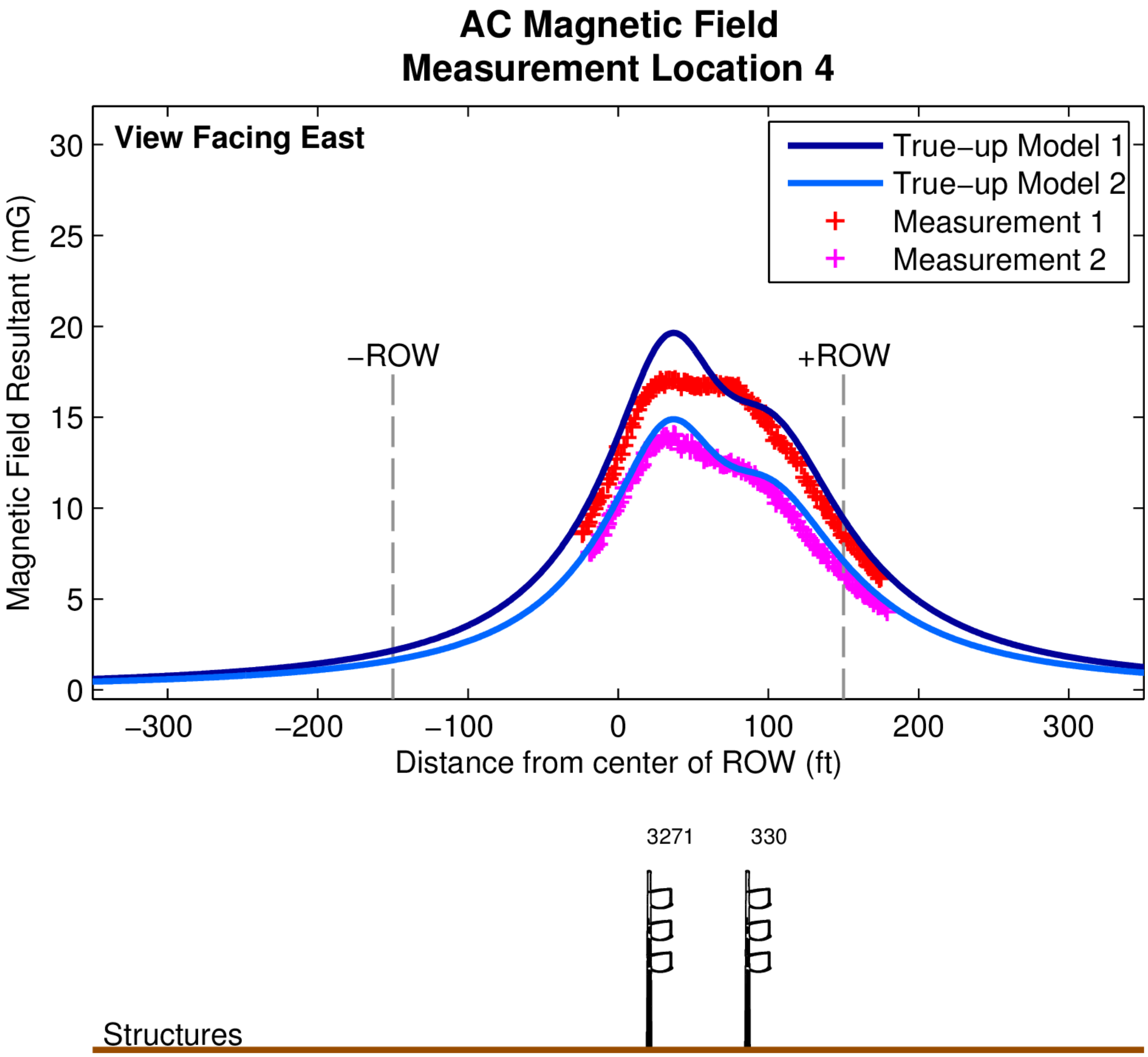



Figure 6. Comparison of calculated and measured magnetic field levels at Site 4, on Hawthorne Lane in Mansfield.

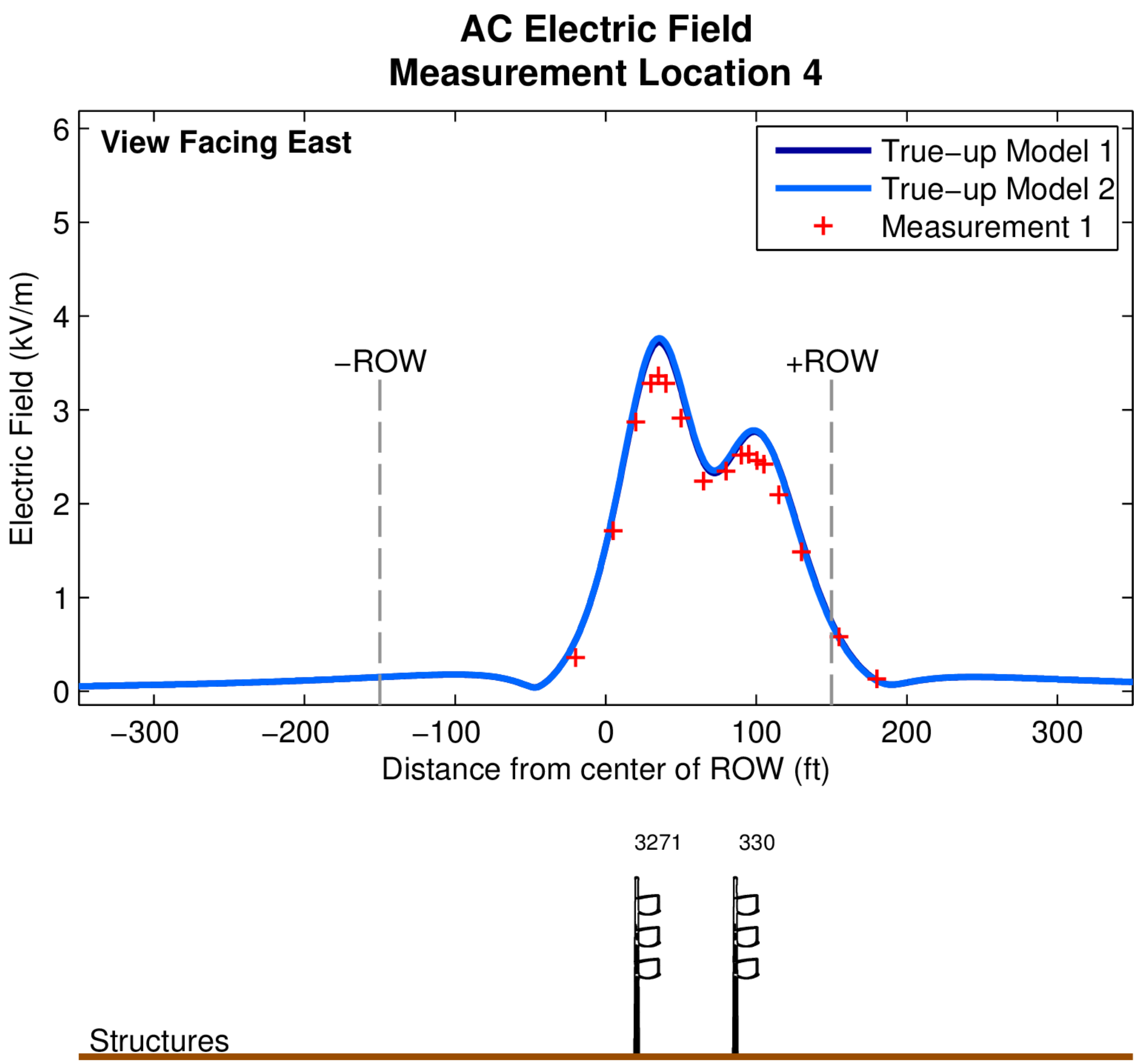



Figure 7. Comparison of calculated and measured electric field levels at Site 4, along Hawthorne Lane in Mansfield.

## Site 8: East of Killingly Rd. in XS-11

In this portion of the route the new 341 line is constructed on a 340-foot wide ROW adjacent to the existing 345-kV 347 line and two existing 23-kV distribution lines (14M22 and 14M28). Figure 8 and Figure 9 depict calculated and measured magnetic and electric field levels at Site 8, respectively. The figures are shown depicting the ROW transect from the vantage point of an observer standing in the ROW looking north.

The two sets of magnetic field measurements were performed October 4 and October 11, with a single set of electric field measurements performed on October 4. The mean deviation between the calculated and measured magnetic field profiles is 9.9% and 9.9%, respectively. The electric field deviation is 8.6%. Most magnetic field measurements are below calculated values, with some slightly above. The electric field measurements are at or below calculated values.

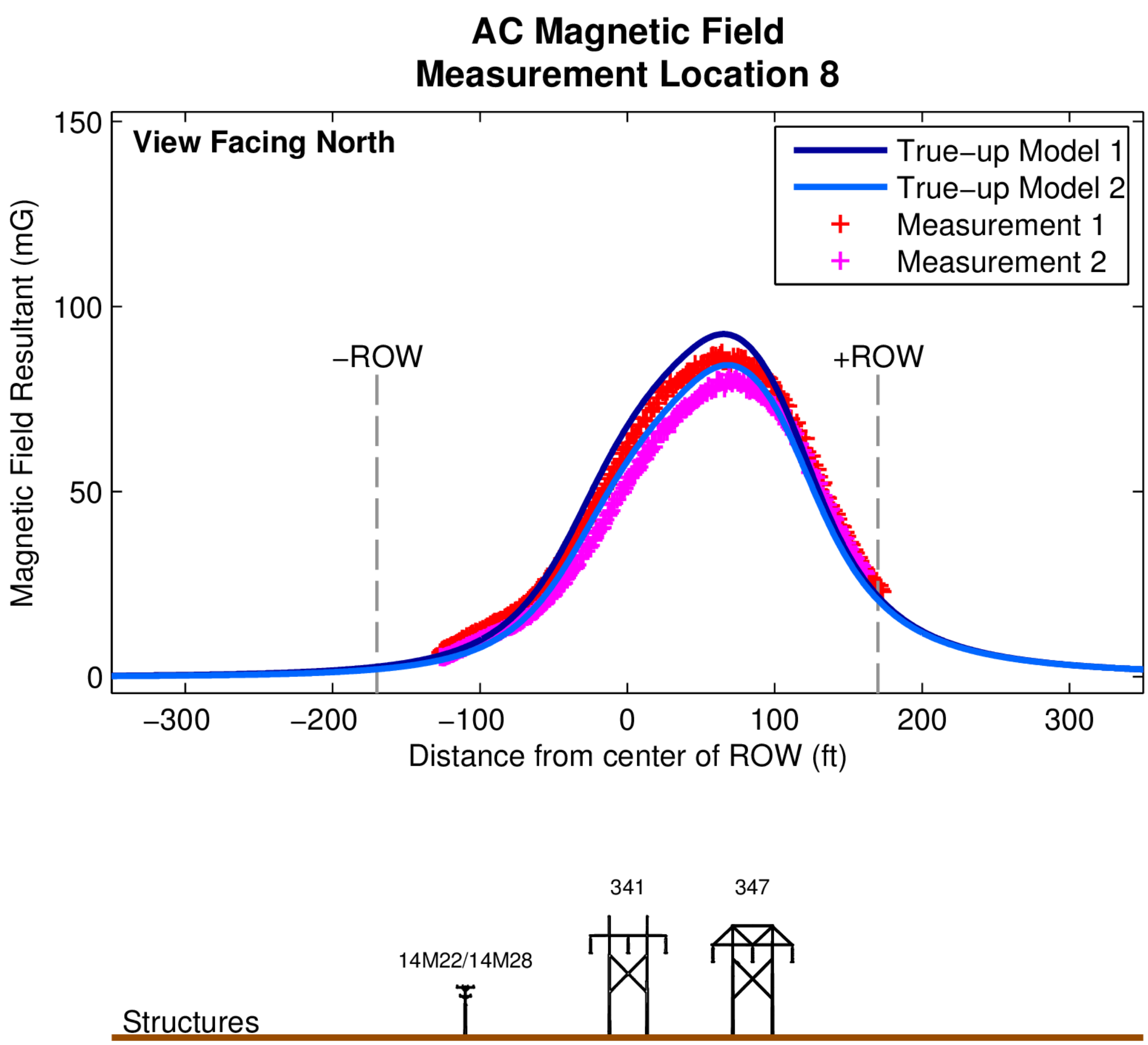



Figure 8. Comparison of calculated and measured magnetic-field levels at Site 8, east of Killingly Avenue in Killingly.

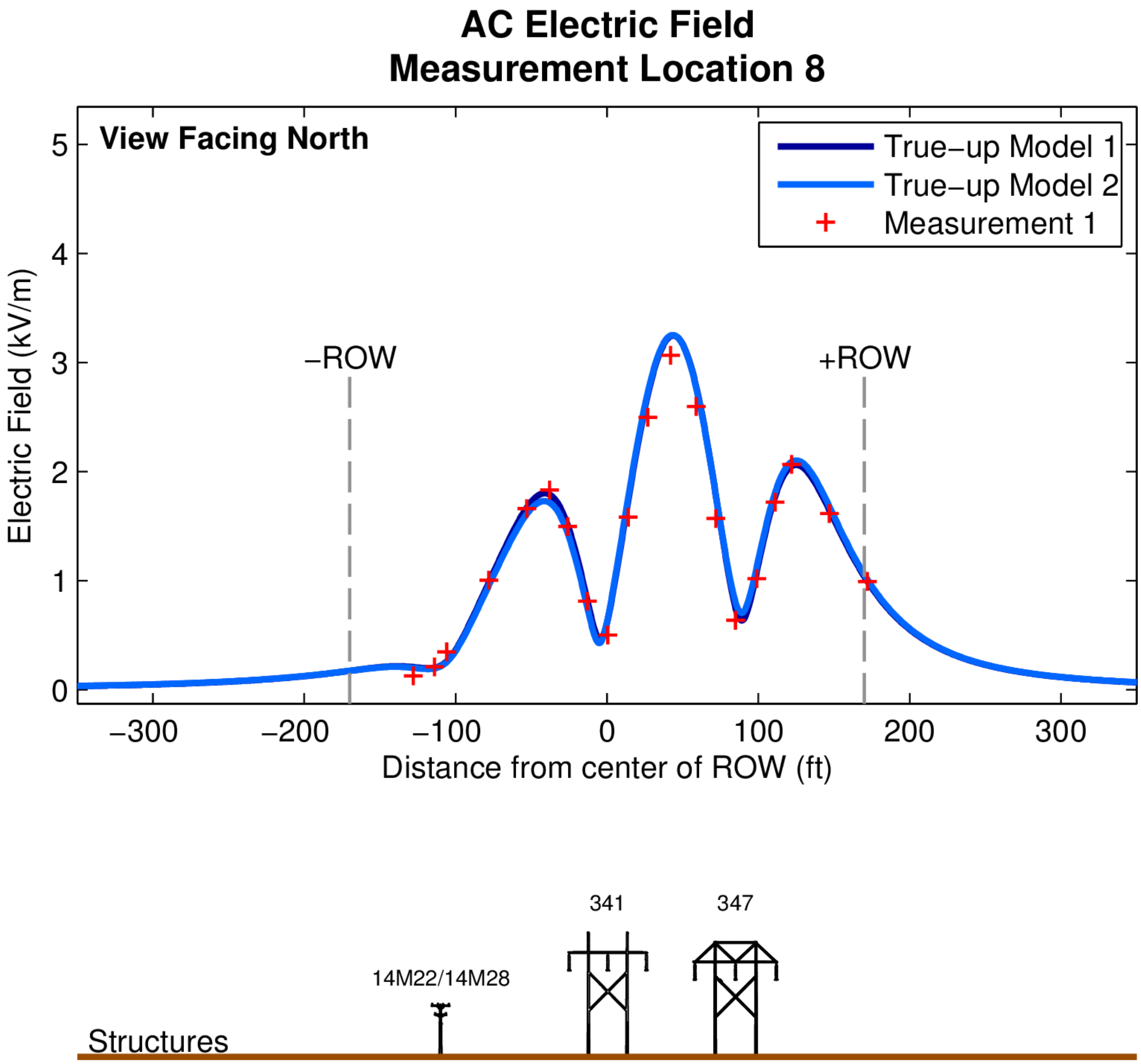



Figure 9. Comparison of calculated and measured electric-field levels at Site 8, east of Killingly Avenue in Killingly.

## Site 9: Behind Elvira Heights in XS-12

In this portion of the route, the new 341 line is constructed on H-frame structures on a 300-foot wide ROW adjacent to the 347 line. The terrain slopes down gradually from southeast to northwest at this location, and on the far northwest portion of the ROW at this location (approximately 45 feet from the 341 line), the terrain drops off precipitously and so measurements were not possible on this portion of the ROW. Figure 10 and Figure 11 depict calculated and measured magnetic- and electric-field levels at Site 9, respectively. The figures are shown from the vantage point of an observer standing in the ROW looking northeast.

The two sets of magnetic-field measurements were performed October 4 and October 11, 2016, with a single set of electric-field measurements performed on October 4, 2016. The mean deviation between the calculated and measured magnetic-field profiles is 7.9% and 5.8% respectively. The electric-field deviation is somewhat higher (12.6%), primarily due to the deviation measured near the southeastern side of the ROW where measurements were made near tall trees, which reduced the electric-field levels compared to the idealized model. Most magnetic- and electric-field measurements are at or below calculated values.

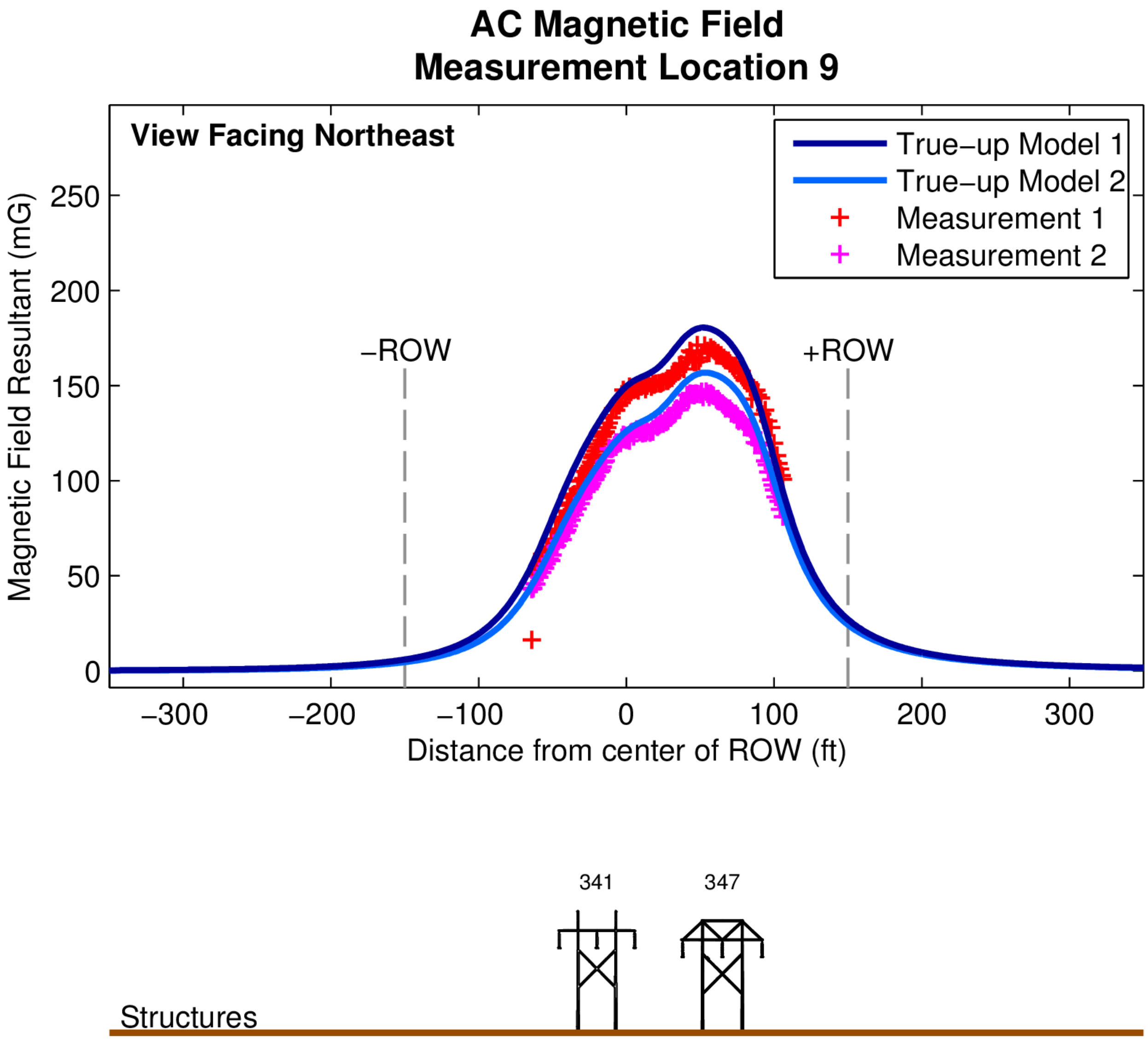



Figure 10. Comparison of calculated and measured magnetic-field levels at Site 9, behind Elvira Heights in Putnam.

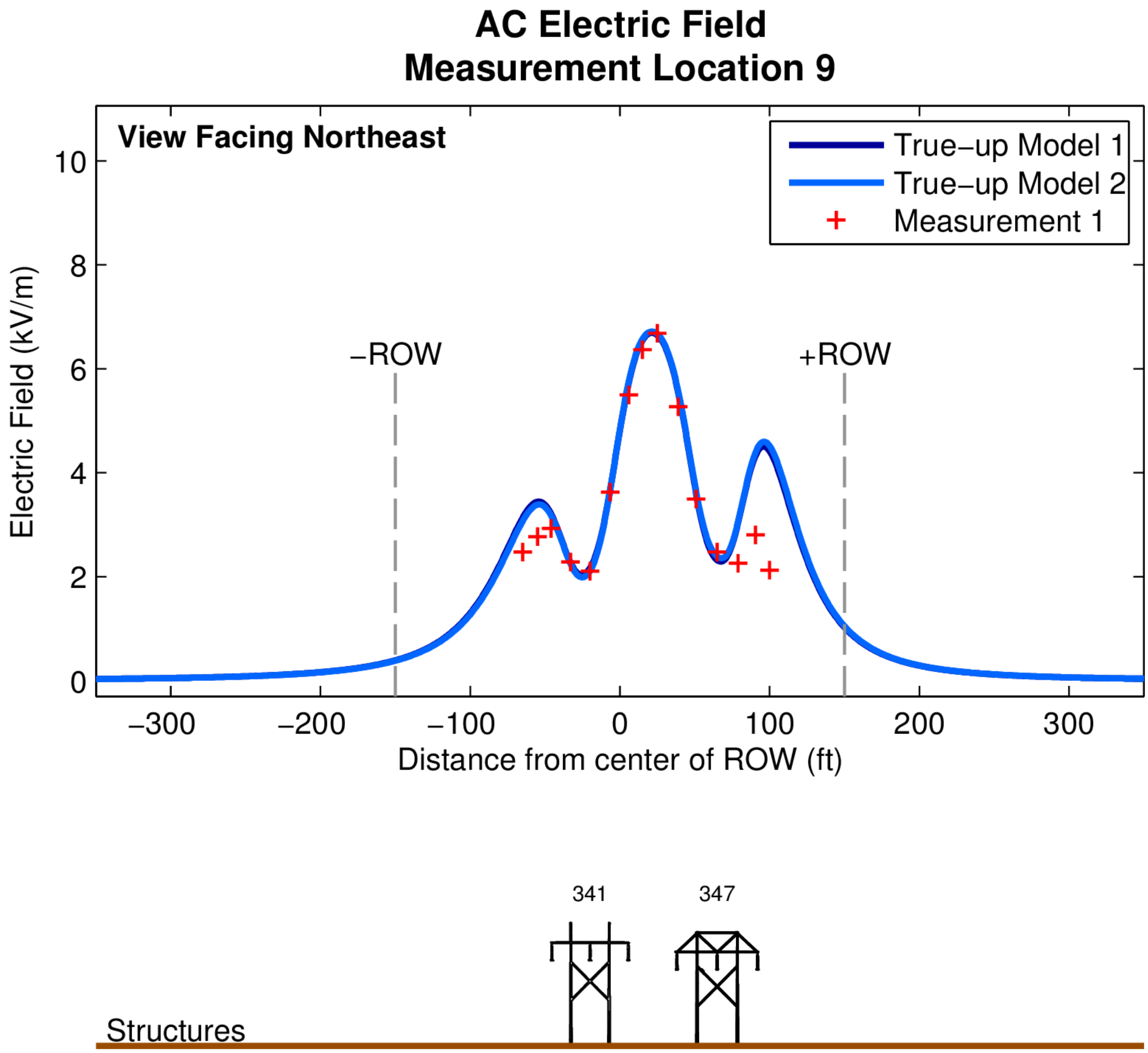



Figure 11. Comparison of calculated and measured electric-field levels at Site 9, behind Elvira Heights in Putnam.

## Measurements at the Card Street Substation

Magnetic-field measurements were performed along a continuous path around the perimeter of the Card Street Substation. The highest recorded magnetic-field levels were recorded where overhead transmission or distribution lines entered or exited the substation, as well as locations where these overhead lines ran roughly parallel to portions of the substation for substantial distances. Multiple overhead transmission and distribution lines enter/exit the substation. Beneath some of these overhead lines, magnetic-field levels were measured to be as high as 104 mG and were lower near others. Away from these transmission or distribution lines, magnetic-field levels were far lower, approximately 25 mG or less. These observations are consistent with IEEE Standard 1127-2013 which states "In a substation, the strongest [electric and magnetic] fields near the perimeter fence come from the transmission and distribution lines entering and leaving the substation. The strength of fields from equipment inside the fence decreases rapidly with distance, reaching very low levels at relatively short distances beyond substation fences." An aerial photograph showing the locations of measurements as well as the data from both measurement paths are shown in Appendix C, Figures C-19 and C-20.

# Discussion and Conclusion

In each of the four true-up comparisons performed, the calculated field levels are slightly higher or equal to the measured field values. This reflects the conservative assumptions used in the modeling, which are designed to ensure that reported field levels represent a conservative but accurate estimate of the field levels to be present after construction of the Project. The small differences observed between the measured and calculated profiles (typically <10%) can be attributed to uncertainty in the monitored current and measured magnetic field, as well as simplifications present in the modeling, such as the assumption of level terrain, steady-state currents, longitudinally uniform geometry, the lack of induced currents in shieldwires, and, for the case of electric-field measurements at Site 9, the presence of tall conductive trees that serves to reduce electric-field levels.

The measured EMF levels compared to those calculations submitted as part of the 2011 Application are reasonably consistent, with the differences primarily due to loading and terrain variations. Comparison between measured and calculated EMF levels using the true-up modeling indicates good agreement between modeling and measurements and confirms the efficacy and accuracy of the modeling approach followed in the Application.

# Appendix A

# EMF Monitoring Plan

# APPENDIX F

# POST-CONSTRUCTION ELECTRIC AND MAGNETIC FIELD MONITORING PLAN

**August 2013**

# I. INTRODUCTION AND PURPOSE

In accordance with the December 27, 2012 Decision and Order of the Connecticut Siting Council (the Council) in Docket 424, The Connecticut Light and Power Company (the Company) proposes the following post-construction electric and magnetic field monitoring plan for the Interstate Reliability Project (Project).

A primary purpose for electric and magnetic field (E & MF) measurements near to transmission lines is to make comparisons to levels predicted by calculations. This purpose is best served by selecting post-construction measurement locations where terrain is relatively flat, conductor configurations and heights are typical and representative, and where few if any confounding field sources and objects exist.

A secondary purpose for such measurements can be to make comparisons between levels measured at points of interest before and after new line construction. However, those points of interest may not be at locations which best serve the primary purpose. Also, measurements of magnetic fields should not be so compared because grid and power-flow circumstances can be significantly different at the times of these before and after measurements.

# II. MONITORING LOCATIONS

The Company's proposed monitoring locations for E & MF are listed in Table 1 at the end of this plan. The selected monitoring locations capture each newly constructed overhead line type that is part of the line design. Additional considerations in location selection are as follows:

## *1. Lines*

At a minimum, the Company chose one readily accessible monitoring location for each overhead line type along the right-of-way (ROW) of each new 345-kV line. Other locations were chosen along sections of the route where 69- or 115-kV lines share the ROW. These monitoring locations are listed in Table 1 and shown on the Volume 3 maps.

At each of the monitoring locations listed in Table 1, measurements will be made within the Company's ROW or on public roadways or on nearby private property outside of the Company's ROW with landowner approval.

## *2. Substations*

The Company will take measurements once on a continuous path along the perimeter fence of the Card Street Substation.

### *3. Measurement Location Characteristics for Lines*

To the extent possible, the Company chose line measurement locations where: (1) the terrain is relatively flat and bare of vegetation; (2) conductor configurations and heights are typical and representative; and (3) few if any confounding sources, such as local distribution lines, and objects exist.

## III. MEASUREMENTS FOR LINE SEGMENTS

The Company will take post-construction measurements of electric and magnetic fields twice at each of the locations listed in Table 1 (below) within 10 months of commencement of 345-kV line operation. The Company will measure electric and magnetic fields along a transect (i.e., profile) passing perpendicularly beneath the new and existing overhead transmission lines at the listed locations. The measurement path will extend to each ROW boundary where reasonable access exists, else to at least 50 feet beyond the outermost line conductors.

**Table 1**
**E & MF Monitoring Locations for the Interstate Reliability Project**

| Site | Cross Section No. (refer to Volume 3) | Municipality | Monitoring Location | D&M Plan Map No. (refer to Volume 3) |
|---|---|---|---|---|
| 1 | 1 | Columbia | Off Baker Hill Road | 2 |
| 2 | 2 | Mansfield | East of Stafford Road | 7 |
| 3 | 2 | Mansfield | Between Storrs Road and Bassetts Bridge Road | 14 |
| 4 | HL-1 | Mansfield | Hawthorne Lane | 15 |
| 5 | 6 | Brooklyn | West of Windham Road | 34 |
| 6 | 6 | Brooklyn | East of Church Street | 42 |
| 7 | 7 | Pomfret | Off Woods Hill Road | 45 |
| 8 | 11 | Killingly | East of Killingly Substation | 54 |
| 9 | 12 | Putnam | Behind Elvira Heights | 62 |

## IV. MEASUREMENT INSTRUMENTATION AND RECORDING

The Company will record all electric and magnetic field measurements at a height of one meter (3.28 feet) above ground in accordance with the industry standard protocol for taking measurements near power lines (IEEE Std. 644-1994 [R2008], "*IEEE Standard Procedures for Measurement of Power Frequency Electric and Magnetic Fields From AC Power Lines*"). The resultant magnetic field will be measured with a 3-axis, recording digital meter (EMDEX II). Electric fields will be measured with an E-Probe attachment accessory to the EMDEX II meter. This accessory enables the EMDEX II to make single-axis measurements of the electric field. Both the EMDEX II magnetic field meter and the E-probe accessory meet the IEEE instrumentation standard for obtaining valid and accurate field measurements at power line frequencies (IEEE Std. 1308-1994, *"IEEE Recommended Practice for Instrumentation: Specifications for Magnetic Flux Density and Electric Field Strength —10 Hz to 3 kHz."*) With this instrumentation, magnetic fields can be recorded continuously while walking and then plotted, whereas electric fields can be measured at spots and then recorded by hand in a data table and then plotted.

## V. REPORTING

Within 12 months of the in-service date of the new 345-kV lines, the Company will provide to the Council a report on these measurements with "true-up" comparisons to predicted values. "True-ups" are electric and magnetic field calculations that are based on site-specific conditions, including the actual conductor heights at a location at the time the measurement is made, current flows on the lines at the time the measurement is made, and the terrain. These calculations are then compared with the measurements taken at the location. True-up comparisons of measurements with calculations will be performed and reported for a couple of locations to demonstrate model accuracy

The report will also include aerial photographs on a scale of 1 inch equals 100 feet to mark each measurement location. For each magnetic field measurement, the coincident transmission line currents, as recorded by the CONVEX SCADA system, will be noted and reported. Additionally, for each measurement location, the size of transmission line conductor types will be reported.

## Appendix B

## Map and of Monitoring Sites

WORK AREA BOUNDARIES IN / NEAR WETLANDS

Vegetation removal will occur within the Vegetation Clearing Limits for Construction as shown, with temporary access routes in and across wetlands as necessary. Additionally, danger or hazard tree removal may be required outside of the Vegetation Clearing Limits for Construction, including within wetlands. For all other construction activities, work area boundaries will be defined by deployed E&S controls (silt fence and straw bales or equivalent). Further:

A. Work area boundaries will not necessarily encompass the entire width of the cleared area (e.g., tree line to tree line), but instead will be defined on a site-specific basis.

B. Boundaries shall be defined by E&S controls and thus may be different in dimension (but may be no greater in total square footage) than depicted on the D&M Plan maps.

C. All construction activities within wetlands, including access roads, work pads, temporary stockpiles of stripped topsoil or spoil (if necessary), excavations, equipment movements, etc., shall be contained within the work area boundaries.

D. Under no circumstances shall any materials (including plowed snow, construction materials, construction debris) be deposited beyond the work area boundaries.

NOTES

1. All work will be conducted in accordance with the relevant portions of CL&P's December 2011 Best Management Practices Manual: Connecticut Construction and Maintenance Environmental Requirements unless more stringent project-specific measures apply. See Volumes 1 and 2.

2. All work will be conducted in accordance with the requirements of regulatory approvals from the U.S. Army Corps of Engineers and the Connecticut Department of Energy and Environmental Protection, and with all Project Protocols. See Detail Sheets 1-4.

3. Erosion and sedimentation control measures will be installed during construction, as required, to comply with the 2002 Connecticut Guidelines for Erosion and Sediment Control, and CL&Ps December 2011 Best Management Practices Manual: Connecticut Construction and Maintenance Environmental Requirements, and applicable regulatory approvals. See Detail Sheets 6 & 7.

4. T&E Species Avoidance and Minimization Measures are required within indicated areas. See Detail Sheet 5.

5. Within 100- and 500-year floodplain areas, construction activities will be in accordance with Connecticut Department of Energy and Environmental Protection permit requirements.

6. Grading plans for temporary work pads and guard structure pads, as indicated, must be submitted to the Connecticut Department of Energy and Environmental Protection no later than two weeks prior to earth-disturbing activities for the subject pads.

7. Wetland Invasive Species Control Best Management Practices apply to work within all wetlands with invasive species. See Detail Sheet 5.

8. Farmland Protection Measures are required within indicated areas. See Detail Sheet 8.

9. Locations where access roads are proposed as permanent are indicated. Permanent access roads will remain after construction only if landowner permission is provided. All other access roads are considered temporary in compliance with regulatory requirements. (See Volume 1, Section 3.5.1).


| STR | NU STR | DESCRIPTION | HEIGHT (FT) | FINISH | FOUNDATION |
|---|---|---|---|---|---|
| 6 | 10706 | 345-kV Single Circuit Steel H-Frame Horizontal Tangent | 85 | Weathering | Direct Embed |
| 7 | 10707 | 345-kV Single Circuit Steel H-Frame Horizontal Tangent | 95 | Weathering | Direct Embed |
| 8 | 10708 | 345-kV Single Circuit Steel H-Frame Horizontal Tangent | 75 | Weathering | Direct Embed |
| 9 | 10709 | 345-kV Single Circuit Steel H-Frame Horizontal Tangent | 80 | Weathering | Direct Embed |
| 10 | 10710 | 345-kV Single Circuit Steel H-Frame Horizontal Tangent | 105 | Weathering | Direct Embed |
| 11 | 10711 | 345-kV Single Circuit Steel H-Frame Horizontal Tangent | 90 | Weathering | Direct Embed |

Index Map

Legend: New Transmission Structure Pole; New Transmission Line; Existing Transmission Structure Pole; Existing Distribution Lines; Existing Distribution Structures; New Guy Anchor; Relocated Guy Anchor; New Guy Wire; Relocated Guy Wire; Existing Access Road; Proposed New Access Road; Alternate Access Road; Permanent (See Note 9); Work Pad; Limit of Disturbance; Existing_ROW; Stone Wall; Property Lines; NU Property; Town Line; Named Public Trails; Vegetation Clearing Limits for Construction; Existing Tree Canopy Line; Wetland; Open Water; Perennial Stream; Intermittent Stream; Vernal Pool; Amphibian Breeding Habitat; T&E Species Area

0 50 100 200 Feet

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DATE | DETAILED M. Goetz | DESIGNED M. Kasinskas & M. Goetz | CHECKED M. Kasinskas

**Northeast Utilities Service Co.**

THE CONNECTICUT LIGHT & POWER CO.

**Interstate Reliability Project Development & Management Plan**

BY: | CHKD | APP | APP

DATE: 8/30/2013 | DATE | DATE | DATE

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WORK AREA BOUNDARIES IN / NEAR WETLANDS

Vegetation removal will occur within the Vegetation Clearing Limits for Construction as shown, with temporary access routes in and across wetlands as necessary. Additionally, danger or hazard tree removal may be required outside of the Vegetation Clearing Limits for Construction, including within wetlands. For all other construction activities, work area boundaries will be defined by deployed E&S controls (silt fence and straw bales or equivalent). Further:

A. Work area boundaries will not necessarily encompass the entire width of the cleared area (e.g., tree line to tree line), but instead will be defined on a site-specific basis.

B. Boundaries shall be defined by E&S controls and thus may be different in dimension (but may be no greater in total square footage) than depicted on the D&M Plan maps.

C. All construction activities within wetlands, including access roads, work pads, temporary stockpiles of stripped topsoil or spoil (if necessary), excavations, equipment movements, etc., shall be contained within the work area boundaries.

D. Under no circumstances shall any materials (including plowed snow, construction materials, construction debris) be deposited beyond the work area boundaries.

NOTES

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2.All work will be conducted in accordance with the requirements of regulatory approvals from the U.S. Army Corps of Engineers and the Connecticut Department of Energy and Environmental Protection, and with all Project Protocols. See Detail Sheets 1-4.

3.Erosion and sedimentation control measures will be installed during construction, as required, to comply with the 2002 Connecticut Guidelines for Erosion and Sediment Control, and CL&Ps December 2011 Best Management Practices Manual: Connecticut Construction and Maintenance Environmental Requirements, and applicable regulatory approvals. See Detail Sheets 6 & 7.

4.T&E Species Avoidance and Minimization Measures are required within indicated areas. See Detail Sheet 5.

5.Within 100- and 500-year floodplain areas, construction activities will be in accordance with Connecticut Department of Energy and Environmental Protection permit requirements.

6.Grading plans for temporary work pads and guard structure pads, as indicated, must be submitted to the Connecticut Department of Energy and Environmental Protection no later than two weeks prior to earth-disturbing activities for the subject pads.

7.Wetland Invasive Species Control Best Management Practices apply to work within all wetlands with invasive species. See Detail Sheet 5.

8.Farmland Protection Measures are required within indicated areas. See Detail Sheet 8.

9.Locations where access roads are proposed as permanent are indicated. Permanent access roads will remain after construction only if landowner permission is provided. All other access roads are considered temporary in compliance with regulatory requirements. (See Volume 1, Section 3.5.1).

| STR | NU STR | DESCRIPTION | HEIGHT (FT) | FINISH | FOUNDATION |
|---|---|---|---|---|---|
| 39 | 10738 | 345-kV Single Circuit Steel Monopole Vertical Deadend | 125 | Weathering | Drilled Shaft |
| 40 | 10739 | 345-kV Single Circuit Steel Monopole Delta Tangent | 110 | Weathering | Drilled Shaft |
| 41 | 10740 | 345-kV Single Circuit Steel H-Frame Horizontal Tangent Strain (0 - 2 deg) | 90 | Weathering | Direct Embed |
| 42 | 10741 | 345-kV Single Circuit Guyed 3-Pole Steel Horizontal Deadend | 85 | Weathering | Direct Embed |
| 43 | 10742 | 345-kV Single Circuit Steel H-Frame Horizontal Tangent | 85 | Weathering | Direct Embed |
| 44 | 10743 | 345-kV Single Circuit Steel H-Frame Horizontal Tangent | 90 | Weathering | Direct Embed |
| 45 | 10744 | 345-kV Single Circuit Steel H-Frame Horizontal Tangent | 105 | Weathering | Direct Embed |

New Transmission Structure Pole
New Transmission Line
Existing Transmission Structure Pole
Existing Distribution Lines
Existing Distribution Structures
New Guy Anchor
Relocated Guy Anchor
New Guy Wire
Relocated Guy Wire
Existing Access Road
Proposed New Access Road
Alternate Access Road
Permanent (See Note 9)
Work Pad
Limit of Disturbance
Existing_ROW
Stone Wall
Property Lines
NU Property
Town Line
Named Public Trails
Vegetation Clearing Limits for Construction
Existing Tree Canopy Line
Wetland
Open Water
Perennial Stream
Intermittent Stream
Vernal Pool
Amphibian Breeding Habitat
T&E Species Area

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DETAILED M. Goetz
CHECKED M. Kasinskas

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**EMF Measurement Path**

WORK AREA BOUNDARIES IN / NEAR WETLANDS

Vegetation removal will occur within the Vegetation Clearing Limits for Construction as shown, with temporary access routes in and across wetlands as necessary. Additionally, danger or hazard tree removal may be required outside of the Vegetation Clearing Limits for Construction, including within wetlands. For all other construction activities, work area boundaries will be defined by deployed E&S controls (silt fence and straw bales or equivalent). Further:

A. Work area boundaries will not necessarily encompass the entire width of the cleared area (e.g., tree line to tree line), but instead will be defined on a site-specific basis.

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C. All construction activities within wetlands, including access roads, work pads, temporary stockpiles of stripped topsoil or spoil (if necessary), excavations, equipment movements, etc., shall be contained within the work area boundaries.

D. Under no circumstances shall any materials (including plowed snow, construction materials, construction debris) be deposited beyond the work area boundaries.

NOTES

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4. T&E Species Avoidance and Minimization Measures are required within indicated areas. See Detail Sheet 5.

5. Within 100- and 500-year floodplain areas, construction activities will be in accordance with Connecticut Department of Energy and Environmental Protection permit requirements.

6. Grading plans for temporary work pads and guard structure pads, as indicated, must be submitted to the Connecticut Department of Energy and Environmental Protection no later than two weeks prior to earth-disturbing activities for the subject pads.

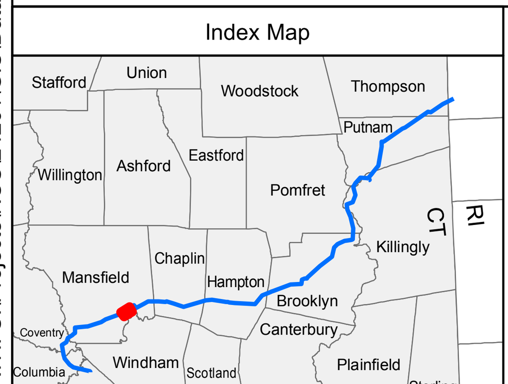
7. Wetland Invasive Species Control Best Management Practices apply to work within all wetlands with invasive species. See Detail Sheet 5.

8. Farmland Protection Measures are required within indicated areas. See Detail Sheet 8.

9. Locations where access roads are proposed as permanent are indicated. Permanent access roads will remain after construction only if landowner permission is provided. All other access roads are considered temporary in compliance with regulatory requirements. (See Volume 1, Section 3.5.1).

| STR | NU STR | DESCRIPTION | HEIGHT (FT) | FINISH | FOUNDATION |
|---|---|---|---|---|---|
| 72 | 10771 | 345-kV Single Circuit Guyed Steel Frame 3-Pole Horizontal Running Angle (2 - 15 deg) | 80 | Weathering | Direct Embed |
| 73 | 10772 | 345-kV Single Circuit Steel H-Frame Horizontal Tangent | 85 | Weathering | Direct Embed |
| 74 | 10773 | 345-kV Single Circuit Guyed 3-Pole Steel Horizontal Deadend | 80 | Weathering | Direct Embed |
| 75 | 10774 | 345-kV Single Circuit Steel H-Frame Horizontal Tangent | 85 | Weathering | Direct Embed |
| 76 | 10775 | 345-kV Single Circuit Steel H-Frame Horizontal Tangent | 75 | Weathering | Direct Embed |
| 77 | 10776 | 345-kV Single Circuit Steel H-Frame Horizontal Tangent | 90 | Weathering | Direct Embed |

Index Map




- New Transmission Structure Pole
- New Transmission Line
- Existing Transmission Structure Pole
- Existing Distribution Lines
- Existing Distribution Structures
- New Guy Anchor
- Relocated Guy Anchor
- New Guy Wire
- Relocated Guy Wire
- Existing Access Road
- Proposed New Access Road
- Alternate Access Road
- Permanent (See Note 9)
- Work Pad
- Limit of Disturbance
- Existing_ROW
- Stone Wall
- Property Lines
- NU Property
- Town Line
- Named Public Trails
- Vegetation Clearing Limits for Construction
- Existing Tree Canopy Line
- Wetland
- Open Water
- Perennial Stream
- Intermittent Stream
- Vernal Pool
- Amphibian Breeding Habitat
- T&E Species Area

0 50 100 200 Feet

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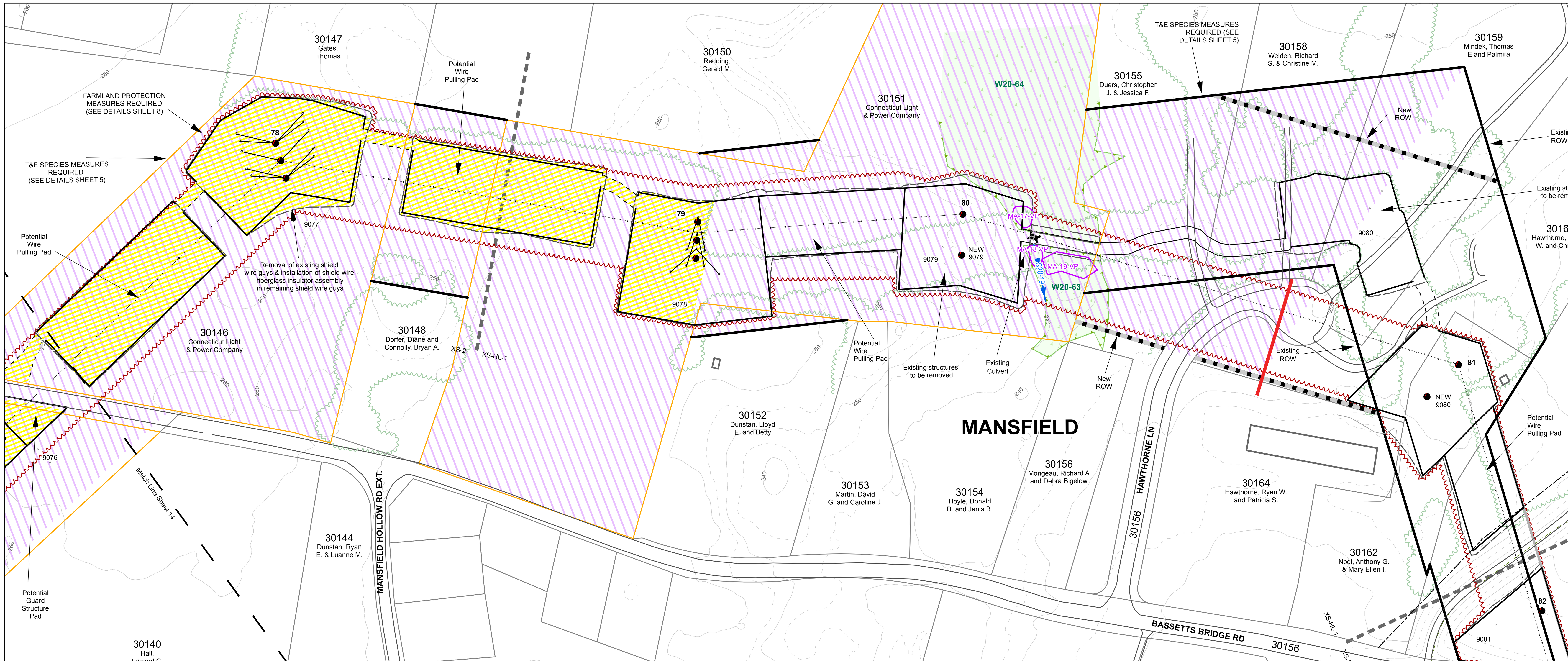
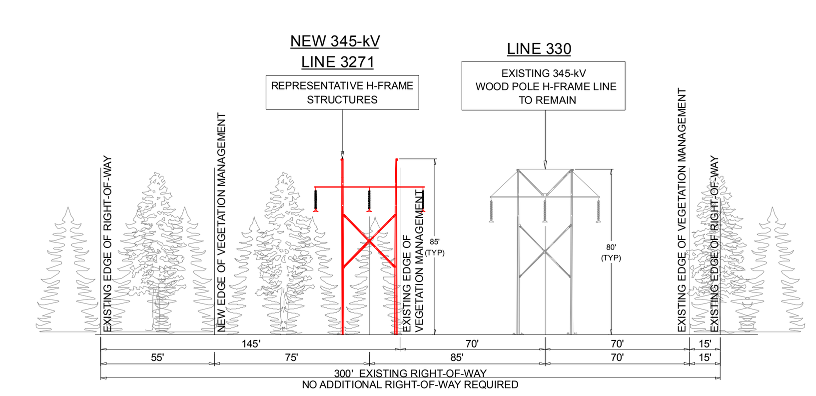
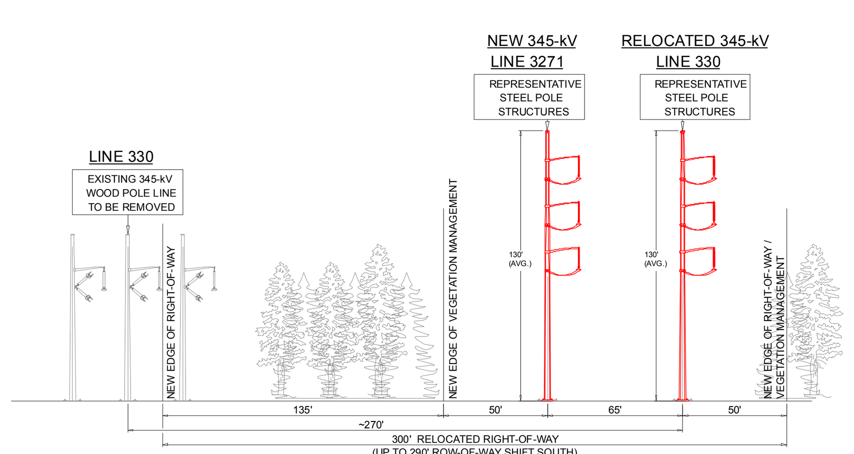
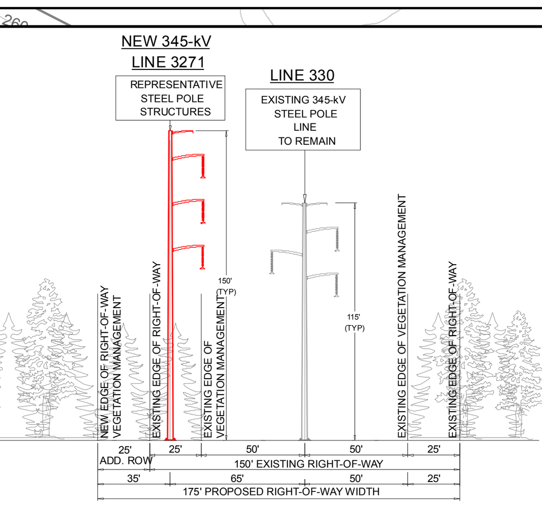



XS-2 BABCOCK HILL JUNCTION TO HAWTHORN LANE R.O.W. SHIFT LOOKING NORTHEASTERLY




HL-1 HAWTHORN LANE R.O.W. SHIFT LOOKING NORTHEASTERLY




XS-3 MANSFIELD HOLLOW STATE PARK TO BASSETTS BRIDGE ROAD LOOKING NORTHEASTERLY

WORK AREA BOUNDARIES IN / NEAR WETLANDS

Vegetation removal will occur within the Vegetation Clearing Limits for Construction as shown, with temporary access routes in and across wetlands as necessary. Additionally, danger or hazard tree removal may be required outside of the Vegetation Clearing Limits for Construction, including within wetlands. For all other construction activities, work area boundaries will be defined by deployed E&S controls (silt fence and straw bales or equivalent). Further:

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B. Boundaries shall be defined by E&S controls and thus may be different in dimension (but may be no greater in total square footage) than depicted on the D&M Plan maps.

C. All construction activities within wetlands, including access roads, work pads, temporary stockpiles of stripped topsoil or spoil (if necessary), excavations, equipment movements, etc., shall be contained within the work area boundaries.

D. Under no circumstances shall any materials (including plowed snow, construction materials, construction debris) be deposited beyond the work area boundaries.

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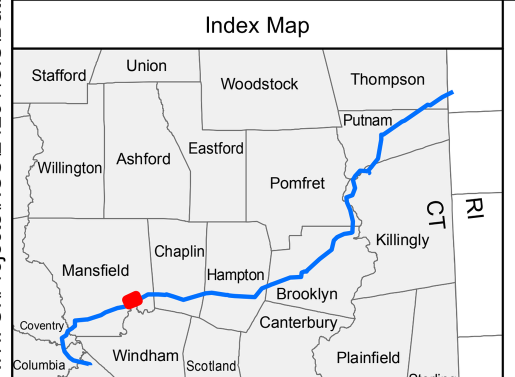
| STR | NU STR | DESCRIPTION | HEIGHT (FT) | FINISH | FOUNDATION |
|---|---|---|---|---|---|
| 78 | 10777 | 345-kV Single Circuit Guyed 3-Pole Steel Horizontal Deadend | 100 | Weathering | Direct Embed |
| 79 | 10778 | 345-kV Single Circuit Guyed 3-Pole Steel Horizontal Running Angle (10 - 20 deg) | 110 | Weathering | Direct Embed |
| 80 | 10779 | 345-kV Single Circuit Steel Monopole Vertical Deadend | 120 | Weathering | Drilled Shaft |
| 81 | 10780 | 345-kV Single Circuit Steel Monopole Vertical Deadend | 140 | Weathering | Drilled Shaft |
| 82 | 10781 | 345-kV Single Circuit Steel Monopole Vertical Tangent | 150 | Galvanized | Drilled Shaft |
| 83 | 10782 | 345-kV Single Circuit Steel Monopole Vertical Deadend | 135 | Galvanized | Drilled Shaft |
| 9079 | 9079 | 345-kV Single Circuit Steel Monopole Vertical Deadend | 120 | Weathering | Drilled Shaft |
| 9080 | 9080 | 345-kV Single Circuit Steel Monopole Vertical Deadend | 140 | Weathering | Drilled Shaft |

Active Farmland Area

T&E Species

Index Map




- New Transmission Structure Pole
- New Transmission Line
- Existing Transmission Structure Pole
- Existing Distribution Lines
- Existing Distribution Structures
- New Guy Anchor
- Relocated Guy Anchor
- New Guy Wire
- Relocated Guy Wire
- Existing Access Road
- Proposed New Access Road
- Alternate Access Road
- Permanent (See Note 9)
- Work Pad
- Limit of Disturbance
- Existing_ROW
- Stone Wall
- Property Lines
- NU Property
- Town Line
- Named Public Trails
- Vegetation Clearing Limits for Construction
- Existing Tree Canopy Line
- Wetland
- Open Water
- Perennial Stream
- Intermittent Stream
- Vernal Pool
- Amphibian Breeding Habitat
- T&E Species Area

0 50 100 200 Feet

| NO. | DATE | REVISIONS | BY | CHK | APP | APP |
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|---|---|
| DATE | DETAILED M. Goetz |
| DESIGNED M. Kasinskas & M. Goetz | CHECKED M. Kasinskas |

Northeast Utilities Service Co.

THE CONNECTICUT LIGHT & POWER CO.

Interstate Reliability Project
Development & Management Plan

| BY: | CHKD | APP | APP |
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| DATE: 8/30/2013 | DATE | DATE | DATE |
| 64261 | | Map Sheet 15 of 66 | |

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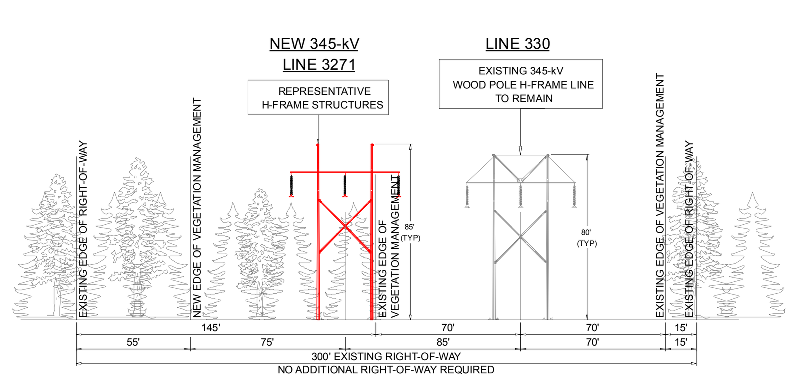


XS-6 VICINITY OF
WILLIMANTIC ROAD (U.S. ROUTE 6)
TO DAY STREET JUNCTION
LOOKING NORTHEASTERLY

WORK AREA BOUNDARIES IN / NEAR WETLANDS

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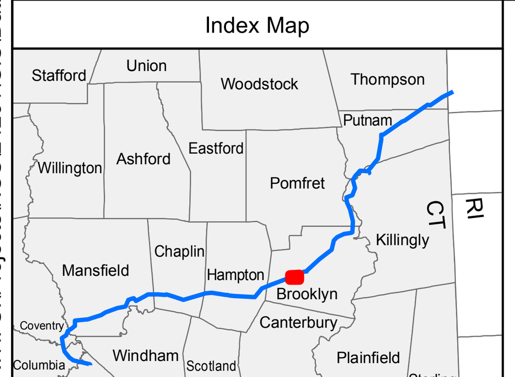
| STR | NU STR | DESCRIPTION | HEIGHT (FT) | FINISH | FOUNDATION |
|---|---|---|---|---|---|
| 174 | 10872 | 345-kV Single Circuit Guyed Steel 3-Pole Horizontal Running Angle (10 - 20 deg) | 100 | Weathering | Direct Embed |
| 175 | 10873 | 345-kV Single Circuit Steel H-Frame Horizontal Tangent | 105 | Weathering | Direct Embed |
| 176 | 10874 | 345-kV Single Circuit Steel H-Frame Horizontal Tangent | 80 | Weathering | Direct Embed |
| 177 | 10875 | 345-kV Single Circuit Steel H-Frame Horizontal Tangent | 90 | Weathering | Direct Embed |
| 178 | 10876 | 345-kV Single Circuit Steel H-Frame Horizontal Tangent | 100 | Weathering | Direct Embed |

Active Farmland Area

Index Map




- New Transmission Structure Pole
- New Transmission Line
- Existing Transmission Structure Pole
- Existing Distribution Lines
- Existing Distribution Structures
- New Guy Anchor
- Relocated Guy Anchor
- New Guy Wire
- Relocated Guy Wire
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- Existing Tree Canopy Line
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- Open Water
- Perennial Stream
- Intermittent Stream
- Vernal Pool
- Amphibian Breeding Habitat
- T&E Species Area

N

0 50 100 200 Feet

| NO. | DATE | REVISIONS | BY | CHK | APP | APP |
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DESIGNED M. Kasinskas & M. Goetz
CHECKED M. Kasinskas

Northeast Utilities Service Co.
THE CONNECTICUT LIGHT & POWER CO.

**Interstate Reliability Project**
**Development & Management Plan**

BY: | CHKD | APP | APP
DATE: 8/30/2013 | DATE | DATE | DATE

64261

Map Sheet 34 of 66

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WORK AREA BOUNDARIES IN / NEAR WETLANDS

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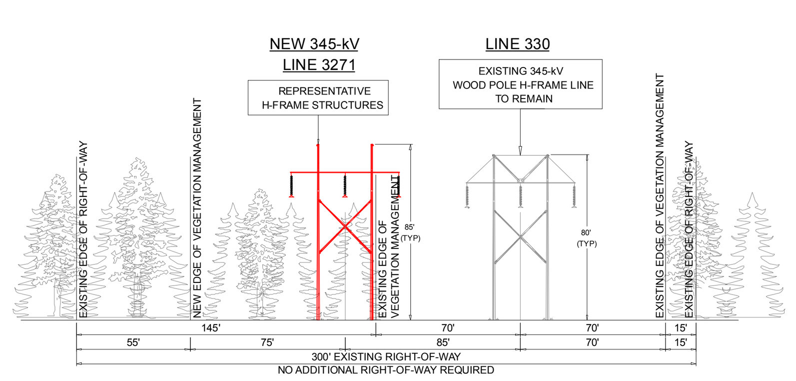
EMF Measurement Path




XS-6 VICINITY OF WILLIMANTIC ROAD (U.S. ROUTE 6) TO DAY STREET JUNCTION LOOKING NORTHEASTERLY

| STR | NU STR | DESCRIPTION | HEIGHT (FT) | FINISH | FOUNDATION |
|---|---|---|---|---|---|
| 213 | 10911 | 345-kV Single Circuit Steel H-Frame Horizontal Tangent | 75 | Weathering | Direct Embed |
| 214 | 10912 | 345-kV Single Circuit Self-Supported Steel 3-Pole Horizontal Running Angle (20 - 30 deg) | 95 | Weathering | Drilled Shaft |
| 215 | 10913 | 345-kV Single Circuit Steel H-Frame Horizontal Tangent | 90 | Weathering | Direct Embed |
| 216 | 10914 | 345-kV Single Circuit Steel H-Frame Horizontal Tangent | 90 | Weathering | Direct Embed |
| 217 | 10915 | 345-kV Single Circuit Steel H-Frame Horizontal Angle Strain (10 - 20 deg) | 75 | Weathering | Drilled Shaft |
| 218 | 10916 | 345-kV Single Circuit Steel H-Frame Horizontal Tangent | 80 | Weathering | Direct Embed |
| 219 | 10917 | 345-kV Single Circuit Steel H-Frame Horizontal Tangent | 80 | Weathering | Direct Embed |

Active Farmland Area

Active Farmland Area

Index Map

Stafford, Union, Woodstock, Thompson, Putnam, Willington, Ashford, Eastford, Pomfret, Chaplin, Hampton, Killingly, Mansfield, Brooklyn, Canterbury, Coventry, Windham, Scotland, Plainfield, Columbia, Lebanon, Sterling, CT, RI

- New Transmission Structure Pole
- New Transmission Line
- Existing Transmission Structure Pole
- Existing Distribution Lines
- Existing Distribution Structures
- New Guy Anchor
- Relocated Guy Anchor
- New Guy Wire
- Relocated Guy Wire
- Existing Access Road
- Proposed New Access Road
- Alternate Access Road
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- Work Pad
- Limit of Disturbance
- Existing_ROW
- Stone Wall
- Property Lines
- NU Property
- Town Line
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- Vegetation Clearing Limits for Construction
- Existing Tree Canopy Line
- Wetland
- Open Water
- Perennial Stream
- Intermittent Stream
- Vernal Pool
- Amphibian Breeding Habitat
- T&E Species Area

0 50 100 200 Feet

N

| NO. | DATE | REVISIONS | BY | CHK | APP | APP |
|---|---|---|---|---|---|---|

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DATE

DETAILED M. Goetz

DESIGNED M. Kasinskas & M. Goetz

CHECKED M. Kasinskas

Northeast Utilities Service Co.

THE CONNECTICUT LIGHT & POWER CO.

**Interstate Reliability Project Development & Management Plan**

BY: | CHKD | APP | APP

DATE: 8/30/2013 | DATE | DATE | DATE

64261

Map Sheet 42 of 66


WORK AREA BOUNDARIES IN / NEAR WETLANDS

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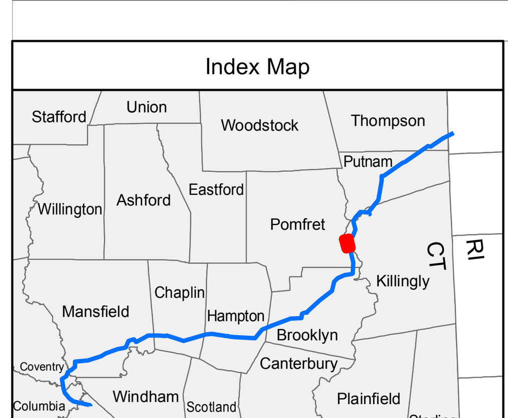
| STR | NU STR | DESCRIPTION | HEIGHT (FT) | FINISH | FOUNDATION |
|---|---|---|---|---|---|
| 236 | 10934 | 345-kV Single Circuit Steel H-Frame Horizontal Tangent | 80 | Weathering | Direct Embed |
| 237 | 10935 | 345-kV Single Circuit Steel H-Frame Horizontal Tangent | 95 | Weathering | Direct Embed |
| 238 | 10936 | 345-kV Single Circuit Guyed 3-Pole Steel Horizontal Strain | 95 | Weathering | Direct Embed |
| 239 | 10937 | 345-kV Single Circuit Steel H-Frame Horizontal Tangent | 105 | Weathering | Direct Embed |
| 240 | 10938 | 345-kV Single Circuit Steel H-Frame Horizontal Tangent Strain (0 - 2 deg) | 90 | Weathering | Direct Embed |




New Transmission Structure Pole
New Transmission Line
Existing Transmission Structure Pole
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Existing Distribution Structures
New Guy Anchor
Relocated Guy Anchor
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Existing Tree Canopy Line
Wetland
Open Water
Perennial Stream
Intermittent Stream
Vernal Pool
Amphibian Breeding Habitat
T&E Species Area

0 50 100 200 Feet

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DATE
DETAILED M. Goetz
DESIGNED M. Kasinskas & M. Goetz
CHECKED M. Kasinskas

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THE CONNECTICUT LIGHT & POWER CO.

**Interstate Reliability Project**
**Development & Management Plan**

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DATE: 8/30/2013 | DATE | DATE | DATE
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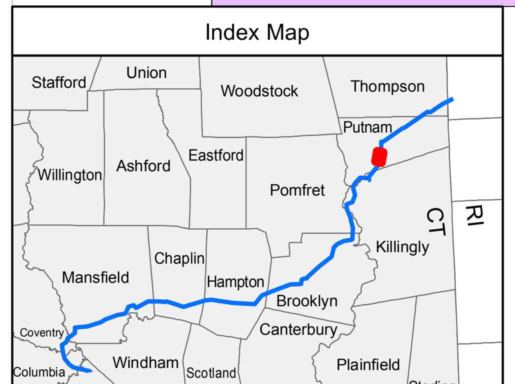
| STR | NU STR | DESCRIPTION | HEIGHT (FT) | FINISH | FOUNDATION |
|---|---|---|---|---|---|
| 280 | 13113 | 345-kV Single Circuit Steel H-Frame Horizontal Tangent | 75 | Weathering | Direct Embed |
| 281 | 13114 | 345-kV Single Circuit Steel H-Frame Horizontal Tangent | 80 | Weathering | Direct Embed |
| 282 | 13115 | 345-kV Single Circuit Steel H-Frame Horizontal Tangent | 90 | Weathering | Direct Embed |
| 283 | 13116 | 345-kV Single Circuit Steel H-Frame Horizontal Tangent | 85 | Weathering | Direct Embed |
| 284 | 13117 | 345-kV Single Circuit Steel H-Frame Horizontal Tangent | 80 | Weathering | Direct Embed |
| 285 | 13118 | 345-kV Single Circuit Steel H-Frame Horizontal Tangent | 85 | Weathering | Direct Embed |

Index Map

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SINCE 1898

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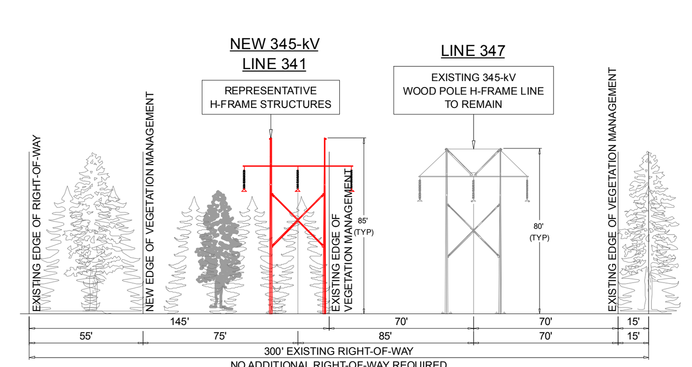


XS-12 HERITAGE ROAD
TO CONNECTICUT/RHODE ISLAND STATE BORDER
LOOKING NORTHEASTERLY

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5.Within 100- and 500-year floodplain areas, construction activities will be in accordance with Connecticut Department of Energy and Environmental Protection permit requirements.

6.Grading plans for temporary work pads and guard structure pads, as indicated, must be submitted to the Connecticut Department of Energy and Environmental Protection no later than two weeks prior to earth-disturbing activities for the subject pads.

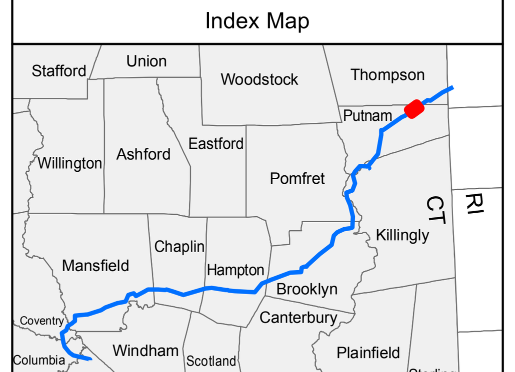
7.Wetland Invasive Species Control Best Management Practices apply to work within all wetlands with invasive species. See Detail Sheet 5.

8.Farmland Protection Measures are required within indicated areas. See Detail Sheet 8.

9.Locations where access roads are proposed as permanent are indicated. Permanent access roads will remain after construction only if landowner permission is provided. All other access roads are considered temporary in compliance with regulatory requirements. (See Volume 1, Section 3.5.1).

| STR | NU STR | DESCRIPTION | HEIGHT (FT) | FINISH | FOUNDATION |
|---|---|---|---|---|---|
| 311 | 13144 | 345-kV Single Circuit Steel H-Frame Horizontal Tangent | 85 | Weathering | Direct Embed |
| 312 | 13145 | 345-kV Single Circuit Steel H-Frame Horizontal Tangent | 75 | Weathering | Direct Embed |
| 313 | 13146 | 345-kV Single Circuit Steel H-Frame Horizontal Tangent | 85 | Weathering | Direct Embed |
| 314 | 13147 | 345-kV Single Circuit Steel H-Frame Horizontal Tangent | 75 | Weathering | Direct Embed |
| 315 | 13148 | 345-kV Single Circuit Steel H-Frame Horizontal Tangent | 80 | Weathering | Direct Embed |
| 316 | 13149 | 345-kV Single Circuit Steel H-Frame Horizontal Tangent | 80 | Weathering | Direct Embed |

Index Map




New Transmission Structure Pole
New Transmission Line
Existing Transmission Structure Pole
Existing Distribution Lines
Existing Distribution Structures
New Guy Anchor
Relocated Guy Anchor
New Guy Wire
Relocated Guy Wire
Existing Access Road
Proposed New Access Road
Alternate Access Road
Permanent (See Note 9)
Work Pad
Limit of Disturbance
Existing_ROW
Stone Wall
Property Lines
NU Property
Town Line
Named Public Trails
Vegetation Clearing Limits for Construction
Existing Tree Canopy Line
Wetland
Open Water
Perennial Stream
Intermittent Stream
Vernal Pool
Amphibian Breeding Habitat
T&E Species Area

0 50 100 200 Feet

| NO. | DATE | REVISIONS | BY | CHK | APP | APP |
|---|---|---|---|---|---|---|

Burns & McDonnell SINCE 1898

DATE
DESIGNED M. Kasinskas & M. Goetz
DETAILED M. Goetz
CHECKED M. Kasinskas

Northeast Utilities Service Co.
THE CONNECTICUT LIGHT & POWER CO.

Interstate Reliability Project
Development & Management Plan

BY: | CHKD | APP | APP
DATE: 8/30/2013 | DATE | DATE | DATE

64261


WORK AREA BOUNDARIES IN / NEAR WETLANDS

Vegetation removal will occur within the Vegetation Clearing Limits for Construction as shown, with temporary access routes in and across wetlands as necessary. Additionally, danger or hazard tree removal may be required outside of the Vegetation Clearing Limits for Construction, including within wetlands. For all other construction activities, work area boundaries will be defined by deployed E&S controls (silt fence and straw bales or equivalent). Further:

A. Work area boundaries will not necessarily encompass the entire width of the cleared area (e.g., tree line to tree line), but instead will be defined on a site-specific basis.

B. Boundaries shall be defined by E&S controls and thus may be different in dimension (but may be no greater in total square footage) than depicted on the D&M Plan maps.

C. All construction activities within wetlands, including access roads, work pads, temporary stockpiles of stripped topsoil or spoil (if necessary), excavations, equipment movements, etc., shall be contained within the work area boundaries.

D. Under no circumstances shall any materials (including plowed snow, construction materials, construction debris) be deposited beyond the work area boundaries.

NOTES

1. All work will be conducted in accordance with the relevant portions of CL&P's December 2011 Best Management Practices Manual: Connecticut Construction and Maintenance Environmental Requirements unless more stringent project-specific measures apply. See Volumes 1 and 2.

2. All work will be conducted in accordance with the requirements of regulatory approvals from the U.S. Army Corps of Engineers and the Connecticut Department of Energy and Environmental Protection, and with all Project Protocols. See Detail Sheets 1-4.

3. Erosion and sedimentation control measures will be installed during construction, as required, to comply with the 2002 Connecticut Guidelines for Erosion and Sediment Control, and CL&Ps December 2011 Best Management Practices Manual: Connecticut Construction and Maintenance Environmental Requirements, and applicable regulatory approvals. See Detail Sheets 6 & 7.

4. T&E Species Avoidance and Minimization Measures are required within indicated areas. See Detail Sheet 5.

5. Within 100- and 500-year floodplain areas, construction activities will be in accordance with Connecticut Department of Energy and Environmental Protection permit requirements.

6. Grading plans for temporary work pads and guard structure pads, as indicated, must be submitted to the Connecticut Department of Energy and Environmental Protection no later than two weeks prior to earth-disturbing activities for the subject pads.

7. Wetland Invasive Species Control Best Management Practices apply to work within all wetlands with invasive species. See Detail Sheet 5.

8. Farmland Protection Measures are required within indicated areas. See Detail Sheet 8.

9. Locations where access roads are proposed as permanent are indicated. Permanent access roads will remain after construction only if landowner permission is provided. All other access roads are considered temporary in compliance with regulatory requirements. (See Volume 1, Section 3.5.1).

| STR | NU STR | DESCRIPTION | HEIGHT (FT) | FINISH | FOUNDATION |
|---|---|---|---|---|---|
| 1 | 10701 | 345-kV Single Circuit Self-Supported Steel 2-Pole Delta Deadend | 120 | Weathering | Drilled Shaft |
| 2 | 10702 | 345-kV Single Circuit Steel Monopole Vertical Deadend | 155 | Weathering | Drilled Shaft |
| 3 | 10703 | 345-kV Single Circuit Steel H-Frame Horizontal Tangent Strain (0 - 2 deg) | 95 | Weathering | Direct Embed |
| 4 | 10704 | 345-kV Single Circuit Steel H-Frame Horizontal Tangent | 85 | Weathering | Direct Embed |
| 5 | 10705 | 345-kV Single Circuit Steel H-Frame Horizontal Tangent | 80 | Weathering | Direct Embed |
| 6 | 10706 | 345-kV Single Circuit Steel H-Frame Horizontal Tangent | 85 | Weathering | Direct Embed |

Index Map

Legend: New Transmission Structure Pole; New Transmission Line; Existing Transmission Structure Pole; Existing Distribution Lines; Existing Distribution Structures; New Guy Anchor; Relocated Guy Anchor; New Guy Wire; Relocated Guy Wire; Existing Access Road; Proposed New Access Road; Alternate Access Road; Permanent (See Note 9); Work Pad; Limit of Disturbance; Existing_ROW; Stone Wall; Property Lines; NU Property; Town Line; Named Public Trails; Vegetation Clearing Limits for Construction; Existing Tree Canopy Line; Wetland; Open Water; Perennial Stream; Intermittent Stream; Vernal Pool; Amphibian Breeding Habitat; T&E Species Area

0 50 100 200 Feet

| NO. | DATE | REVISIONS | BY | CHK | APP | APP |
|---|---|---|---|---|---|---|

Burns & McDonnell SINCE 1898

DATE | DETAILED M. Goetz | DESIGNED M. Kasinskas & M. Goetz | CHECKED M. Kasinskas

**Northeast Utilities Service Co.**

THE CONNECTICUT LIGHT & POWER CO.

**Interstate Reliability Project Development & Management Plan**

BY: | CHKD | APP | APP
DATE: 8/30/2013 | DATE | DATE | DATE

64261

Map Sheet 1 of 66

# Appendix C

# Calculated and Measured EMF levels at the Monitoring Sites

A comparison of the modeling results and measurements was summarized in the body of the report above. This Appendix provides a detailed analysis of the measurements and comparison with as-built conditions and the original model for each individual measurement location.

Results for each of the nine measurement sites (as well as the Card Street Substation) are presented below. Both electric fields and magnetic fields were measured at each of sites 1-9, while at the Card Street Substation, only magnetic-field levels were measured. For each measurement site, a 1" = 100' scale map showing the location of the new line (3271 or 341) as well as the location of the ROW edges and measurement locations is included in Appendix B.

Electric- and magnetic-field levels are presented in separate figures. In each of these figures actual measurement values are shown by a series of '+' markers. Two sets of measurements (on separate days) were performed at each location for the magnetic field, and 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 once at each site and individual measurement locations were separated by 5-50 feet and so generally appear as discrete '+' symbols indicating the measured value. Where applicable, for the true-up measurements, the results of the true-up model (created using the loading at the time of measurements as well as measurements of conductor height and conductor location) is shown in a solid blue and teal lines, while individual measurements are shown in corresponding '+' markers.

Additionally, the magnetic-field measurements surrounding the Card Street Substation are presented in Figure C-19 with a corresponding aerial photograph showing the locations of various landmarks identified within the data is shown in Figure C-20.

## Site 1

Measurements at Site 1 were performed on October 4 and November 2, 2016.  A graphical summary of results is presented below.

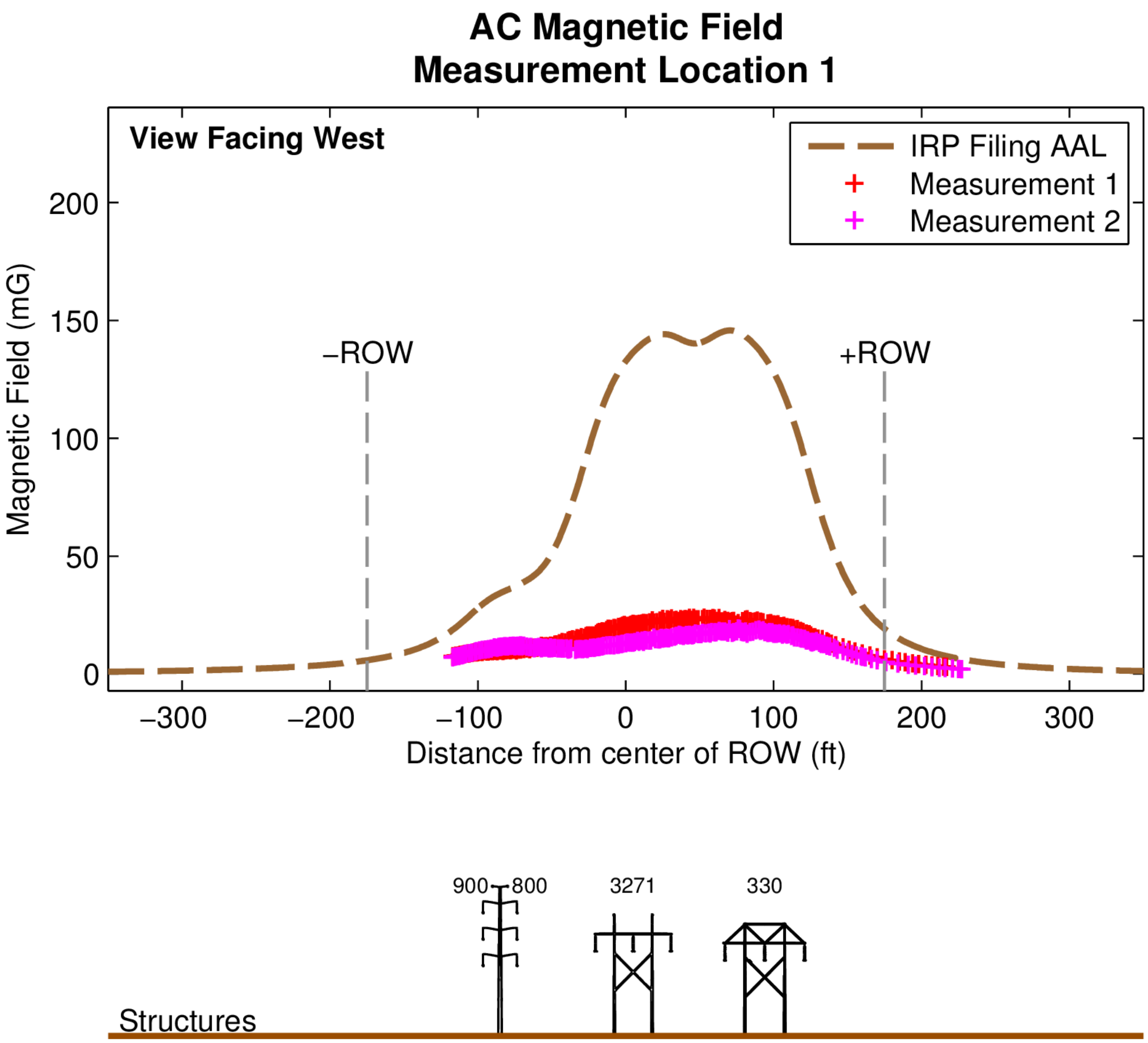



Figure C-1.    Measured magnetic-field levels at Site 1 in XS-1.

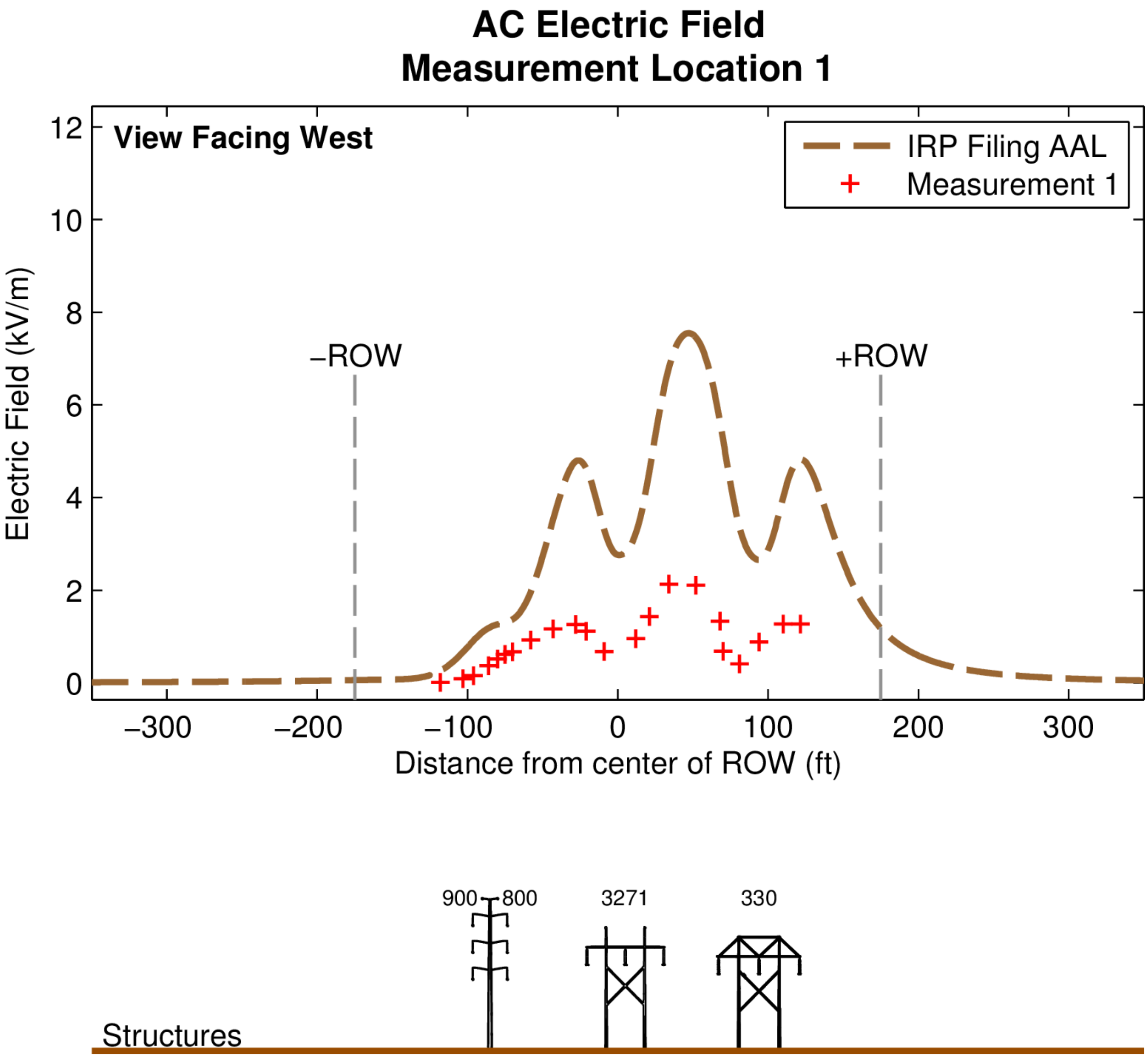



Figure C-2. Measured electric-field levels at Site 1 in XS-1.

## Site 2

Measurements at Site 2 were performed on October 4 and November 2, 2016. A graphical summary of results is presented below.

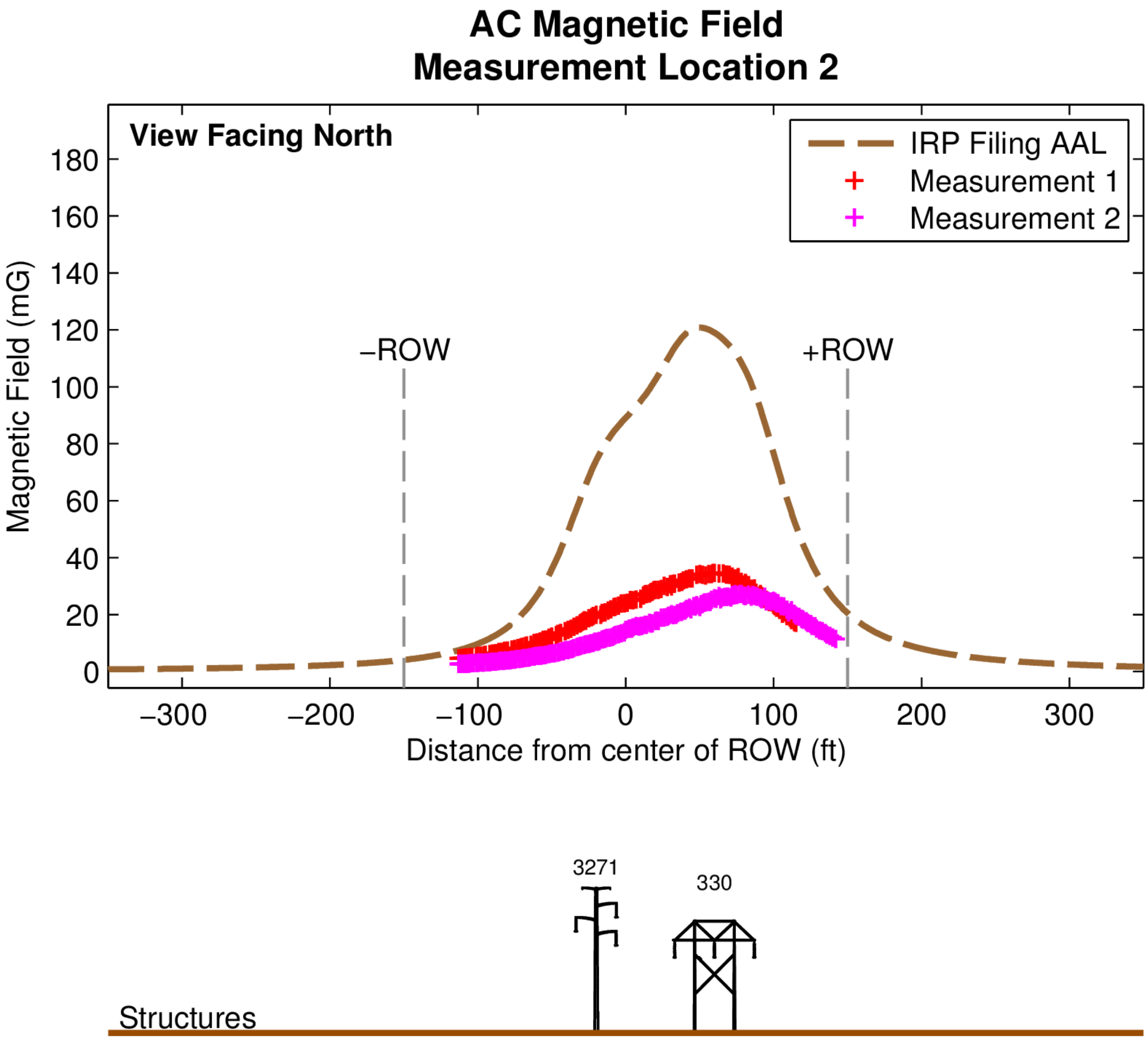
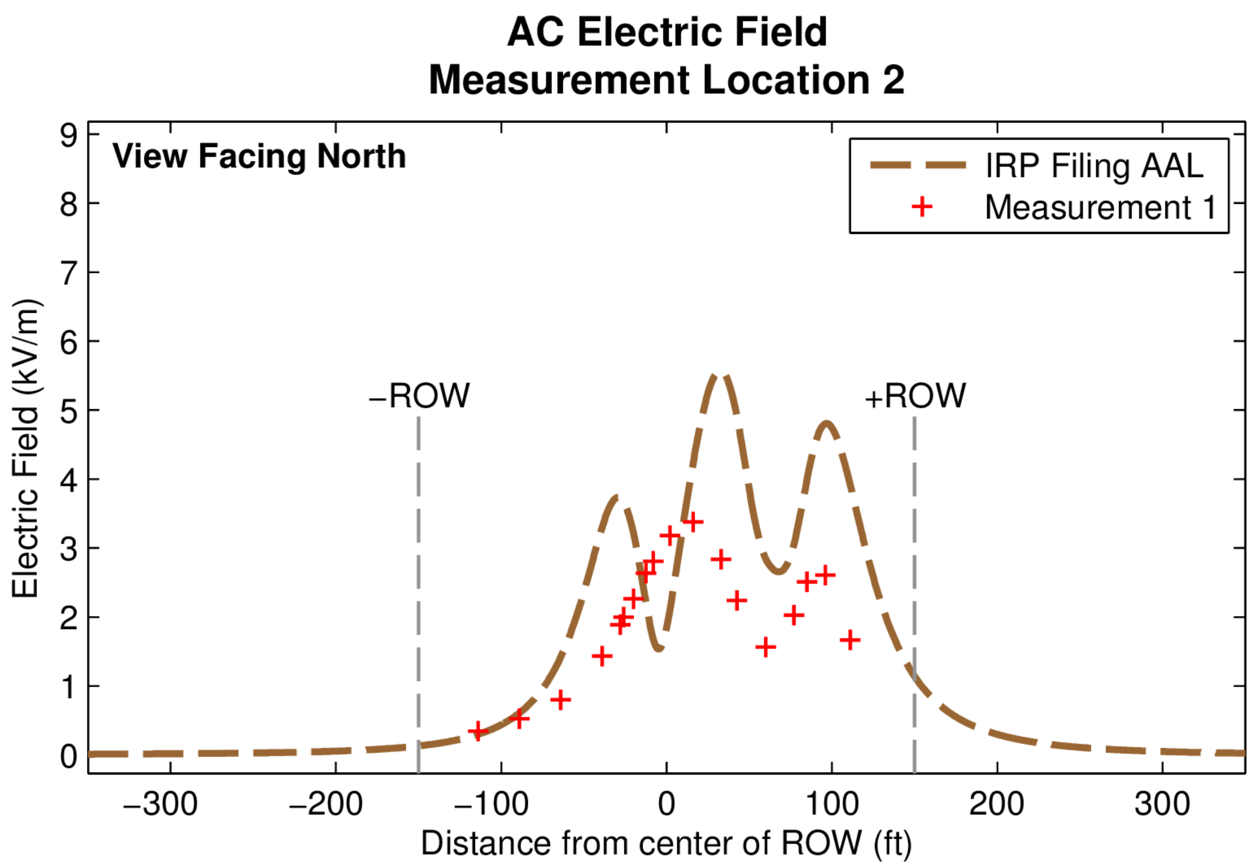



Figure C-3. Measured magnetic-field levels at Site 2 in XS-2.



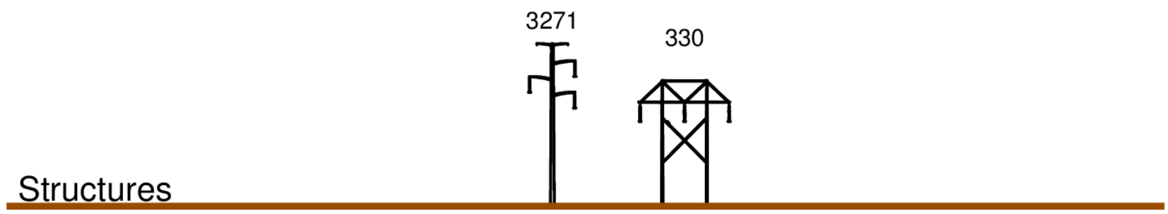




Figure C-4. Measured electric-field levels at Site 2 in XS-2.

## Site 3

Measurements at Site 3were performed on October 4 and November 2, 2016. A graphical summary of results is presented below along with true-up modeling results.

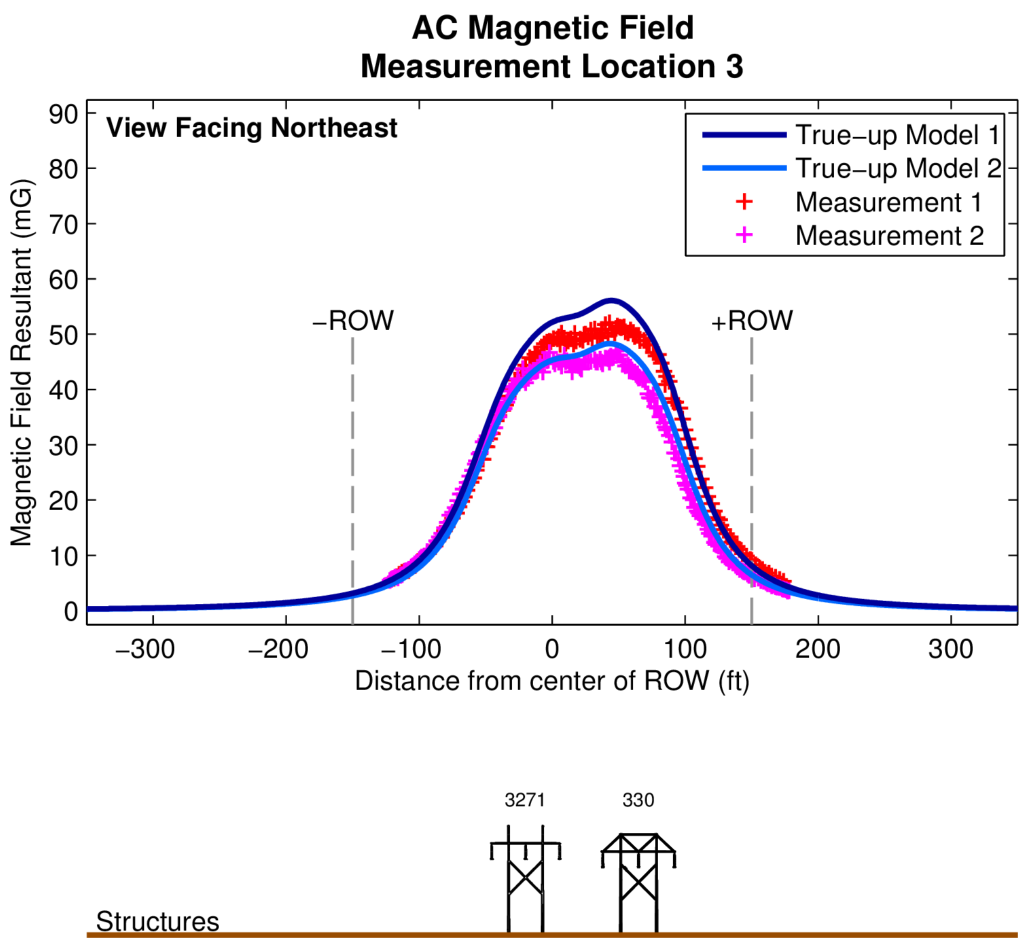



Figure C-5. Measured magnetic-field levels at Site 3 in XS-2.

True-up modeling results are shown in dark blue and teal lines for measurement 1 and 2, respectively.

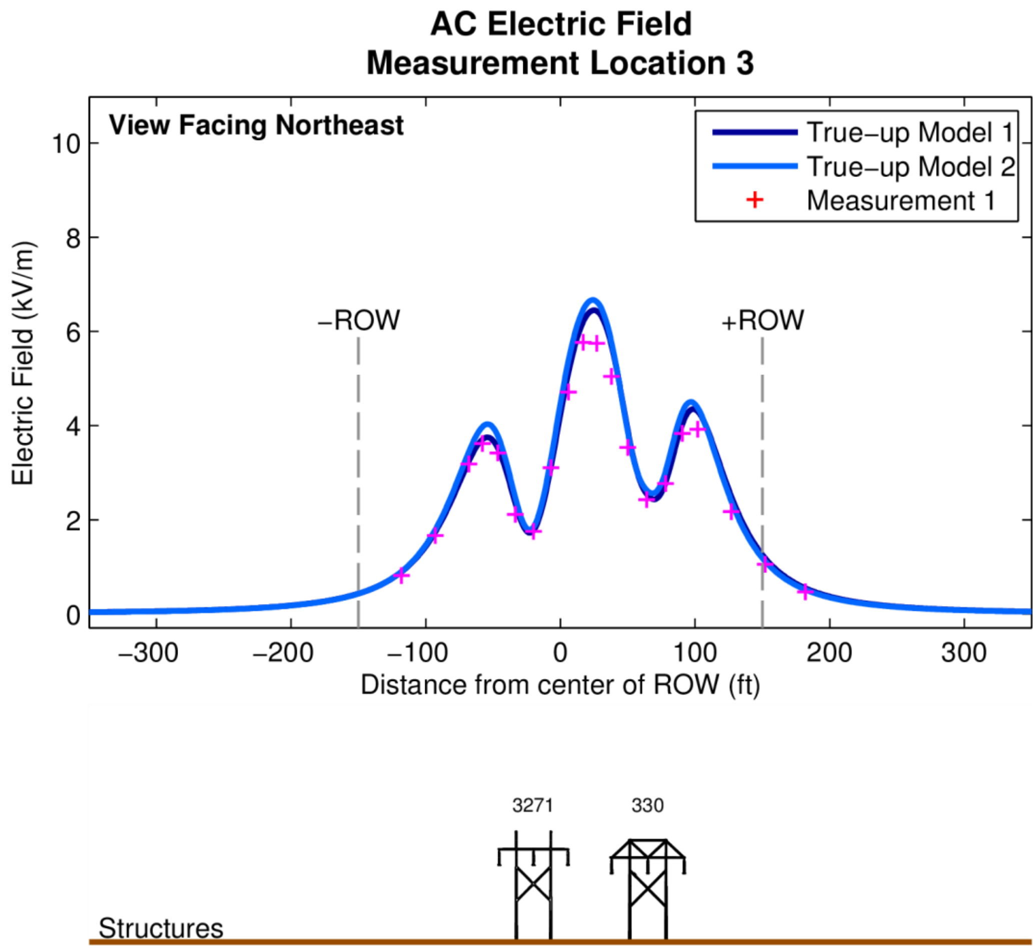



Figure C-6. Measured electric-field levels at Site 3 in XS-2.

Electric-field measurements were performed only once as electric-field levels are not expected to vary significantly with changes in loading. In developing a true-up model for the corresponding magnetic-field measurements, however, an electric-field true-up model is also generated and so is included for reference. Note that the two true-up models differ very little, as expected due to relatively small changes in measured conductor height.

## Site 4

Measurements at Site 4 were performed on October 4 and November 2, 2016. A graphical summary of results is presented below along with true-up modeling results.

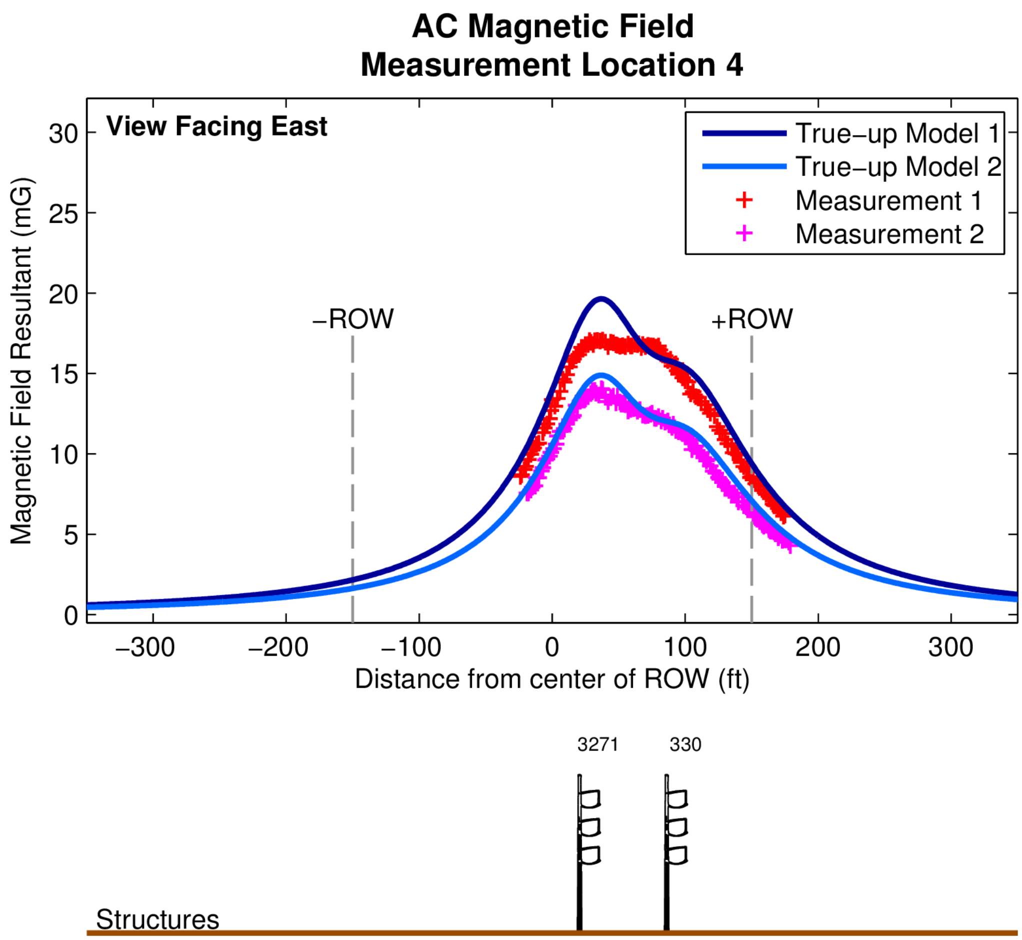



Figure C-7. Measured magnetic-field levels at Site 4 on Hawthorne Lane.

True-up modeling results are shown in dark blue and teal lines for measurement 1 and 2, respectively.

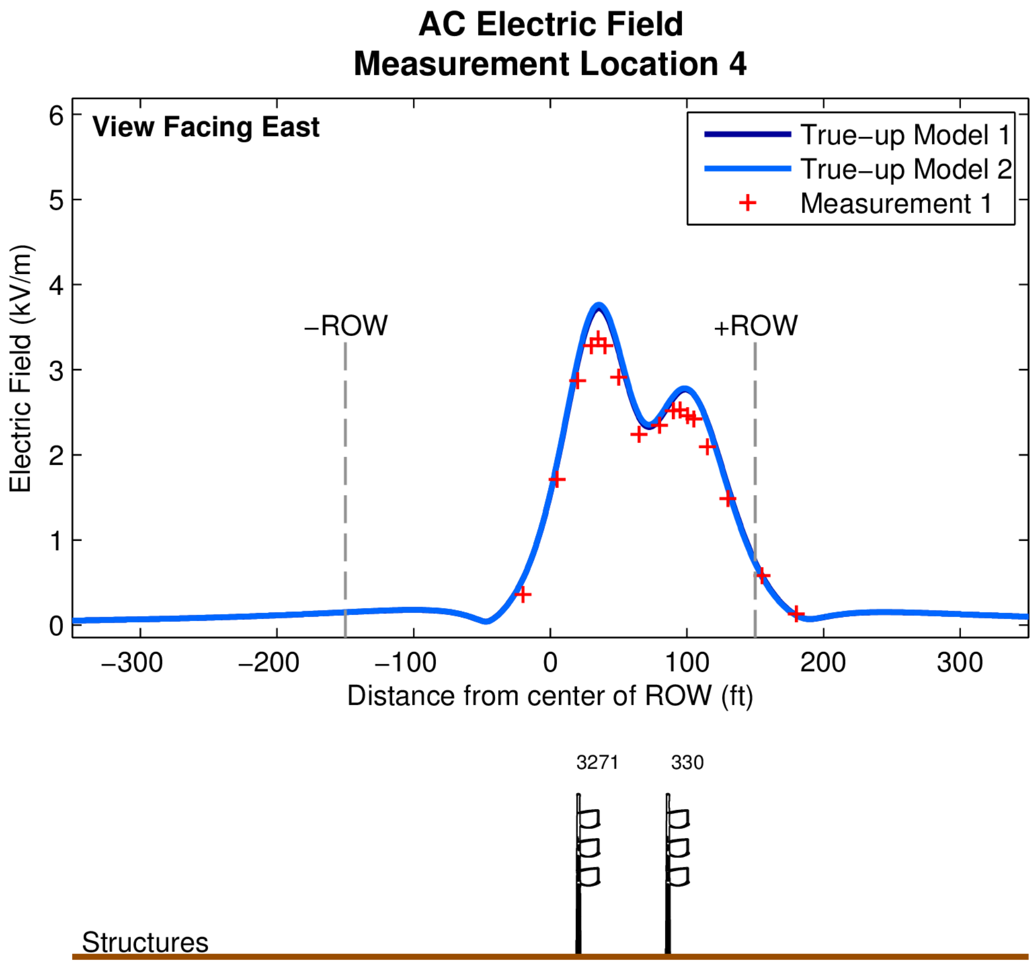



Figure C-8. Measured electric-field levels at Site 4 on Hawthorne Lane.

Electric-field measurements were performed only once as electric-field levels are not expected to vary significantly with changes in loading. In developing a true-up model for the corresponding magnetic-field measurements, however, an electric-field true-up model is also generated and so is included for reference. Note that the difference in the electric-field levels between the two true-up models is so small that it cannot be seen in the figure.

## Site 5

Measurements at Site 5 were performed on October 4 and November 2, 2016. A graphical summary of results is presented below.

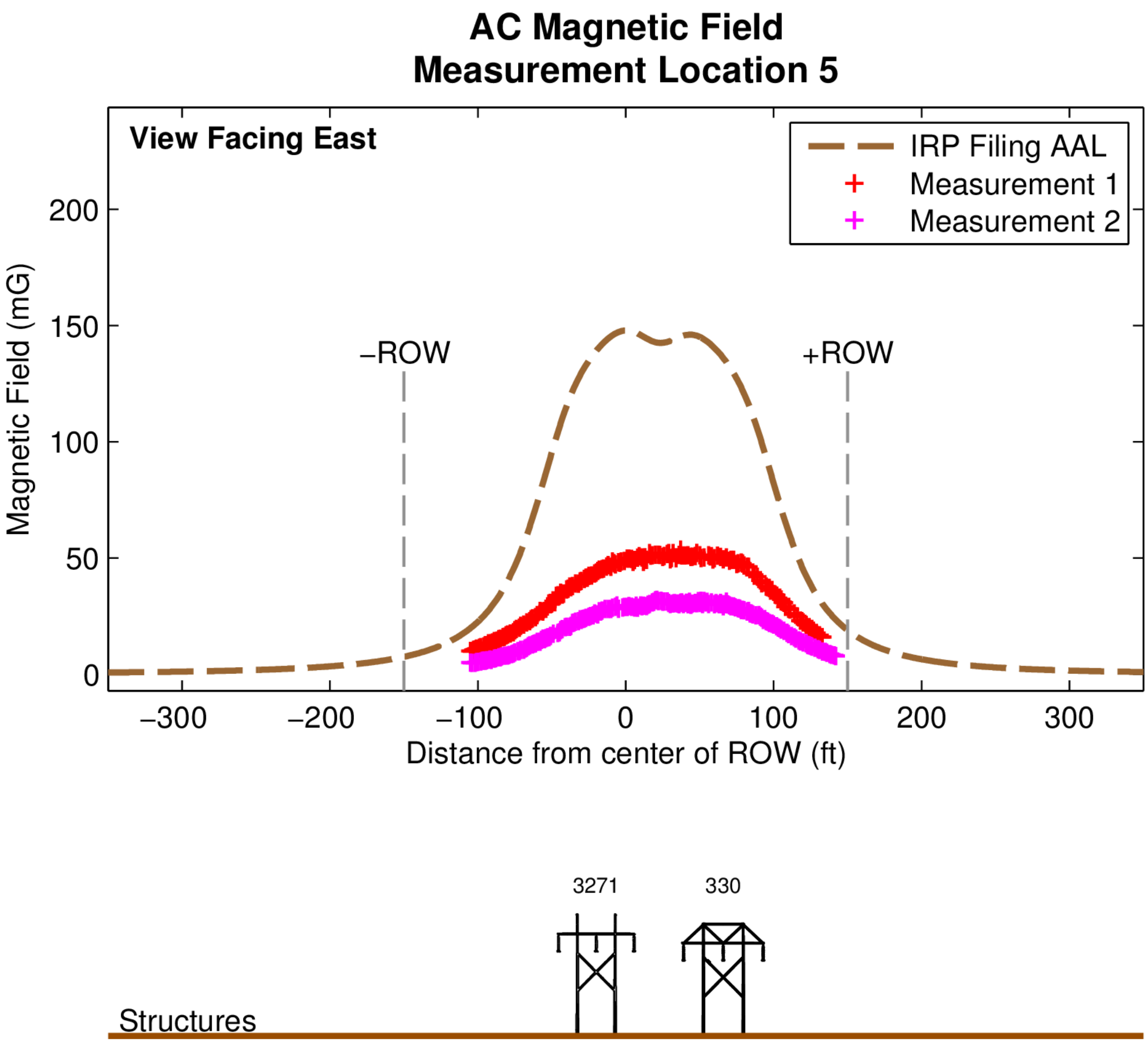



Figure C-9. Measured magnetic-field levels at Site 5 in XS-6.

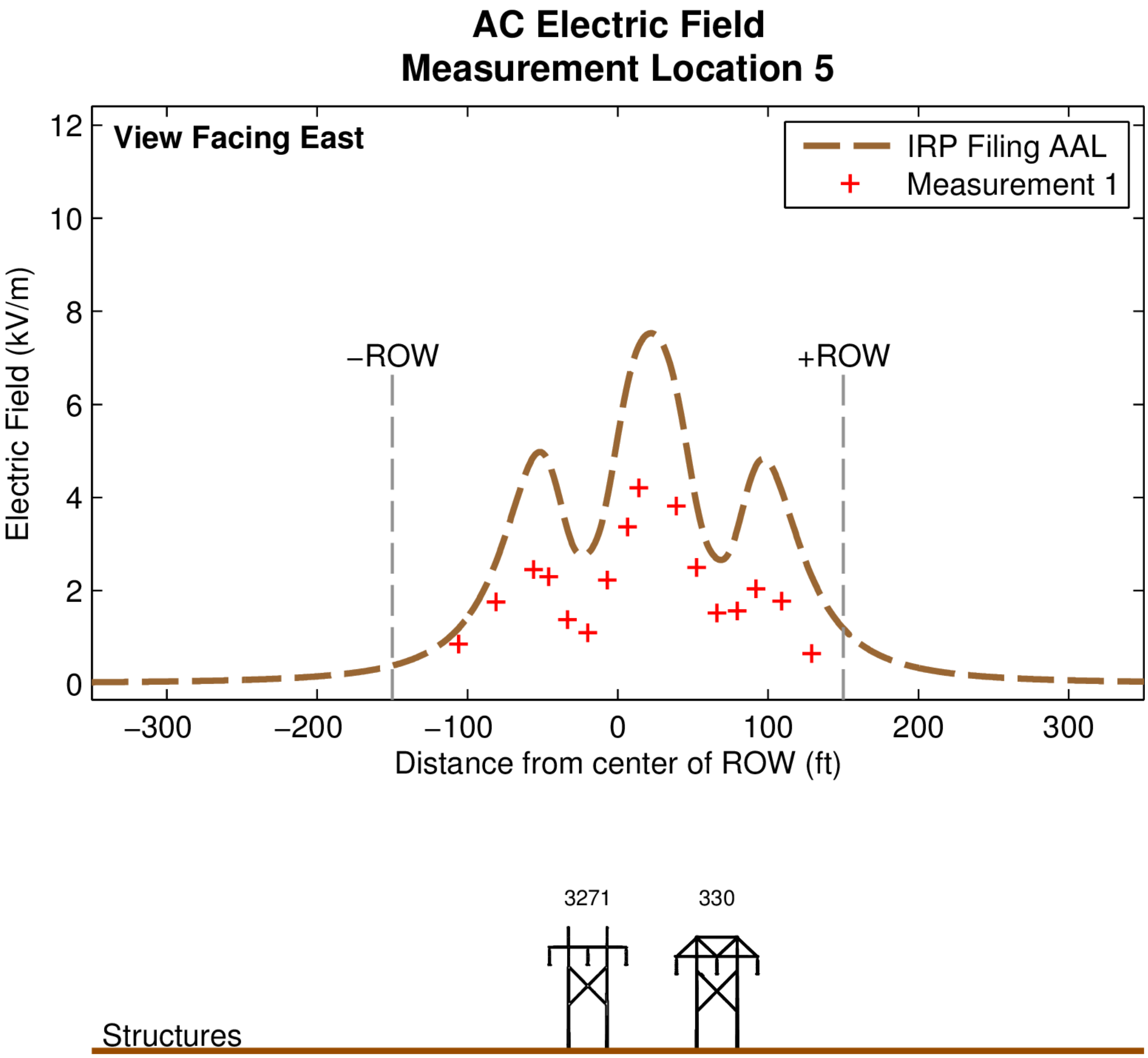



Figure C-10.  Measured electric-field levels at Site 5 in XS-6.

## Site 6

Measurements at Site 6 were performed on October 5 and November 2, 2016. A graphical summary of results is presented below.

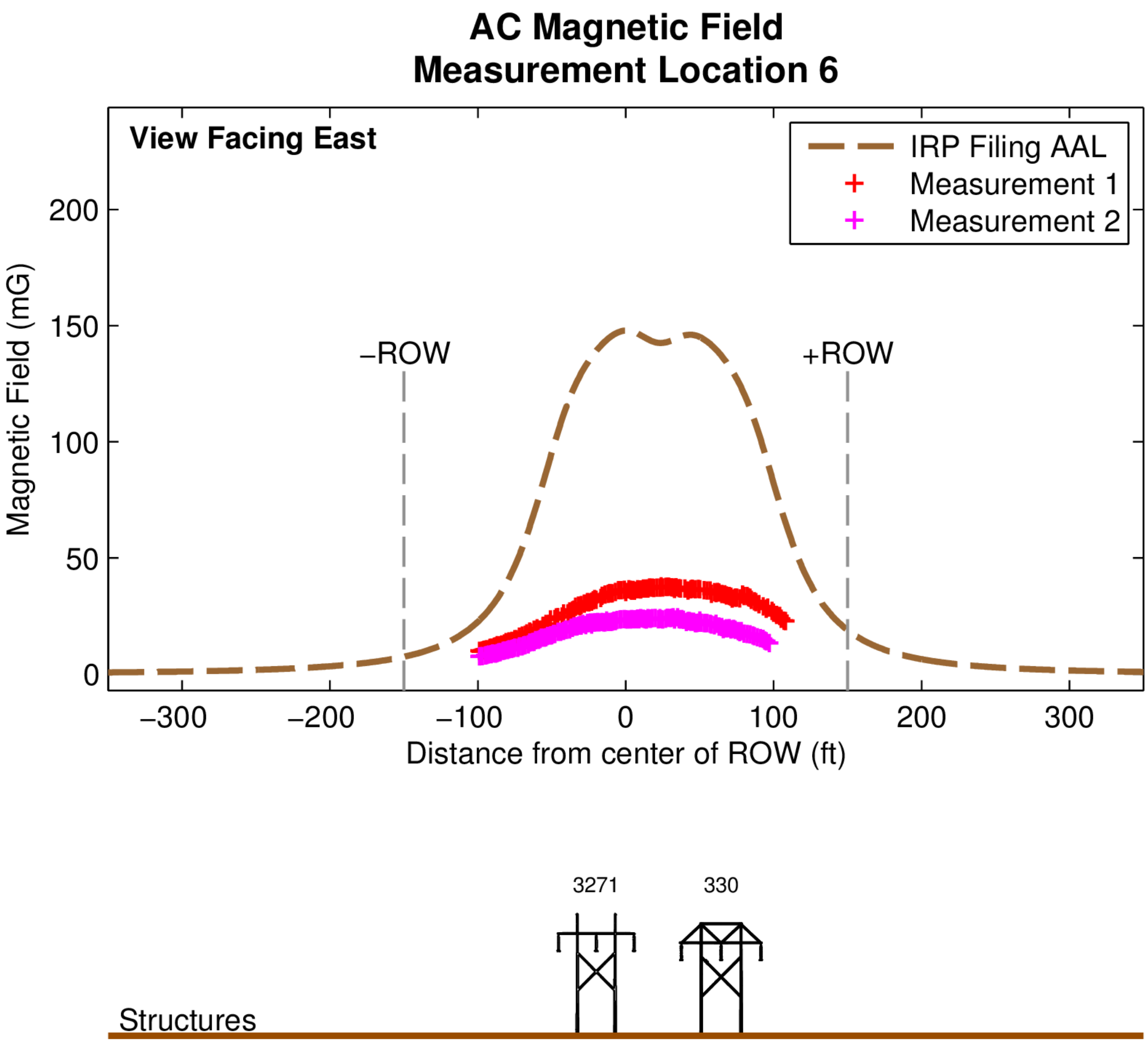



Figure C-11. Measured magnetic-field levels at Site 6 in XS-6.

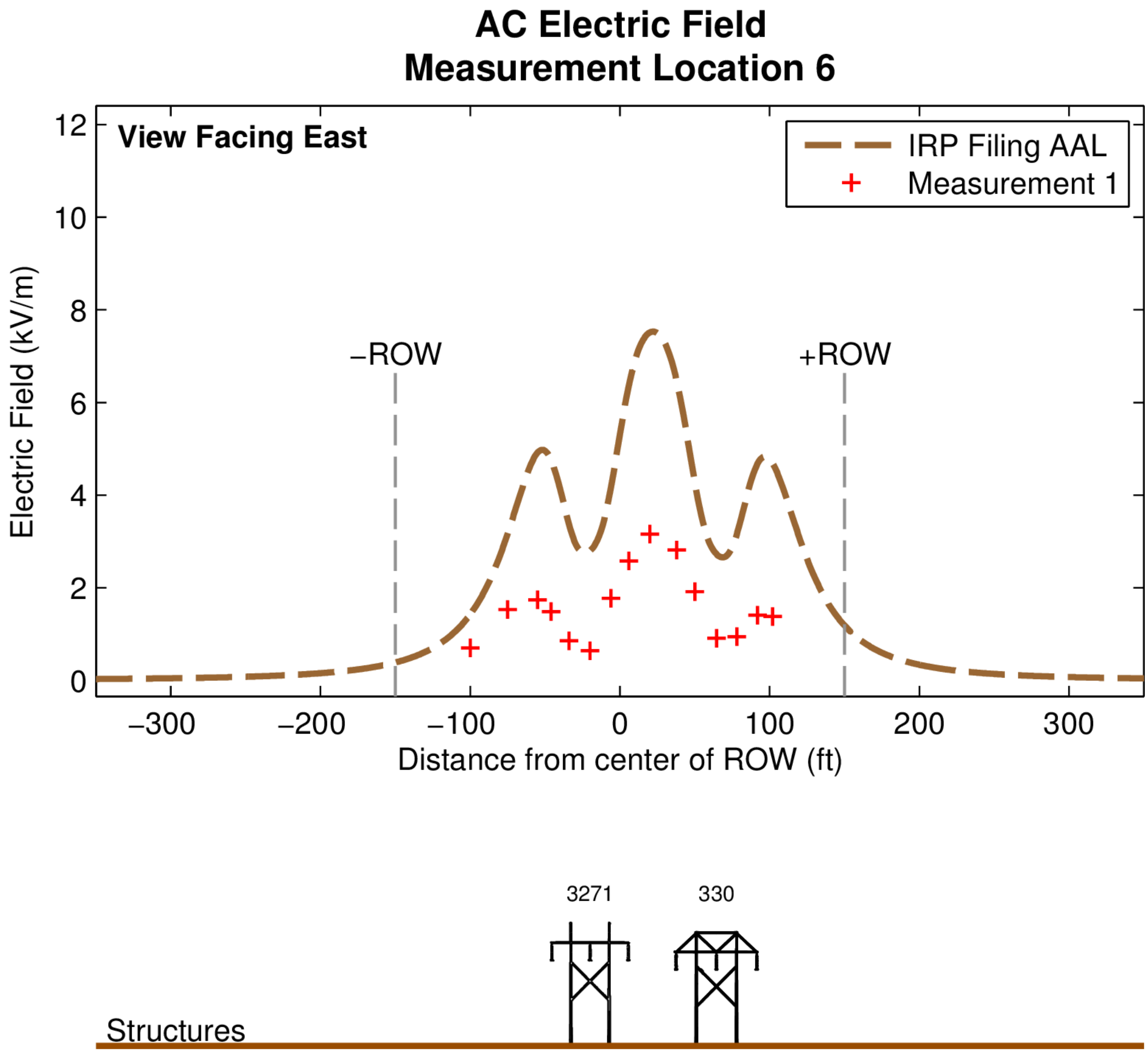



Figure C-12. Measured electric-field levels at Site 6 in XS-6.

## Site 7

Measurements at Site 7 were performed on October 5 and November 2, 2016. A graphical summary of results is presented below.

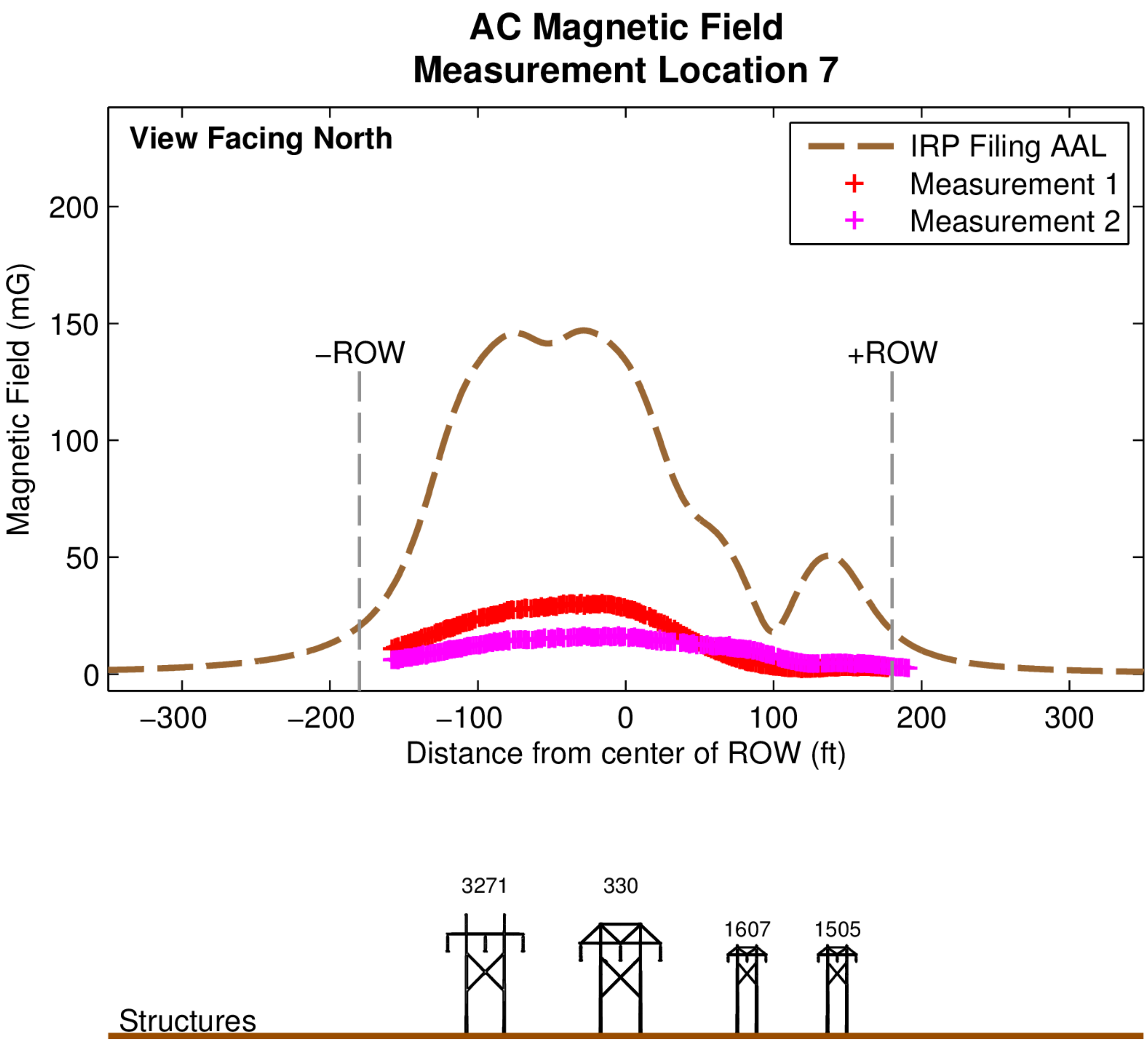



Figure C-13. Measured magnetic-field levels at Site 7 in XS-7.

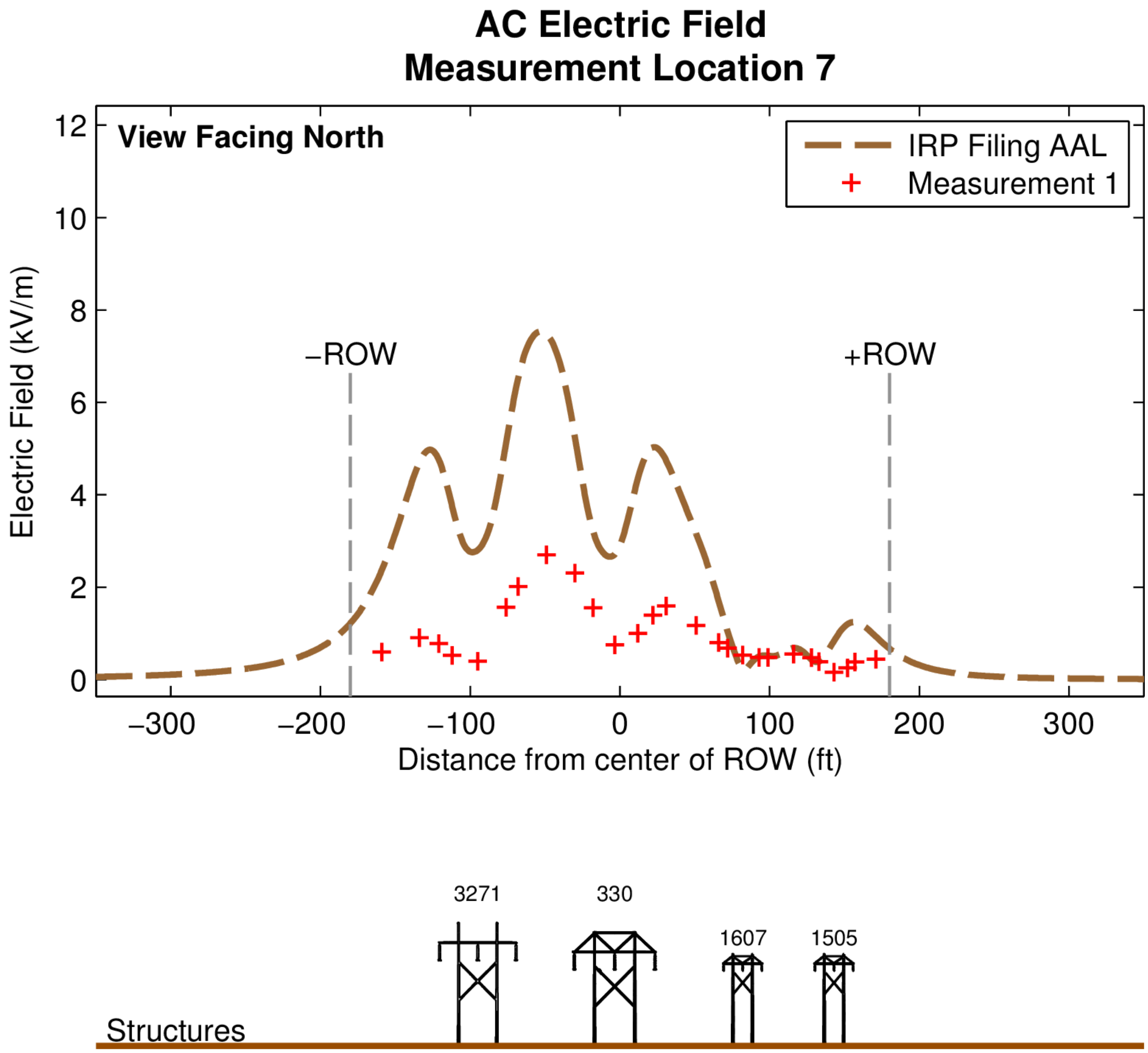



Figure C-14. Measured electric-field levels at Site 7 in XS-7.

## Site 8

Measurements at Site 8 were performed on October 5 and October 11, 2016. A graphical summary of results is presented below along with true-up modeling results.

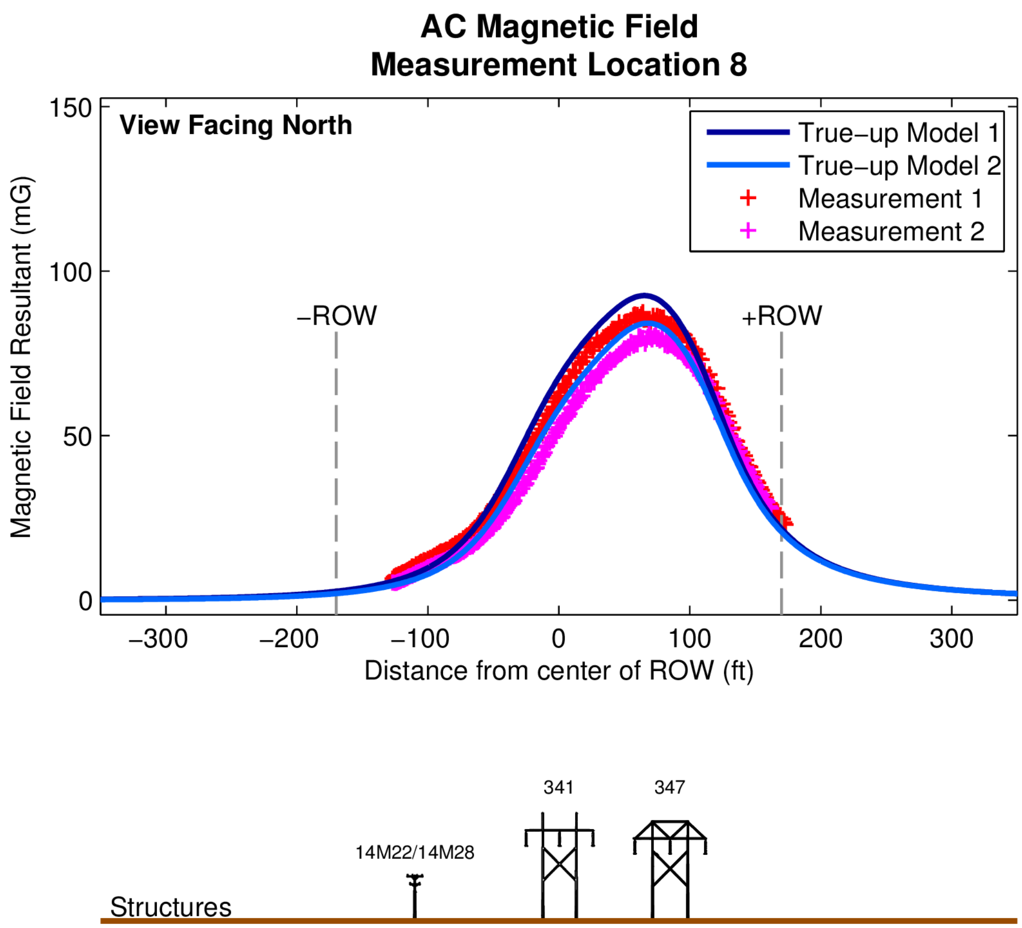



Figure C-15. Measured magnetic-field levels at Site 8 in XS-11.

True-up modeling results are shown in dark blue and teal lines for measurement 1 and 2, respectively.

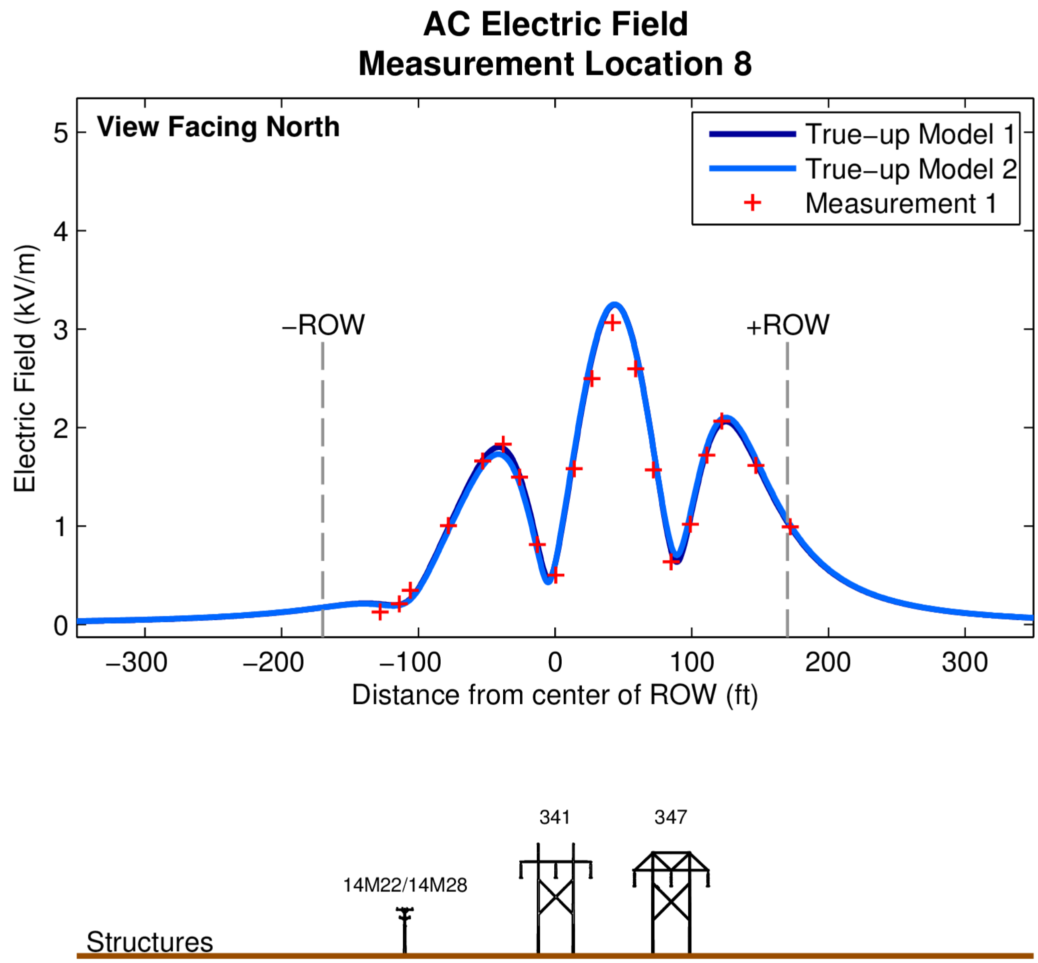



Figure C-16. Measured magnetic-field levels at Site 8 in XS-11.

Electric-field measurements were performed only once as electric-field levels are not expected to vary significantly with changes in loading. In developing a true-up model for the corresponding magnetic-field measurements, however, an electric-field true-up model is also generated and so is included for reference. Note that the difference in the electric-field levels between the two true-up models is so small that it cannot be seen in the figure.

## Site 9

Measurements at Site 9 were performed on October 5 and October 11, 2016. A graphical summary of results is presented below along with true-up modeling results.

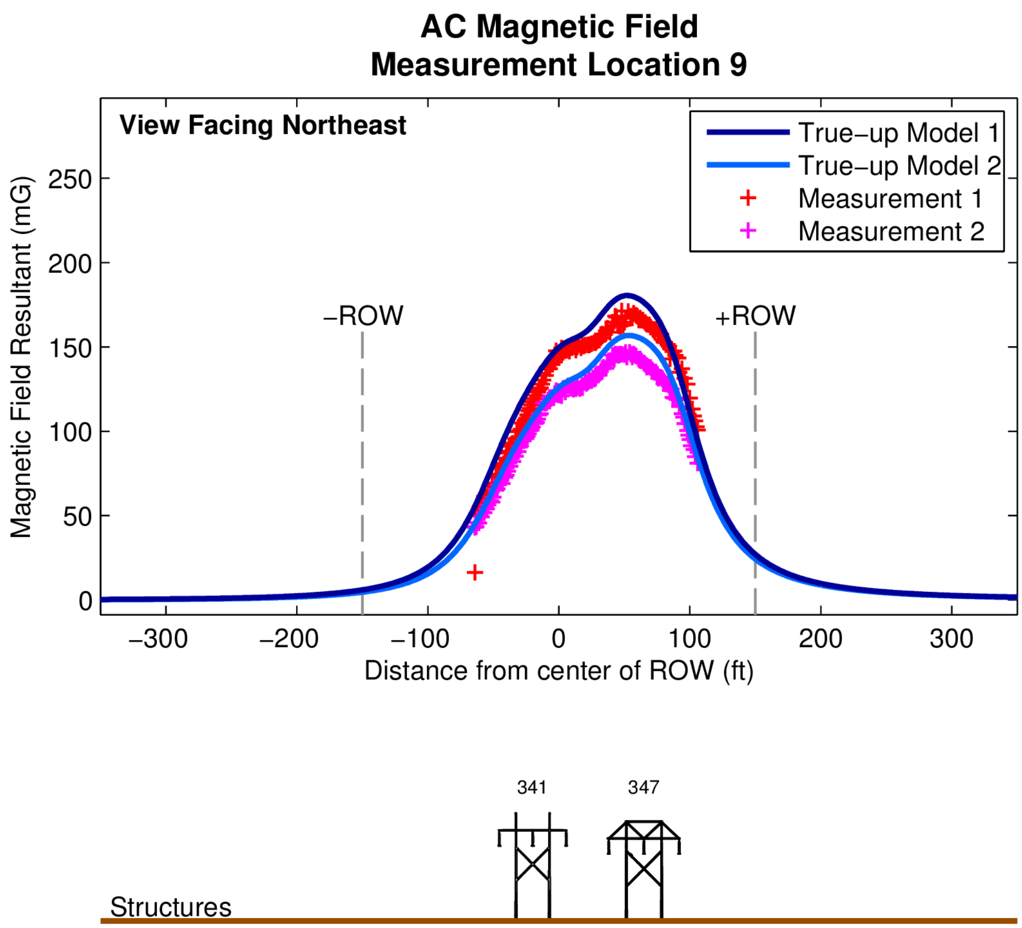



Figure C-17. Measured magnetic-field levels at Site 9 in XS-12.

True-up modeling results are shown in dark blue and teal lines for measurement 1 and 2, respectively.

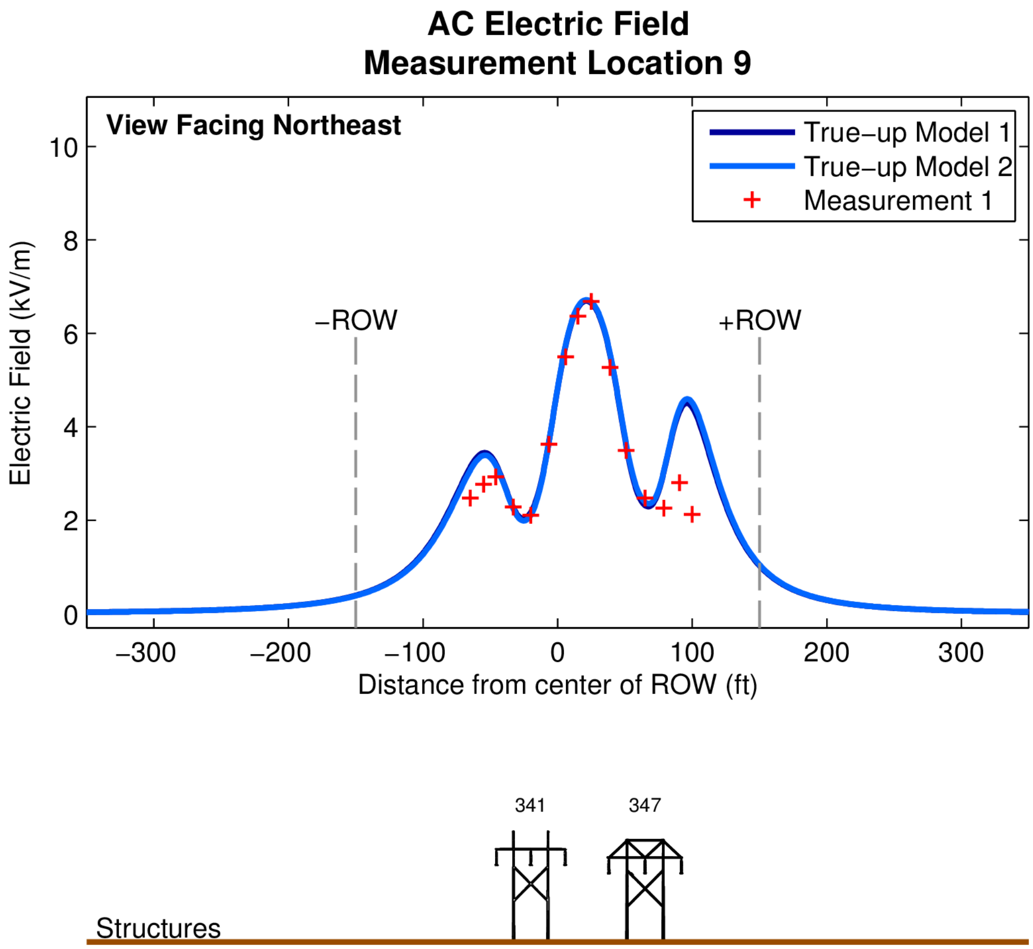



Figure C-18. Measured magnetic-field levels at Site 9 in XS-12.

Electric-field measurements were performed only once as electric-fields levels are not expected to vary significantly with changes in loading. In developing a true-up model for the corresponding magnetic-field measurements, however, an electric-field true-up model is also generated and so is included for reference. Note that the difference in the electric-field levels between the two true-up models is so small that it cannot be seen in the figure.

## Card Street Substation

Measurements at the Card Street Substation were performed on October 4 and November 2, 2016. A graphical summary of results is presented below along with an aerial photograph showing the locations of various landmarks identified in the data.

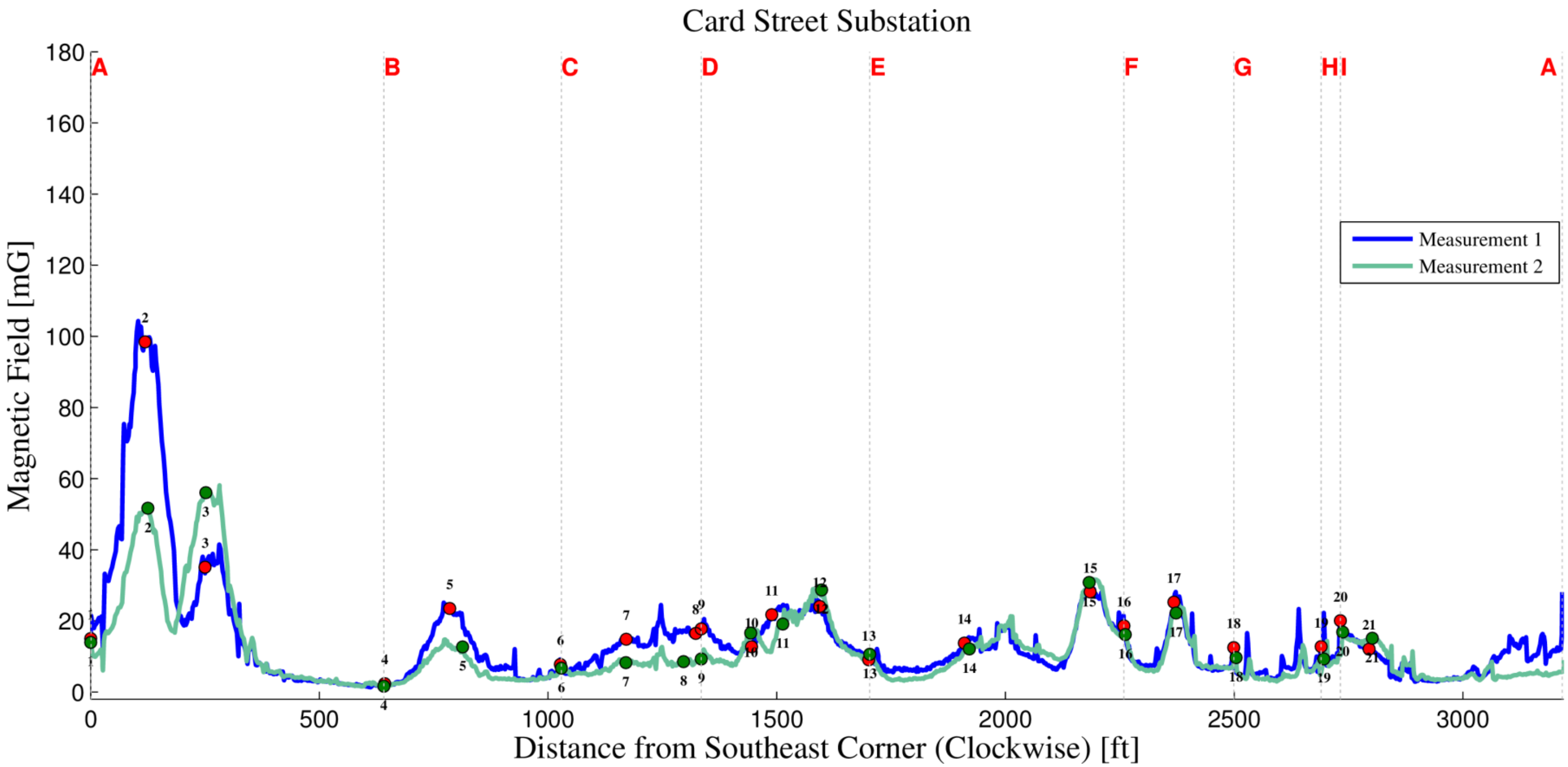



Figure C-19. Magnetic-field levels measured around the perimeter of the Card Street Substation.

Measurements proceeded clockwise from the southeast corner (labeled 'A') of the substation. Alphabetic labels indicate the corners of the substation, Numerical labels 1 to 21 indicate locations where measurements were marked for plotting on Figure C-20 below.

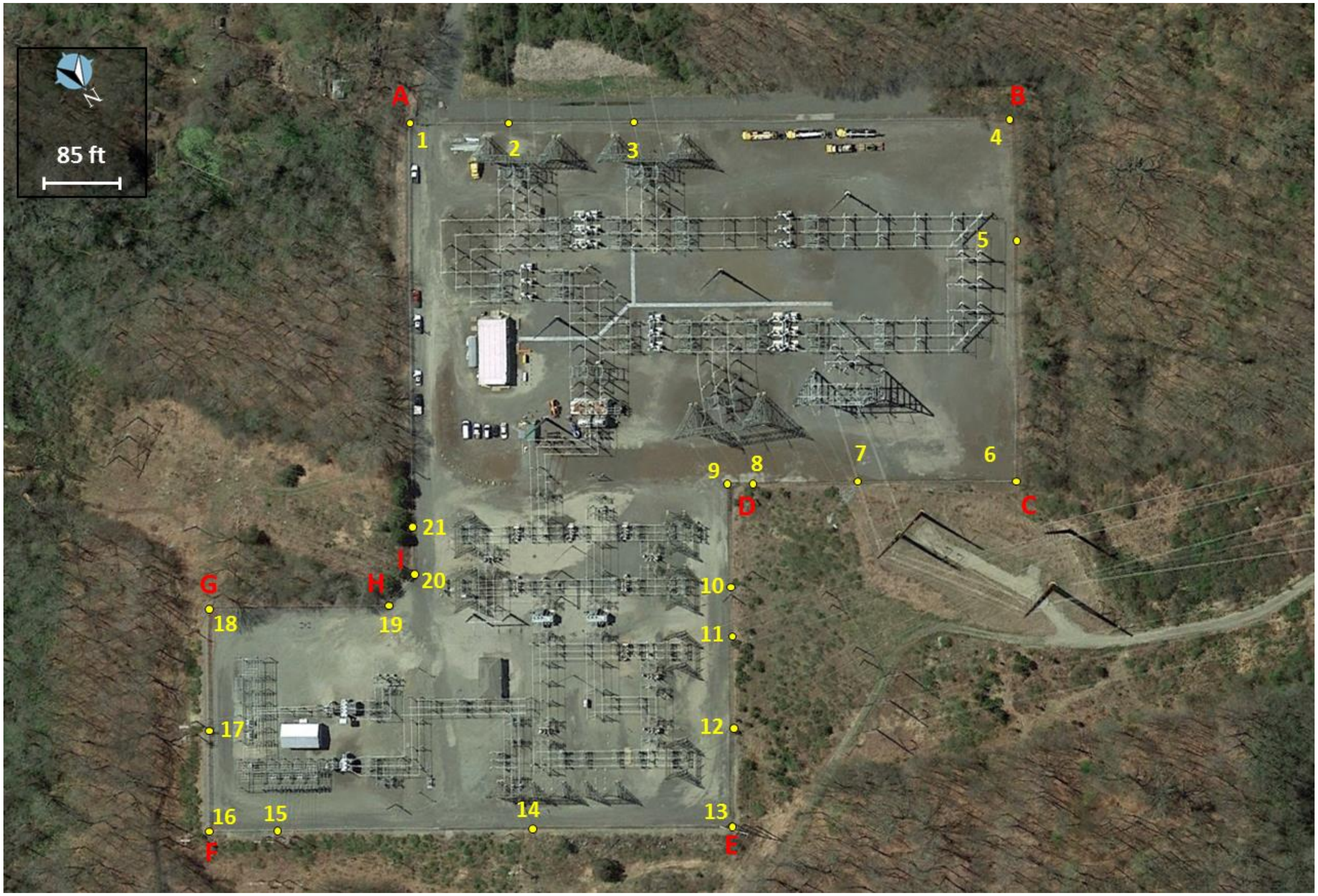



Figure C-20. Aerial photograph of the Card Street Substation showing the location of specific measurement locations marked for comparison to locations shown in Figure C-19.

# Appendix D

## Tables of Transmission Line Loadings, Conductor Heights, and Conductor Types

**Table D-1. Table of conductor size at each measurement site for pre-construction and post-construction cases**

| Measurement Site (Cross Section No.) | | Pre-construction Line No. | Pre-construction Conductor† (kcmil or AWG) | Post-construction Line No. | Post-construction Conductor† (kcmil or AWG) |
|---|---|---|---|---|---|
| 1 (XS-1) | Cards Mill Road | 800 | 1272 | 800 | 1272 |
| | | 900 | 1272 | 900 | 1272 |
| | | 330 | 2-954 | 330 | 2-954 |
| | | — | — | 3271 | 2-1590 |
| 2 (XS-2) | Off East Stafford Road | 330 | 2-954 | 330 | 2-954 |
| | | — | — | 3271 | 2-1590 |
| 3 (XS-2) | South of Bassetts Bridge Road | 330 | 2-954 | 330 | 2-954 |
| | | — | — | 3271 | 2-1590 |
| 4 (HL-1) | Hawthorne Lane | 330 | 2-954 | 330 | 2-1590 |
| | | — | — | 3271 | 2-1590 |
| 5 (XS-6) | West of Windham Road | 330 | 2-954 | 330 | 2-954 |
| | | — | — | 3271 | 2-1590 |
| 6 (XS-6) | East of Church Street | 330 | 2-954 | 330 | 2-954 |
| | | — | — | 3271 | 2-1590 |
| 7 (XS-7) | Hartford Pike | 1505 | 1272 | 1505 | 1272 |
| | | 1607 | 1272 | 1607 | 1272 |
| | | 330 | 2-954 | 330 | 2-954 |
| | | — | — | 3271 | 2-1590 |
| 8 (XS-11) | East of Killingly Avenue | 14M22 | 2/0 Copper | 14M22 | 2/0 Copper |
| | | 14M28 | 2/0 Copper | 14M28 | 2/0 Copper |
| | | 347 | 2-954 | 347 | 2-954 |
| | | — | — | 341 | 2-1590 |
| 9 (XS-12) | Behind Elvira Heights | 347 | 2-954 | 347 | 2-954 |
| | | — | — | 341 | 2-1590 |

† Unless otherwise indicated, conductor type is aluminum conductor steel reinforced.

**Table D-2. Table of recorded transmission line loading and measured minimum conductor heights**

| Measurement Site (Cross Section No.) | | Line No. | Nominal Voltage (kV) | Measurement 1 | | Measurement 2 | | Minimum Conductor Height (ft) | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Loading (Amperes) | Phase Angle (degrees) | Loading (Amperes) | Phase Angle (degrees) | Measurement 1 | Measurement 2 |
| 1 (XS-1) | Cards Mill Road | 800 | 69 | 9.0 | -6.9 | 11.0 | -0.5 | 41.9 | 41.6 |
| | | 900 | 69 | 11.1 | -7.7 | 12.8 | -2.0 | 40.8 | 40.5 |
| | | 330 | 345 | 229.0 | -21.3 | 169.9 | -173.6 | 51.4 | 50.3 |
| | | 3271 | 345 | 238.7 | -20.0 | 176.1 | -172.0 | 57.6 | 57.3 |
| 2 (XS-2) | Off East Stafford Road | 330 | 345 | 277.1 | -18.9 | 193.2 | -174.3 | 42.8 | 43.0 |
| | | 3271 | 345 | 286.5 | -17.5 | 205.7 | -173.0 | 58.6 | 58.8 |
| 3 (XS-2) | South of Bassetts Bridge Road | 330 | 345 | 272.3 | -19.1 | 226.9 | -175.1 | 36.8 | 35.9 |
| | | 3271 | 345 | 282.1 | -17.4 | 236.8 | -173.4 | 41.0 | 39.8 |
| 4 (HL-1) | Hawthorne Lane | 330 | 345 | 230.5 | -21.6 | 174.2 | -171.4 | 51.1 | 51.0 |
| | | 3271 | 345 | 240.0 | -19.9 | 179.3 | -169.6 | 43.4 | 43.2 |
| 5 (XS-6) | West of Windham Road | 330 | 345 | 367.6 | -13.9 | 200.3 | -173.5 | 42.8 | 42.7 |
| | | 3271 | 345 | 381.0 | -12.5 | 212.2 | -172.2 | 46.7 | 46.0 |
| 6 (XS-6) | East of Church Street | 330 | 345 | 341.9 | -14.2 | 216.4 | -175.0 | 52.2 | 54.9 |
| | | 3271 | 345 | 357.2 | -12.7 | 228.6 | -173.6 | 56.3 | 59.3 |
| 7 (XS-7) | Hartford Pike | 1505 | 115 | 25.3 | 68.0 | 42.6 | -6.8 | 41.5 | 41.6 |
| | | 1607 | 115 | 0.1 | 45.0 | 83.4 | -22.2 | 42.6 | 42.8 |
| | | 330 | 345 | 331.4 | -14.8 | 164.2 | -166.6 | 51.2 | 51.2 |
| | | 3271 | 345 | 343.6 | -13.4 | 173.3 | -165.3 | 63.1 | 62.5 |

| Measurement Site (Cross Section No.) | | Line No. | Nominal Voltage (kV) | Measurement 1 | | Measurement 2 | | Minimum Conductor Height (ft) | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Loading (Amperes) | Phase Angle (degrees) | Loading (Amperes) | Phase Angle (degrees) | Measurement 1 | Measurement 2 |
| 8 (XS-11) | East of Killingly Avenue | 14M22 | 23 | Unavailable | Unavailable | Unavailable | Unavailable | 28.9 | 29.4 |
| | | 14M28 | 23 | Unavailable | Unavailable | Unavailable | Unavailable | 28.9 | 29.4 |
| | | 347 | 345 | 847.9 | 0.0 | 773.8 | -0.1 | 53.2 | 52.8 |
| | | 341 | 345 | 635.6 | -1.3 | 543.5 | -2.1 | 57.2 | 57.3 |
| 9 (XS-12) | Behind Elvira Heights | 347 | 345 | 857.8 | -0.9 | 744.8 | -1.3 | 34.1 | 33.8 |
| | | 341 | 345 | 636.3 | -1.8 | 527.7 | -2.4 | 35.3 | 35.2 |

# Appendix E

## 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*

# 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 LITE

Frequency: 60 Hertz

Serial Number: 104950

Date of Calibration: 12/17/2015

Re-Calibration suggested at one year from above date.

Scientific Research & Consulting Services
etc.
Established 1982
ENERTECH Consultants

ENERTECH Consultants
494 Salmar Avenue, Suite 200
Campbell, California 95008
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H. Christopher Hooper
*Calibration Inspector*

suparule

# Calibration Certificate

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| | |
|---|---|
| ***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.

ISO 9001:2008 EQA ✓ QUALITY ASSURED COMPANY

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

Kestrel®
Weather & Environmental Meters
by NK

# Certificate of Conformity

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

## Methods Used in Calibration and Testing

### Wind Speed:

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

### Temperature:

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

### Direction / Heading

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

### Relative Humidity:

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

### Barometric Pressure:

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

**Approved By:**

Michael Naughton, Engineering Manager

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