Electric and Magnetic Field (EMF) Modeling Analysis for the West Roxbury to Needham Reliability Project

Prepared for

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1 Introduction and Summary

Eversource Energy (Eversource) has proposed to construct a new combination overhead/underground 115-kilovolt (kV) transmission line between the Baker Street Substation located on Baker Street in the West Roxbury section of Boston and the Needham Substation located on Chestnut Street in Needham. This project is known as the West Roxbury to Needham Reliability Project. As shown in the attached Candidate Route Map (Appendix A), the new overhead line segment of approximately 1.57 miles is to be installed on Eversource's existing right-of-way (ROW) #3 that runs in an east-west direction between the Baker Street Substation and the Valley Road area in Needham adjacent to the Massachusetts Bay Transportation Authority ("MBTA") Needham Line commuter rail corridor (Epsilon, 2015). For this overhead segment, one of the two existing 115-kV circuits (for overhead line segments east of Gardner Street in West Roxbury, the 240-510 circuit, and for overhead line segments west of Gardner Street in West Roxbury, the 110-522 circuit) will be moved to a new set of steel monopoles, with the other circuit remaining in service on the existing double-circuit towers. In the vicinity of the Valley Road cul-de-sac, the 110-522 115-kV line will be transitioned to a new underground 115-kV transmission line that is expected to be installed predominantly in public or private roads between Valley Road and the Needham Substation, with the other 240-510 115-kV line remaining in service on the existing double-circuit towers between Valley Road and the Needham Substation.

Epsilon Associates, Inc. (Epsilon) requested that Gradient perform an independent assessment of the electric and magnetic field (EMF) impacts associated with the West Roxbury to Needham Reliability Project. For this assessment, EMF impacts were modeled for several representative overhead and underground line cross-sections using projected non-emergency summer peak and average transmission line loadings provided by Eversource for the year 2018, which is the expected in-service date for the project (Leonard, 2016).

As described in this report, modeled EMF values both within and at the edges of ROW #3 for each of the overhead line cross-sections representative of the post-project circuit configurations and 2018 load conditions (referred to in the report as "With-Project" EMF results; these modeled results are compared to modeled results for present-day circuit configurations and 2018 load conditions, which are referred to in the report as "Without-Project" EMF results) were all well below the health-based guidelines issued by the International Commission on Non-Ionizing Radiation Protection (ICNIRP) for continuous public exposure to EMFs (4.2 kilovolts per meter [kV/m] and 2,000 milligauss [mG]; ICNIRP, 2010). Importantly, for each of the three representative overhead line cross-sections evaluated in the EMF assessment (East of Gardner Street, West of Gardner Street/East of Valley Road cul-de-sac, West of Valley Road cul-de-sac), the modeled results showed that With-Project within-ROW maximum EMF values were all less than the corresponding Without-Project within-ROW maximum values. For example, for the non-emergency summer peak 2018 load level modeling scenario, the With-Project within-ROW maximum magnetic field values ranged from 37.4-53.1 mG for the three overhead line cross-sections, as compared to the Without-Project within-ROW maximum magnetic field value of 67.8 mG. For electric fields, the With-Project within-ROW maximum electric field values ranged from 1.58-2.23 kV/m for the three overhead line cross-sections, as compared to the Without-Project within-ROW maximum electric field value of 2.63 kV/m. These lower With-Project within-ROW maximum EMF values are primarily due to the greater separation between the two circuits that will result from their placement on two different poles for the project, as compared to the present-day circuit configuration in which the two circuits are located on a single pole.

As shown in Table 1.1, the modeling also demonstrated that EMF values at the ROW #3 edges were frequently reduced for the With-Project circuit configurations, as compared to the Without-Project circuit configurations for the modeling of 2018 loading conditions. This is particularly the case for the West of Valley Road cul-de-sac overhead line segment that is the only overhead line segment in which the ROW sometimes passes close to residential neighborhoods in the Town of Needham. For the non-emergency summer peak 2018 load level modeling scenario, modeled Without-Project magnetic field values ranged from 6.3-64.5 mG at the southern edge of ROW #3 and 2.8-18.7 mG at the northern edge of ROW #3, as compared to modeled With-Project magnetic field values that ranged from 2.7-29.3 mG and 1.4-10.6 mG at the southern and northern edges of the ROW, respectively.[1] Similarly, the EMF modeling for the West of Valley Road cul-de-sac overhead line cross-section yielded modeled Without-Project electric field values ranging from 0.03-2.29 kV/m at the southern edge of ROW #3 and 0.05-0.11 kV/m at the northern edge of ROW #3, as compared to modeled With-Project magnetic field values ranging from 0.05-0.95 kV/m and 0.03-0.07 kV/m at the southern and northern edges of the ROW, respectively. These reductions in modeled EMF values at the edges of ROW #3 for this overhead line segment are primarily due to the removal of the overhead 110-522 line from service in the ROW from the Valley Road cul-de-sac to the Needham Substation.

Table 1.1 Modeled Edge-of-ROW Magnetic Field Values for Each Overhead Cross-section and Load Scenario

Load Scenario	Cross Section/Route Segment	Southern Edge-of-ROW Magnetic Field (mG)[1]		Northern Edge-of-ROW Magnetic Field (mG)[1]	
		Without-Project	With-Project	Without-Project	With-Project
Non-emergency summer peak 2018 load level	East of Gardner St.	8.6-9.5	8.4-9.2	5.2-35.1	6.1-42.5
	West of Gardner St./ East of Valley Road cul-de-sac	8.2-23.9	10.3-31.9	3.7-8.8	3.6-8.3
	West of Valley Road cul-de-sac	6.3-64.5	2.7-29.3	2.8-18.7	1.4-10.6
Average 2018 load level	East of Gardner St.	4.0-4.4	3.9-4.3	2.4-16.3	2.9-19.8
	West of Gardner St./ East of Valley Road cul-de-sac	3.8-11.1	4.8-14.8	1.7-4.1	1.7-3.9
	West of Valley Road cul-de-sac	2.9-29.9	1.3-13.6	1.3-8.7	0.7-4.9

Notes:
mG = Milligauss; ROW = Right-of-Way.
(1) Ranges are provided to reflect the range in the locations of the southern and northern ROW edges for the different route segments.

For the proposed underground 115-kV line segments, modeled magnetic field levels immediately above the underground cables (at a height of 3 feet [~1 m] above ground) are well below the ICNIRP health-based guideline of 2,000 mG for public exposure to magnetic fields (Table 1.2). At the non-emergency summer peak 2018 loading, the With-Project maximum magnetic field value generated by the proposed underground line in the standard inverted-delta (∇) configuration was 71 mG, falling to 7.8 mG at a horizontal distance of ±20 feet away from the centerline of the conductors. At peak load, in the vicinity of manhole/splice vault sections, the With-Project maximum magnetic field value was 98.6 mG, falling to 20 mG at a horizontal distance of ±20 feet away from the centerline of the conductors. At annual average load, the maximum modeled magnetic field value for the majority of the line length (for the ∇

[1] Note that we reported ranges for edge-of-ROW EMFs that correspond to maximum and minimum locations of the northern and southern edges of ROW #3 provided by Epsilon Associates, Inc. for three overhead line sections based on an existing conditions survey plan prepared by VHB Associates, Inc., titled "NSTAR ROW #3, Needham, Dedham, Boston, MA," dated January 22, 2015/rev. February 10, 2015.

configuration) was 33 mG, falling to 3.6 mG at ±20 feet; for the vertical conductor configuration in the splice vaults, the corresponding maximum modeled magnetic field was 46 mG, falling to 9 mG at ± 20 feet from the centerline of the conductors. In all cases, field values decrease rapidly with lateral distance from the lines. Underground lines produce no above-ground electric fields, so these new 115-kV conductors will not produce any above-ground electric fields.

Table 1.2 Modeled Magnetic Fields Three Feet Above Ground Surface for With-Project Underground Line 110-522 Segments

Line Section	Load Scenario	Maximum Magnetic Field (mG), Directly Above Line	Magnetic Field (mG), 20 ft to Either Side of Centerline
Typical Inverted-Delta (∇) Line Sections	Average 2018 load level	32.8	3.6
	Non-emergency summer peak 2018 load level	70.9	7.8
Splice Vault Sections	Average 2018 load level	45.6	9.4
	Non-emergency summer peak 2018 load level	98.6	20.3

Note:
mG = Milligauss.

Section 2 of this report describes the nature of EMFs, provides values for EMF levels from common sources, and reports on available EMF exposure guidelines. Section 3 outlines the EMF modeling procedures for calculating EMF strengths as a function of lateral distance from an electric transmission (or distribution line) and provides graphical and tabular results for the modeled cross-sections. Section 4 summarizes the conclusions, and the Reference list provides the references cited in this report.

2 Nature of Electric and Magnetic Fields

All matter contains electrically charged particles. Most objects are electrically neutral because positive and negative charges are present in equal numbers. When the balance of electric charges is altered, we experience electrical effects, such as the static electricity attraction between a comb and our hair or drawing sparks after walking on a synthetic rug in the wintertime. Electrical effects occur both in nature and through our society's use of electric power (generation, transmission, consumption).

2.1 Units for EMFs Are Kilovolts Per Meter (kV/m) and Milligauss (mG)

The electrical tension on utility power lines is expressed in volts or kilovolts (1 kV = 1,000 V). Voltage is the "pressure" of the electricity and can be envisioned as analogous to the pressure of water in a plumbing system. The existence of a voltage difference between power lines and ground results in an "electric field," usually expressed in units of kilovolts per meter (kV/m). The size of the electric field depends on the voltage, the separation between lines and ground, and other factors.

Power lines also carry an electric current that creates a "magnetic field." The units for electric current are amperes (A) and are a measure of the "flow" of electricity. Electric current can be envisioned as analogous to the flow of water in a plumbing system. The magnetic field produced by an electric current is usually expressed in units of gauss (G) or milligauss (mG) (1 G = 1,000 mG). Another unit for magnetic field levels is the microtesla (μT) (1 μT = 10 mG). The size of the magnetic field depends on the electric current, the distance to the current-carrying conductor, and other factors.

2.2 There Are Many Natural and Man-made Sources of EMFs

Everyone experiences a variety of natural and man-made EMFs. EMF levels can be slowly varying or steady (often called "direct current" or "DC fields"), or can vary in time (often called "alternating current" or "AC fields"). When the time variation of interest corresponds to that of power line currents (*i.e.*, 60 cycles per second), the fields are called "60-hertz (Hz)" EMF. Man-made magnetic fields are common in everyday life. For example, many childhood toys contain magnets. Such permanent magnets generate strong, steady (DC) magnetic fields. Typical toy magnets (*e.g.*, "refrigerator door" magnets) have fields of 100,000-500,000 mG. On a larger scale, Earth's core also creates a steady DC magnetic field that can be easily demonstrated with a compass needle. The size of Earth's magnetic field in the northern US is about 550 mG (over 100 times smaller than fields generated by "refrigerator door" magnets).

2.3 Power-frequency EMFs Are Found Near Electric Lines and Appliances

Electric power transmission lines, distribution lines, and electric wiring in buildings carry AC currents and voltages that change size and direction at a frequency of 60 Hz. These 60-Hz currents and voltages create 60-Hz EMFs nearby. The size of the magnetic field is proportional to the line current, and the size of the electric field is proportional to the line voltage. The EMF associated with electrical wires and electrical equipment decrease rapidly with increasing distance away from the electrical wires.

When EMF derives from different wires that are in close proximity, or adjacent to one another, the size of the net EMF produced will be somewhere in the range between the sum of EMF from the individual sources and the difference of the EMF from the individual sources. EMF may partially add, or partially cancel, but generally, because adjacent wires are often carrying current in opposite directions, the EMF produced tends not to be additive.

EMFs in the home arise from electric appliances, indoor wiring, grounding currents on pipes and ground wires, and outdoor distribution or transmission circuits. Inside residences, typical baseline 60-Hz magnetic fields (away from appliances) range from 0.5-5.0 mG.

Higher 60-Hz magnetic field levels are found near operating appliances. For example, can openers, mixers, blenders, refrigerators, fluorescent lamps, electric ranges, clothes washers, toasters, portable heaters, vacuum cleaners, electric tools, and many other appliances generate magnetic fields of size 40-300 mG at distances of 1 foot (NIEHS, 2002). Magnetic fields from personal care appliances held within half a foot (*e.g.*, shavers, hair dryers, massagers) can produce average fields of 600-700 mG. At school and in the workplace, lights, motors, copy machines, vending machines, video-display terminals, pencil sharpeners, electric tools, electric heaters, and building wiring are all sources of 60-Hz magnetic fields.

2.4 State, National, and International Guidelines for EMFs Are Available

The US has no federal standards limiting occupational or residential exposure to 60-Hz EMF. Table 2.1 shows guidelines suggested by national and world health organizations that are designed to be protective against any adverse health effects. The limit values should not be viewed as demarcation lines between safe and dangerous levels of EMFs, but rather, levels that assure safety with an adequate margin of safety to allow for uncertainties in the science. Table 2.2 lists guidelines that have been adopted by various states in the US. State guidelines are not health-effect based and have typically been adopted to maintain the *status quo* for EMFs on and near transmission line ROWs.

Table 2.1 60-Hz EMF Guidelines Established by Health and Safety Organizations

Organization	Magnetic Field	Electric Field
American Conference of Governmental and Industrial Hygienists (ACGIH) (occupational)	10,000 mG[1] 1,000 mG[2]	25 kV/m[1] 1 kV/m[2]
International Commission on Non-Ionizing Radiation Protection (ICNIRP) (general public, continuous exposure)	**2,000 mG**	**4.2 kV/m**
Non-Ionizing Radiation (NIR) Committee of the American Industrial Hygiene Assoc. (AIHA) endorsed (in 2003) ICNIRP's occupational EMF levels for workers	4,170 mG	8.3 kV/m
Institute of Electrical and Electronics Engineers (IEEE) Standard C95.6 (general public, continuous exposure)	9,040 mG	5.0 kV/m
UK, National Radiological Protection Board (NRPB) (now the Health Protection Agency [HPA])	2,000 mG	4.2 kV/m
Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) (Draft Standard, December 2006[3])	3,000 mG	4.2 kV/m

Notes:
EMF = Electric and Magnetic Field; kV/m = Kilovolts Per Meter; mG = Milligauss; ROW = Right-of-Way.
(1) The ACGIH guidelines for the general worker (ACGIH, 2015, p. 128-131).
(2) The ACGIH guideline for workers with cardiac pacemakers (ACGIH, 2015, p. 128-131).
(3) ARPANSA (2006, 2008).

Table 2.2 State EMF Standards and Guidelines for Transmission Lines

State	Line Voltage (kV)	Electric Field (kV/m)		Magnetic Field (mG)	
		On ROW	Edge ROW	On ROW	Edge ROW
Florida[1]	69-230	8.0	2.0[2]		150
	500	10.0			200, 250[3]
Massachusetts			**1.8**		**85**
Minnesota		8.0			
Montana		7.0[4]	1.0[5]		
New Jersey			3.0		
New York[3]		11.8 11.0[6] 7.0[4]	1.6		200
Oregon		9.0			

Notes:
EMF = Electric and Magnetic Field; kV/m = Kilovolts Per Meter; mG = Milligauss; ROW = Right-of-Way.
Sources: NIEHS (2002); FLDEP (2008); MAEFSB (2010).
(1) Magnetic fields for winter-normal (*i.e.*, at maximum current-carrying capability of the conductors).
(2) Includes the property boundary of a substation.
(3) 500-kV double-circuit lines built on existing ROWs.
(4) Maximum for highway crossings.
(5) May be waived by the landowner.
(6) Maximum for private road crossings.

3 EMF Modeling

3.1 Software Program Used for Modeling EMFs for Line Cross-sections

The FIELDS computer program, designed by Southern California Edison, was utilized to calculate EMF strengths from the proposed lines. This program operates using Maxwell's equations, which accurately apply the laws of physics as related to electricity and magnetism (EPRI, 1982, 1993). Modeled fields using this program are both precise and accurate for the input data utilized. Results of the model have been checked extensively against each other and against other software (*e.g.*, CORONA, from the Bonneville Power Administration, US Dept. of Energy) to ensure that the implementation of the laws of physics are consistent. In these validation tests, program results for EMFs were found to be in very good agreement with each other (Mamishev and Russell, 1995).

3.2 Power-line Loads

Magnetic fields produced by the proposed lines were modeled using line loadings communicated by Eversource (Leonard, 2016). The current per phase satisfies the relationship:

(Eq. 3.1)
$$S = \sqrt{3} \times V \times I_{phase}$$

where:

S	=	The power in kilovolt-amps (kVA)
V	=	The line voltage in kilovolts (kV)
I_{phase}	=	The current per phase in amperes (A)

Thus, the current per phase conductor is:

(Eq. 3.2)
$$I_{phase} = \frac{S}{\sqrt{3} \times V}$$

Real power is given in megawatts (MW) (P), and apparent power in megavolt-amps (MVA) (S).[2] To convert between power quoted in MW to MVA, one must divide by the power factor.

Both Without-Project and With-Project transmission line electric current and voltage values provided by Eversource are summarized in Table 3.1 for the two circuits by load scenario (Leonard, 2016).

[2] MVA is apparent power and is the vector sum of real (active) and imaginary (reactive) power. MW and MVA are not the same unless power factor = 1.0, which, in a practical AC circuit, is generally not the case.

Table 3.1 Modeled Without-Project and With-Project Electric Current (A) and Voltages (kV) by Load Scenario for West Roxbury to Needham 115-kV Transmission Lines

Load Scenario	110-522 (115-kV)				240-510 (115-kV)			
	Electric Current (A)		Electric Voltage (kV)		Electric Current (A)		Electric Voltage (kV)	
	Without-Project	With-Project	Without-Project	With-Project	Without-Project	With-Project	Without-Project	With-Project
Average 2018 load level	199	212	118.9	119	200	192	118.9	119
Non-emergency summer peak 2018 load level	432	458	118.0	118.1	428	412	118.0	118.1

Notes:
A = Amperes; kV = Kilovolt.
(1) Direction of current flow is from Needham Tap to Baker Street Substation for both lines and load scenarios.

3.3 EMF Modeling for the Without-Project and With-Project Circuits

For the existing overhead 110-522 and 240-510 115-kV circuit configuration in ROW #3, Gradient modeled electric and magnetic fields expected to exist 3 feet (~1 meter) above the ground surface for a single representative cross-section with the conductor configurations and phasings depicted in Appendix B and under the 2018 projected loading scenarios described above. Although there is some variation in the location depicted for the ground wire on the existing double-circuit towers (*e.g.*, northern side of tower, southern side of tower, middle of tower – *i.e.*, dead end on pole), the model assumed that it is located in the middle, at the highest point of the support tower for the EMF modeling.

EMF modeling was also conducted for three cross-sections selected to represent different overhead line segments corresponding to possible With-Project transmission line configurations:

1. East of Gardner Street Cross-section, which represents the segment where Line 110-522 remains in service on the existing double-circuit towers, and Line 240-510 is moved to a newly constructed set of steel monopoles (see Proposed Construction – East of Gardner Street figure in Appendix B);
2. West of Gardner Street/East of Valley Road cul-de-sac Cross-section, which represents the segment where Line 240-510 remains in service on the existing double-circuit towers, and Line 110-522 is moved to a newly constructed set of steel monopoles (see Proposed Construction – West of Gardner Street figure in Appendix B); and
3. West of Valley Road cul-de-sac Cross-section, which represents the segment where Line 110-522 has been taken out of service due to the new underground routing for this circuit that begins at this location, and only Line 240-510 remains in service on the existing double-circuit towers (with the same conductor configuration and phasings as per the Proposed Construction – West of Gardner Street figure in Appendix B).

For each Without-Project and With-Project cross-section, a cross-sectional view of EMF strengths was modeled as a function of distance perpendicular to the direction of current flow along a segment of the route where the transmission line runs straight. Variation in the height of the nearby grade along ROW #3 was not accounted for given the general Eversource policy to model EMF for the most conservative location of lowest conductor sag (*i.e.*, closest to the ground surface); for 115-kV transmission lines, this corresponds to 30 feet above the ground for the lowest conductors (Bodkin, 2015). Given variability in the location of the ROW edges for the overhead line segments, EMF levels were modeled out to 200 feet on either side of the existing double-circuit tower. Ranges for edge-of-ROW EMFs correspond to maximum and minimum locations of the northern and southern edges of ROW #3 that were based on an existing conditions survey plan prepared by VHB Associates, Inc.

EMF modeling of the proposed underground 115-kV circuit included calculation of magnetic fields levels expected to exist 3 feet (~1 meter) above the ground surface per standard industry practices (IEEE Power Engineering Society, 1995a,b) for the loading scenarios described above. Eversource provided Gradient with proposed conductor configuration schematics as well as circuit specifications (select drawings are included as Appendix C to this report). The 115-kV transmission line conductors are within three 8-inch diameter ducts depicted below in Figure 3.1, which shows them in an inverted-delta (∇) arrangement (note that the fourth duct shown in Figure 3.1 is a spare duct). The vertical and horizontal spacing between the centerline of the conductors is 14 inches (additional details are shown in Appendix C).

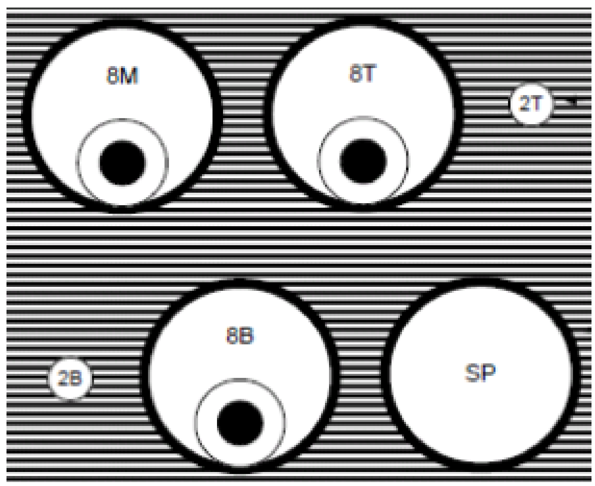


Figure 3.1 The Inverted-Delta Configuration of the Underground, 115-kV Conductors, Inside 7.27" ID, HDPE Pipes Having 0.639" Walls

The configuration of the conductors while passing through a splice vault is shown in Figure 3.2. This figure, which was taken from the detailed schematic in Appendix C, shows the conductors arranged vertically above each other, with a separation of 2 feet.

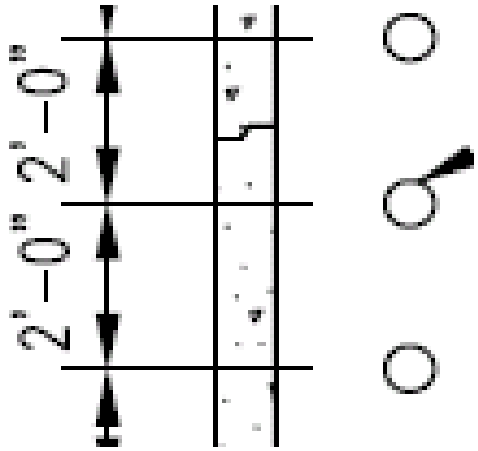


Figure 3.2 Vertical Configuration of the Individual Phase Conductors (Circles on the Right) During Their Travel Through the Splice Vault/ Manhole Section

3.4 EMF Modeling Results

3.4.1 Magnetic Field Modeling Results for Overhead Line Cross-sections

Detailed results of the magnetic field modeling for the Without-Project and With-Project overhead transmission line cross-sections are summarized in Table 3.2 and Figures 3.3-3.5. As reflected in this table and the figures, With-Project magnetic field values for the overhead transmission line cross-sections all fall below the health-based guideline of the ICNIRP for continuous public exposure to magnetic fields (2,000 mG; ICNIRP, 2010), both at the ROW edges and within ROW #3. Moreover, both the table and figures show that With-Project within-ROW maximum magnetic field values are less than the corresponding Without-Project within-ROW maximum value for each of the three cross-sections. Specifically, for the non-emergency summer peak 2018 load level modeling scenario, the With-Project within-ROW maximum magnetic field values ranged from 37.4-53.1 mG for the three overhead line cross-sections, as compared to the Without-Project within-ROW maximum magnetic field value of 67.8 mG. Similarly, for the average 2018 load level modeling scenario, the With-Project within-ROW maximum magnetic field values ranged from 17.4-24.6 mG for the three overhead line cross-sections and were thus less than the Without-Project within-ROW maximum magnetic field value of 31.5 mG.

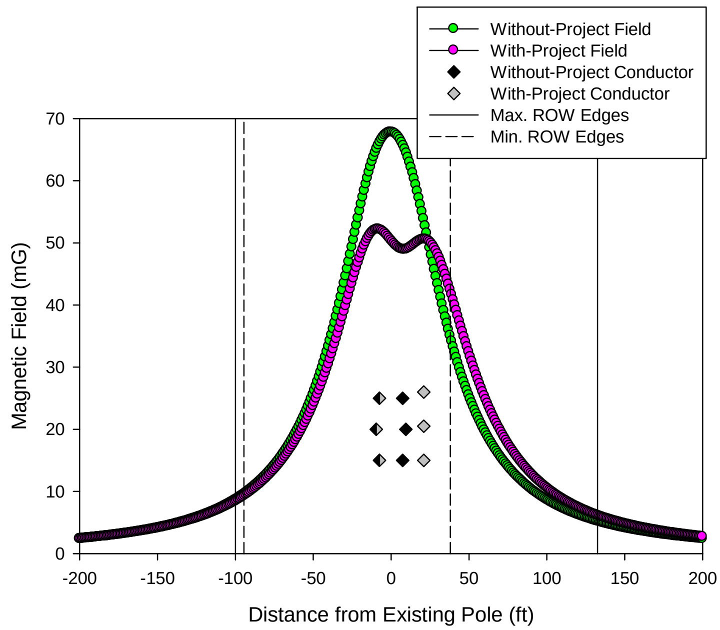
Figures 3.3-3.5 show the ranges in the locations of the southern and northern ROW #3 edges for the three overhead line cross-sections. With-Project magnetic field values are frequently reduced as compared to Without-Project values at the edges of the ROW, with only slightly increased With-Project magnetic field values along the southern ROW edge for just one of the three overhead line segments (the West of Gardner Street/East of Valley Road cul-de-sac line segment due to the installation of the new steel monopoles with the relocated Line 110-522 circuit to the south of the existing towers in this segment) and along the northern ROW edges for just one of the three overhead line segments (the East of Gardner Street line segment due to the installation of the new steel monopoles with the relocated Line 240-510 circuit to the north of the existing towers in this segment). In all other instances, With-Project magnetic field values are reduced at the ROW edges as compared to Without-Project magnetic field values.

Table 3.2 Modeled Peak Edge-of-ROW and Within-ROW Magnetic Field Values for Each Overhead Cross-section and Load Scenario

Load Scenario	Cross Section/ Route Segment	Southern Edge-of-ROW Magnetic Field (mG)[1]		Northern Edge-of-ROW Magnetic Field (mG)[1]		Within-ROW Maximum Magnetic Field (mG)	
		Without-Project	With-Project	Without-Project	With-Project	Without-Project	With-Project
Non-emergency summer peak 2018 load level	East of Gardner St.	8.6-9.5	8.4-9.2	5.2-35.1	6.1-42.5	67.8	52.2
	West of Gardner St./ East of Valley Road cul-de-sac	8.2-23.9	10.3-31.9	3.7-8.8	3.6-8.3	67.8	53.1
	West of Valley Road cul-de-sac	6.3-64.5	2.7-29.3	2.8-18.7	1.4-10.6	67.8	37.4
Average 2018 load level	East of Gardner St.	4.0-4.4	3.9-4.3	2.4-16.3	2.9-19.8	31.5	24.2
	West of Gardner St./ East of Valley Road cul-de-sac	3.8-11.1	4.8-14.8	1.7-4.1	1.7-3.9	31.5	24.6
	West of Valley Road cul-de-sac	2.9-29.9	1.3-13.6	1.3-8.7	0.7-4.9	31.5	17.4

Notes:
mG = Milligauss; ROW = Right-of-Way.
(1) Ranges are provided to reflect the range in the locations of the southern and northern ROW edges for the different route segments.

(a)



(b)

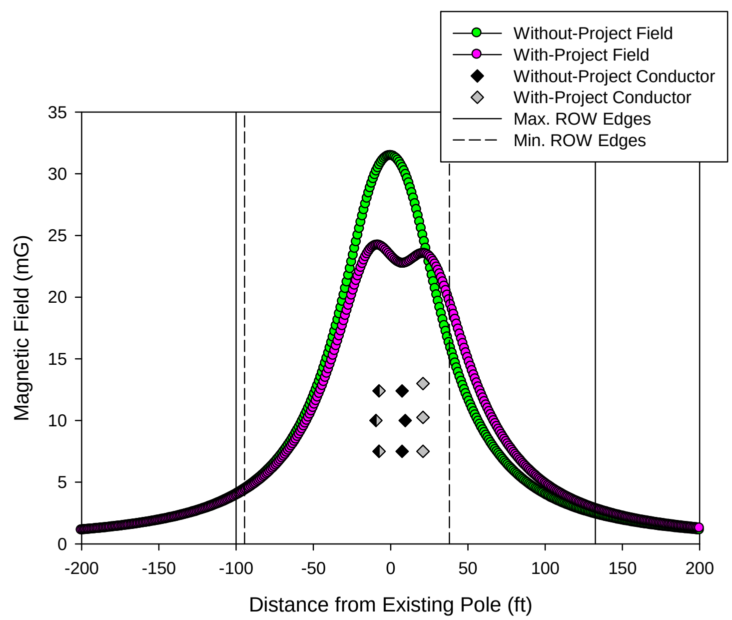
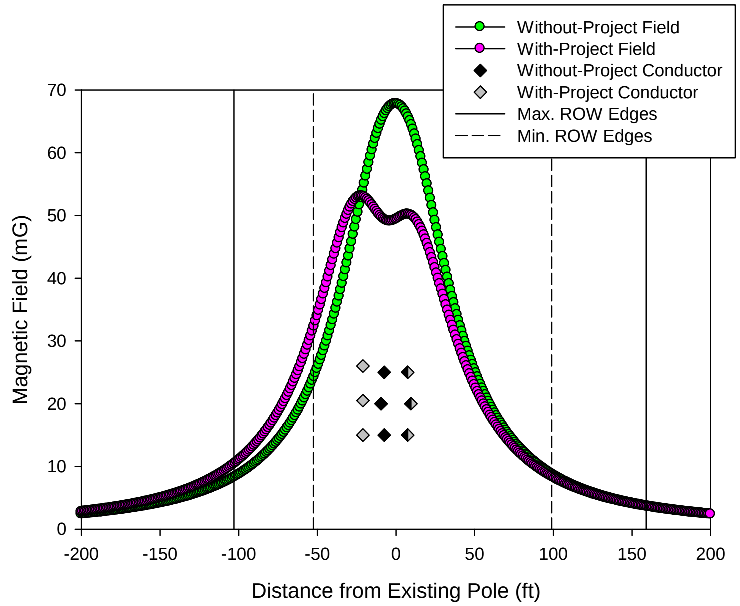


Figure 3.3 East of Gardner Street ROW Cross-section Magnetic Field Values at Projected Non-emergency Summer Peak 2018 Load Level (Panel a) and Average 2018 Load Level (Panel b). The view is to the west towards the Needham Substation, with the cross-section being shown perpendicular to the directions of electric current. The Transmission Line 110-522 conductors are shown on the far left (black and gray diamonds), and the relocated Transmission Line 240-510 conductors are shown on the far right (gray diamonds). The centerline of the existing ROW #3 tower has been set at x = 0, and the vertical solid and dashed lines indicate the maximum and minimum locations of the ROW edges, respectively, for this line segment.

(a)



(b)

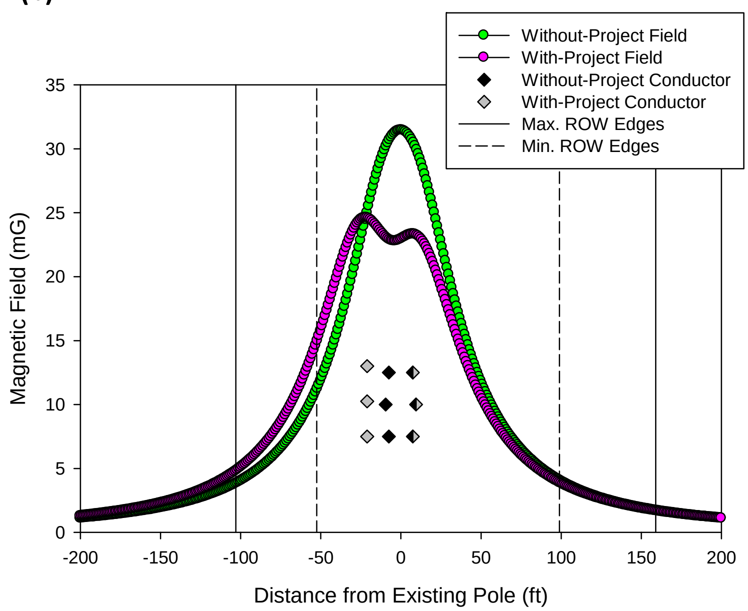
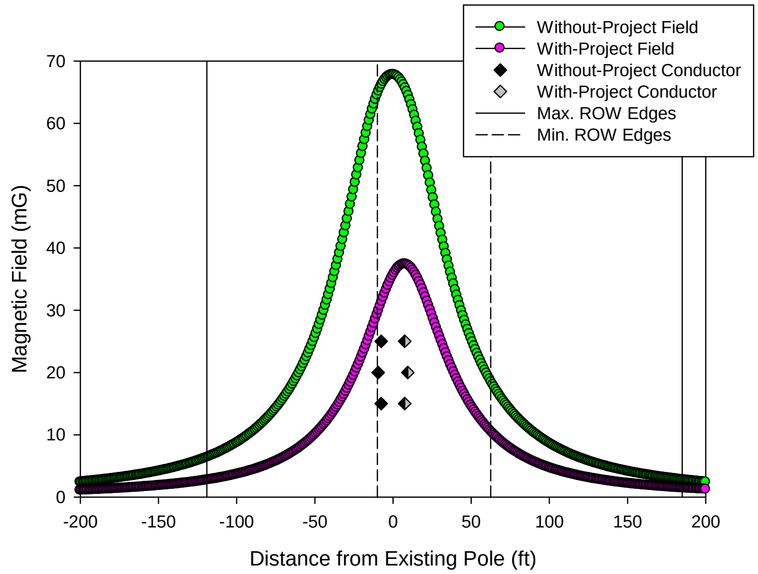


Figure 3.4 West of Gardner Street/East of Valley Road Cul-de-sac ROW Cross-section Magnetic Field Values at Projected Non-emergency Summer Peak 2018 Load Level (Panel a) and Average 2018 Load Level (Panel b). The view is to the west towards the Needham Substation, with the cross-section being shown perpendicular to the directions of electric current. The Transmission Line 240-510 conductors are shown on the far right (black and gray diamonds), and the relocated Transmission Line 110-522 conductors are shown on the far left (gray diamonds). The centerline of the existing ROW #3 tower has been set at x = 0, and the vertical solid and dashed lines indicate the maximum and minimum locations of the ROW edges, respectively, for this line segment.

(a)



(b)

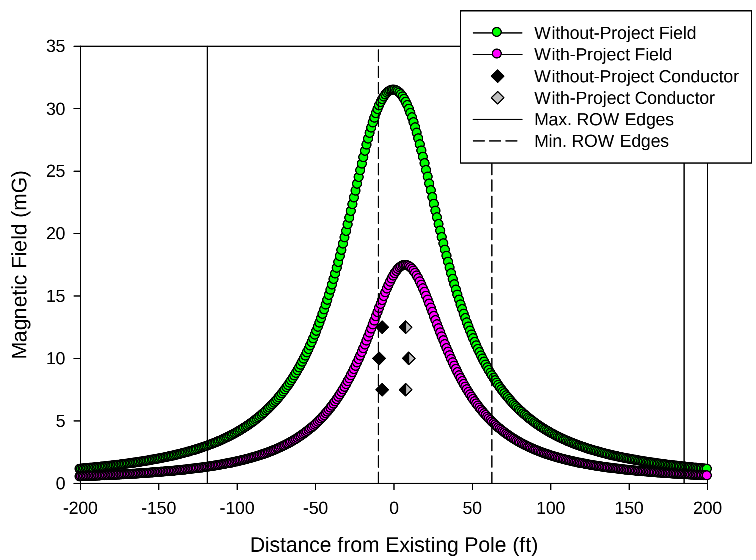


Figure 3.5 West of Valley Road Cul-de-sac ROW Cross-section Magnetic Field Values at Projected Non-emergency Summer Peak 2018 Load Level (Panel a) and Average 2018 Load Level (Panel b). The view is to the west towards the Needham Substation, with the cross-section being shown perpendicular to the directions of electric current. The existing Transmission Line 110-522 conductors that are to be taken out of service are shown on the far left (black diamonds), while the Transmission Line 240-510 conductors are shown on the far right (black and gray diamonds). The centerline of the existing ROW #3 tower has been set at x = 0, and the vertical solid and dashed lines indicate the maximum and minimum locations of the ROW edges, respectively, for this line segment.

3.4.2 Magnetic Field Modeling Results for Underground Line Segments

The graphs in Figures 3.6 and 3.7 plot the magnetic field *versus* horizontal distance from centerline, both for the standard inverted-delta (∇) underground conductor configuration, and for the vertical conductor configuration in splice vault/manhole sections. In both cases, all modeled magnetic field values fall well below the ICNIRP health-based guidelines for public exposure to EMF (2,000 mG, see Section 2, Table 2.1).

Both graphs show that magnetic field values decrease rapidly with lateral distance from the lines. At the non-emergency summer peak 2018 loading, the maximum modeled magnetic field value generated by the proposed underground line was 71 mG, falling to 7.8 mG at a horizontal distance of ±20 feet away from the centerline of the conductors. At peak load, in the vicinity of manhole/splice vault sections, the maximum magnetic field value was 98.6 mG, falling to 20 mG at a horizontal distance of ±20 feet away from the centerline of the conductors. At annual average load, the maximum modeled magnetic field value for the majority of the line length (for the ∇ configuration) was 33 mG, falling to 3.6 mG at ±20 feet; for the vertical conductor configuration in the splice vaults, the corresponding maximum modeled magnetic field was 46 mG, falling to 9 mG at ±20 feet from the centerline of the conductors. Underground lines produce no above-ground electric fields, so no electric field model results are provided.

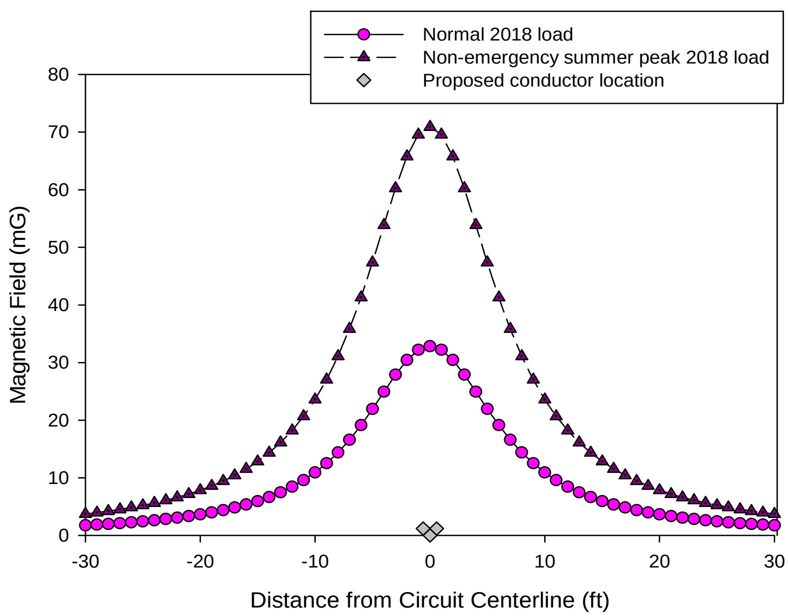


Figure 3.6 Magnetic Field *versus* Lateral Distance from the Centerline of the Conductors (x = 0 ft) for the Proposed Underground Line 110-522 Conductors at Projected Non-emergency Summer Peak 2018 Load Level (Purple Triangles) and Average 2018 Load Level (Pink Circles)

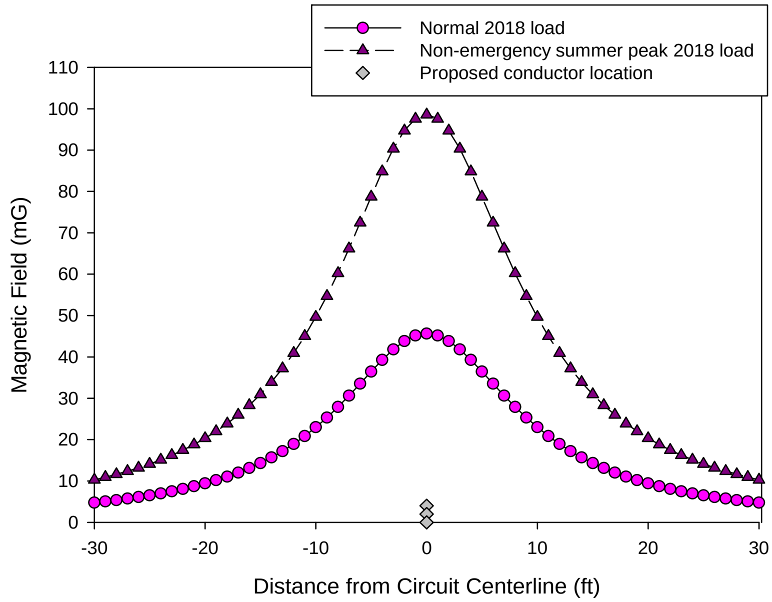


Figure 3.7 Magnetic Field *versus* Lateral Distance from the Centerline of the Conductors (x = 0 ft) for the Vertical Configuration of the Proposed Line 110-522 Underground Conductors at Projected Non-emergency Summer Peak 2018 Load Level (Purple Triangles) and Average 2018 Load Level (Pink Circles)

3.4.3 Electric Field Modeling Results for Overhead Line Cross-sections

Because the electric field is dependent on voltage and the spatial configuration of the conductors, and has little dependence on load, there are only six unique electric field profiles: Without-Project and With-Project for the East of Gardner Street cross-section, Without-Project and With-Project for the West of Gardner Street/East of Valley Road cul-de-sac cross-section, and Without-Project and With-Project for the West of Valley Road cul-de-sac cross-section.[3] Results of the electric field modeling are summarized in Table 3.3 and Figures 3.8-3.10.

[3] The minor differences in voltages shown for the two loading scenarios in Table 3.1 will only result in negligible differences in electric fields for the two loading scenarios.

Table 3.3 Modeled Peak Edge-of-ROW and Within-ROW Electric Field Values by Overhead Cross-section

Cross Section/ Route Segment	Location	Without-Project Electric Field (kV/m)[1]	With-Project Electric Field (kV/m)[1]
East of Gardner Street	Southern Edge-of-ROW	0.10-0.11	0.091-0.094
	Northern Edge-of-ROW	0.08-0.39	0.04-1.11
	Within-ROW Maximum	2.63	2.23
West of Gardner Street/ East of Valley Road cul-de-sac	Southern Edge-of-ROW	0.03-0.11	0.04-0.40
	Northern Edge-of-ROW	0.06-0.10	0.05-0.09
	Within-ROW Maximum	2.63	2.23
West of Valley Road cul-de-sac	Southern Edge-of-ROW	0.03-2.29	0.05-0.95
	Northern Edge-of-ROW	0.05-0.11	0.03-0.07
	Within-ROW Maximum	2.63	1.58

Notes:
kV/m = Kilovolts Per Meter; ROW = Right-of-Way.
(1) Ranges are provided for the ROW edges to reflect the range in the locations of the southern and northern ROW edges for the different route segments.

Similar to the magnetic field results, all modeled pre- and With-Project within-ROW maximum electric field values are well below the health-based guideline of the ICNIRP for continuous public exposure to electric fields of 4.2 kV/m (ICNIRP, 2010). In addition, the electric field modeling results show that the With-Project within-ROW maximum electric fields are reduced as compared to the Without-Project within-ROW maximum electric fields.

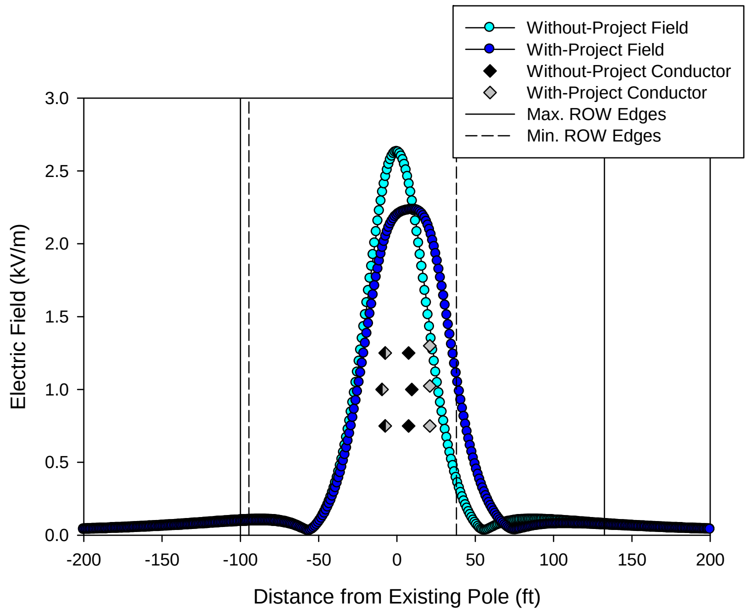


Figure 3.8 East of Gardner Street ROW Cross-section Electric Field Values. The view is to the west towards the Needham Substation, with the ROW cross-section being shown perpendicular to the directions of electric current. The Transmission Line 110-522 conductors are shown on the far left (black and gray diamonds), and the relocated Transmission Line 240-510 conductors are shown on the far right (gray diamonds). The centerline of the existing ROW #3 tower has been set at x = 0, and the vertical solid and dashed lines indicate the maximum and minimum locations of the ROW edges, respectively, for this line segment.

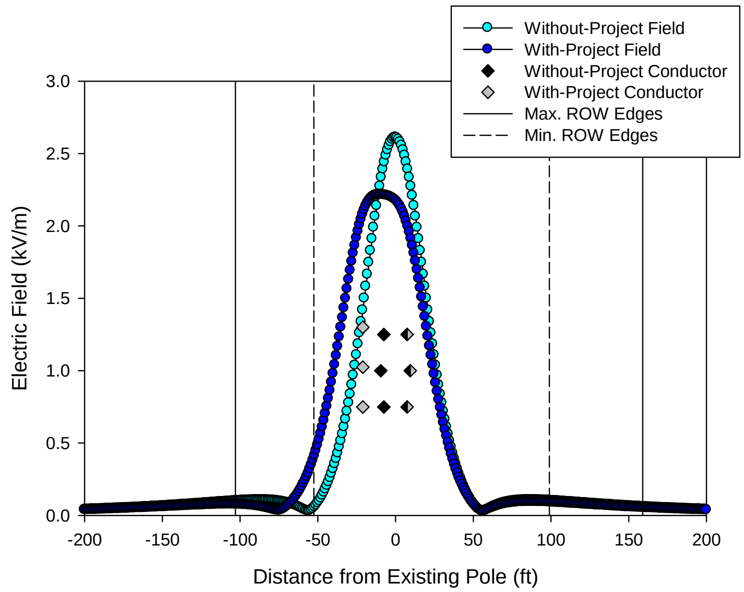


Figure 3.9 West of Gardner Street/East of Valley Road Cul-de-sac ROW Cross-section Electric Field Values. The view is to the west towards the Needham Substation, with the ROW cross-section being shown perpendicular to the directions of electric current. The Transmission Line 240-510 conductors are shown on the far right (black and gray diamonds) and the relocated Transmission Line 110-522 conductors are shown on the far left (gray diamonds). The centerline of the existing ROW #3 tower has been set at x = 0, and the vertical solid and dashed lines indicate the maximum and minimum locations of the ROW edges, respectively, for this line segment

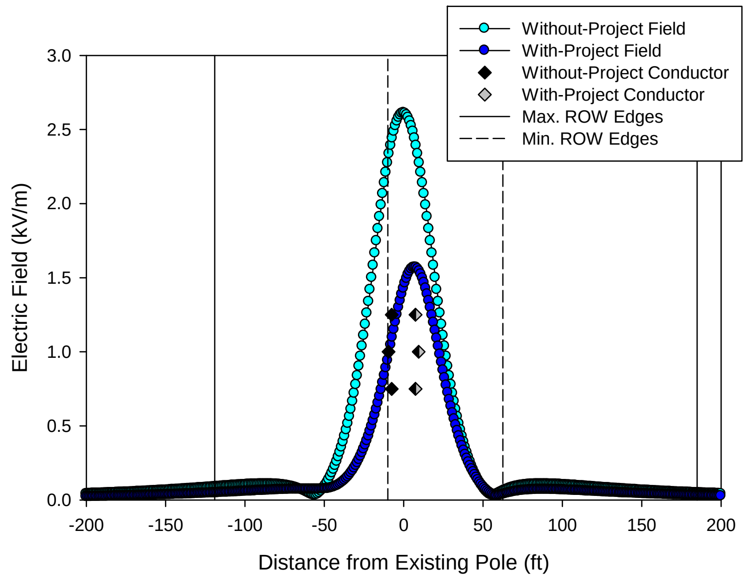


Figure 3.10 West of Valley Road Cul-de-sac ROW Cross-section Electric Field Values. The view is to the west towards the Needham Substation. The existing Transmission Line 110-522 conductors that are to be taken out of service are shown on the far left (black diamonds), and the Transmission Line 240-510 conductors are shown on the far right (black and gray diamonds). The centerline of the existing ROW #3 tower has been set at x = 0, and the vertical solid and dashed lines indicate the maximum and minimum locations of the ROW edges, respectively, for this line segment.

4 Conclusions

Using the FIELDS model, Gradient calculated the EMF levels at 3 feet (~1 meter) above the ground surface for representative cross-sections of overhead 115-kV transmission lines between the Baker Street Substation and the Needham Substation for the present-day circuit configuration and post-project circuit configurations, and for typical cross-sections of the proposed 115-kV underground conductors to be installed between the Valley Road area in Needham and the Needham Substation. EMF modeling was performed using projected non-emergency summer peak and average transmission line loadings provided by Eversource for the year 2018, which is the expected in-service date for the project. As discussed above, the maximum modeled electric and magnetic field levels predicted within and at the edges of ROW #3, as well as the maximum magnetic field levels predicted above the proposed underground circuits, all fall well below accepted health-based guidelines for allowable public exposure to electric and magnetic fields (4.2 kV/m and 2,000 mG, respectively; ICNIRP, 2010).

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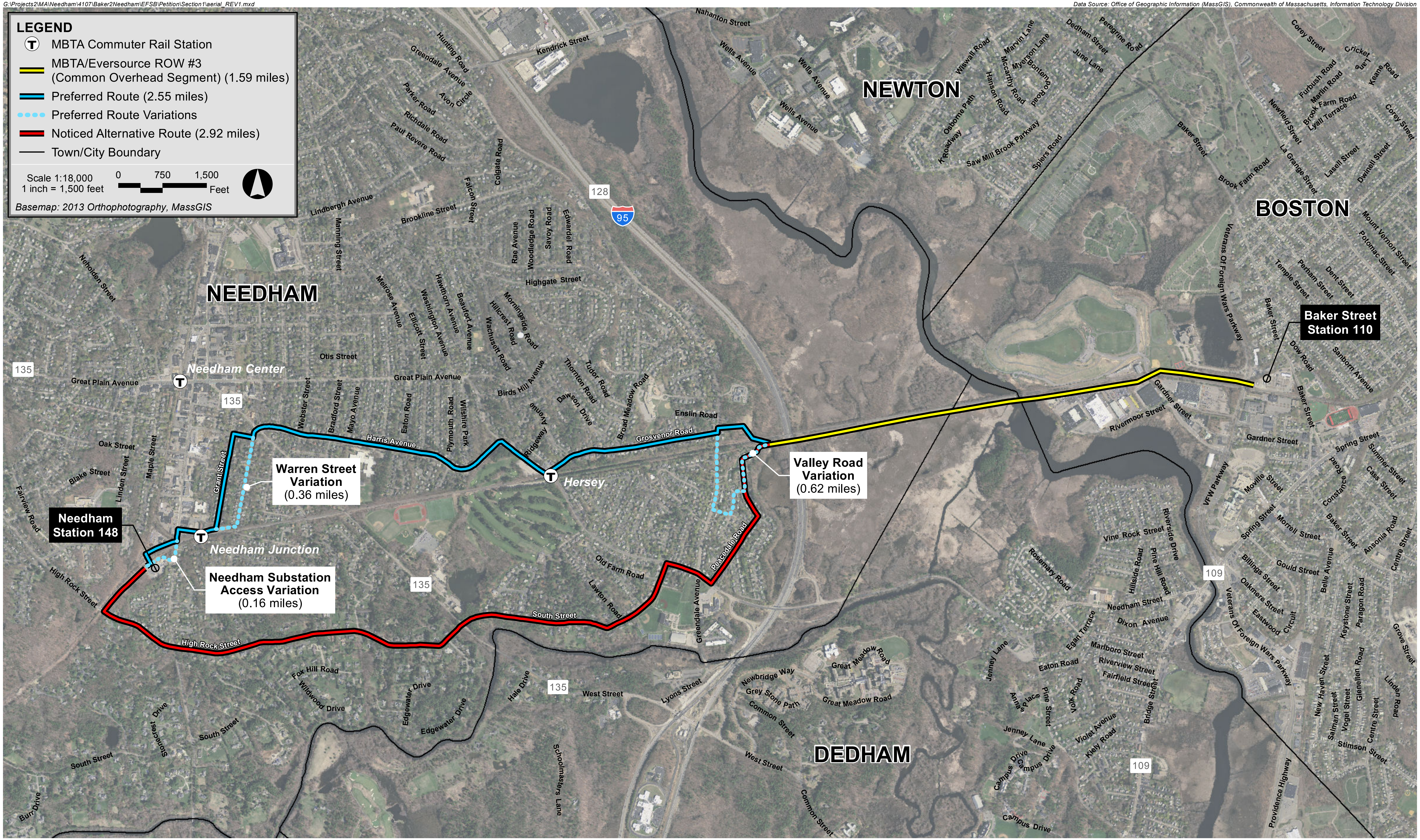
Appendix A

Plan View Candidate Route Map for the West Roxbury to Needham Reliability Project (from Epsilon, 2015)

G:\Projects2\MA\Needham\4107\Baker2Needham\EFSB\Petition\Section1\aerial_REV1.mxd

Data Source: Office of Geographic Information (MassGIS), Commonwealth of Massachusetts, Information Technology Division



West Roxbury to Needham Reliability Project

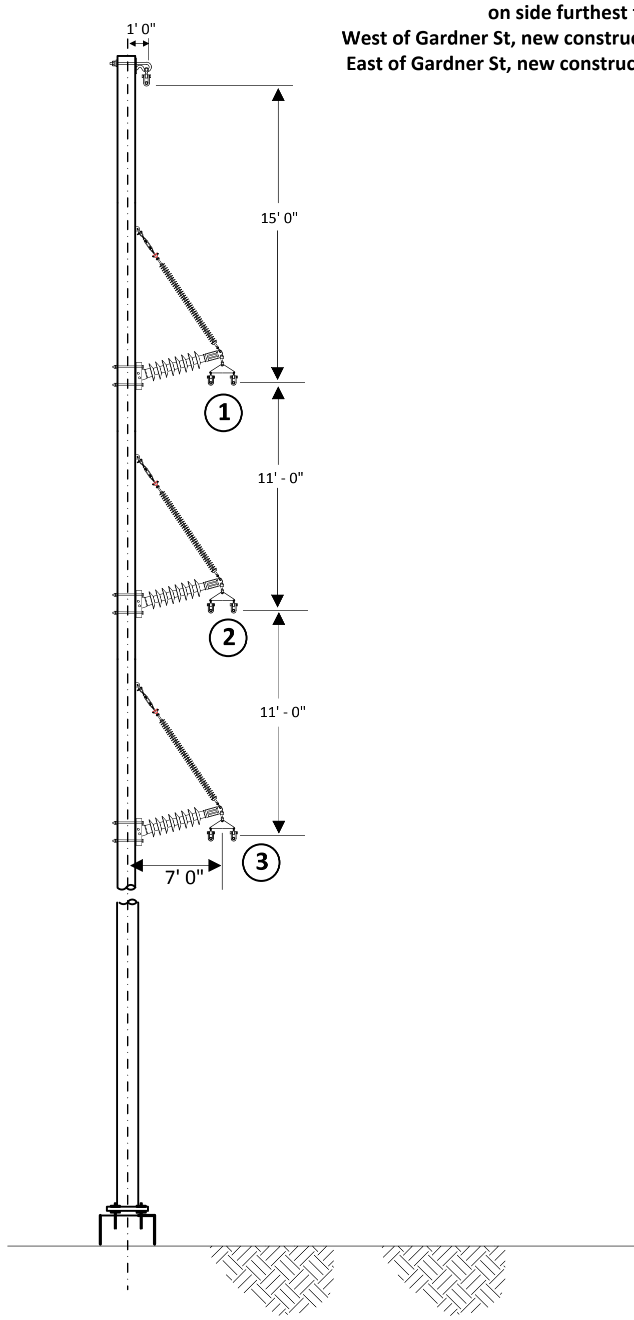
EVERSOURCE

Figure 1-2
Aerial Locus Map

Appendix B

West Roxbury to Needham Reliability Project Overhead Tower Outlines and Configurations

Proposed construction for line to be split off, will be installed on side furthest from tracks
West of Gardner St, new construction will be on line 110-522
East of Gardner St, new construction will be on line 240-510



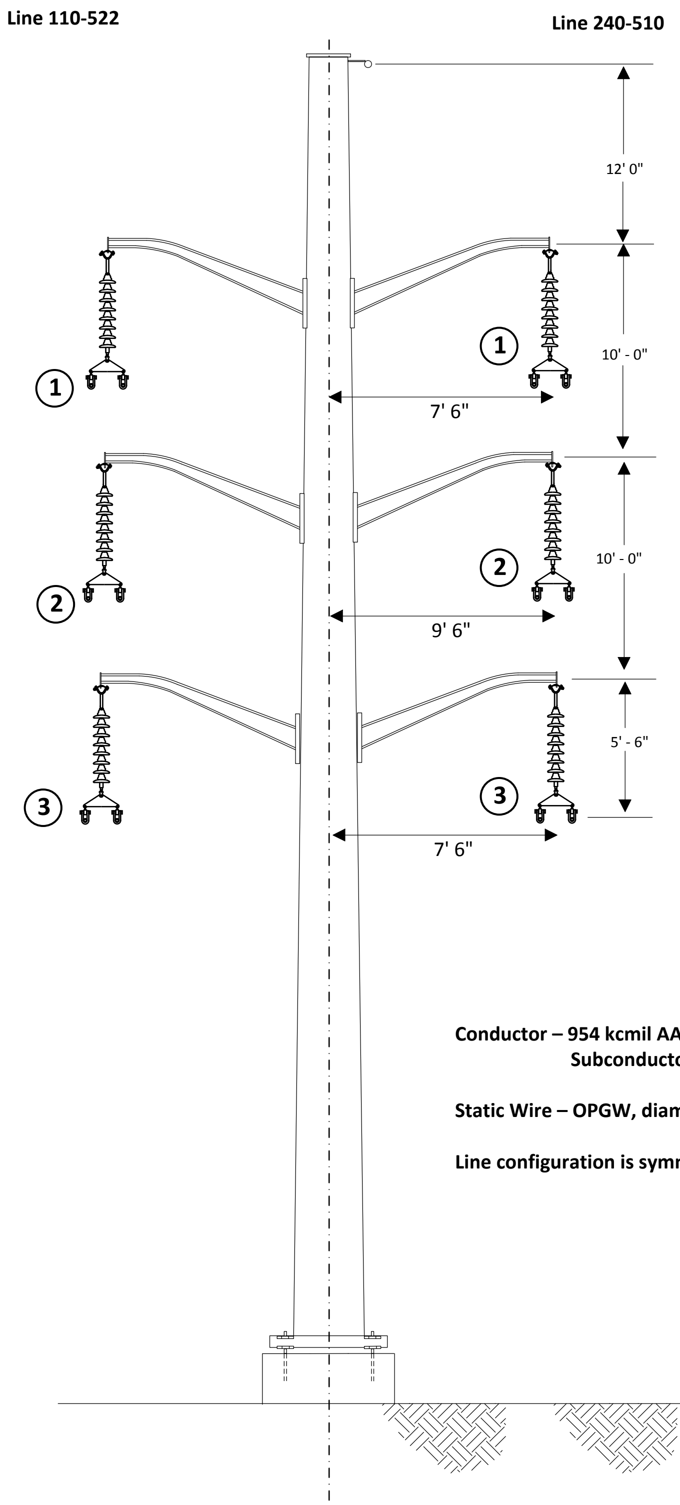
Conductor – 954 kcmil AAC, 37, “Magnolia”, two subconductors per phase
Subconductor spacing 18"; conductor diameter 1.124"

Static Wire – OPGW, diameter 0.512"

EVERSOURCE ENERGY

Baker to Needham DCT Split
Configuration of Proposed New Line
For EMF and Permitting Only

View is looking west toward Needham



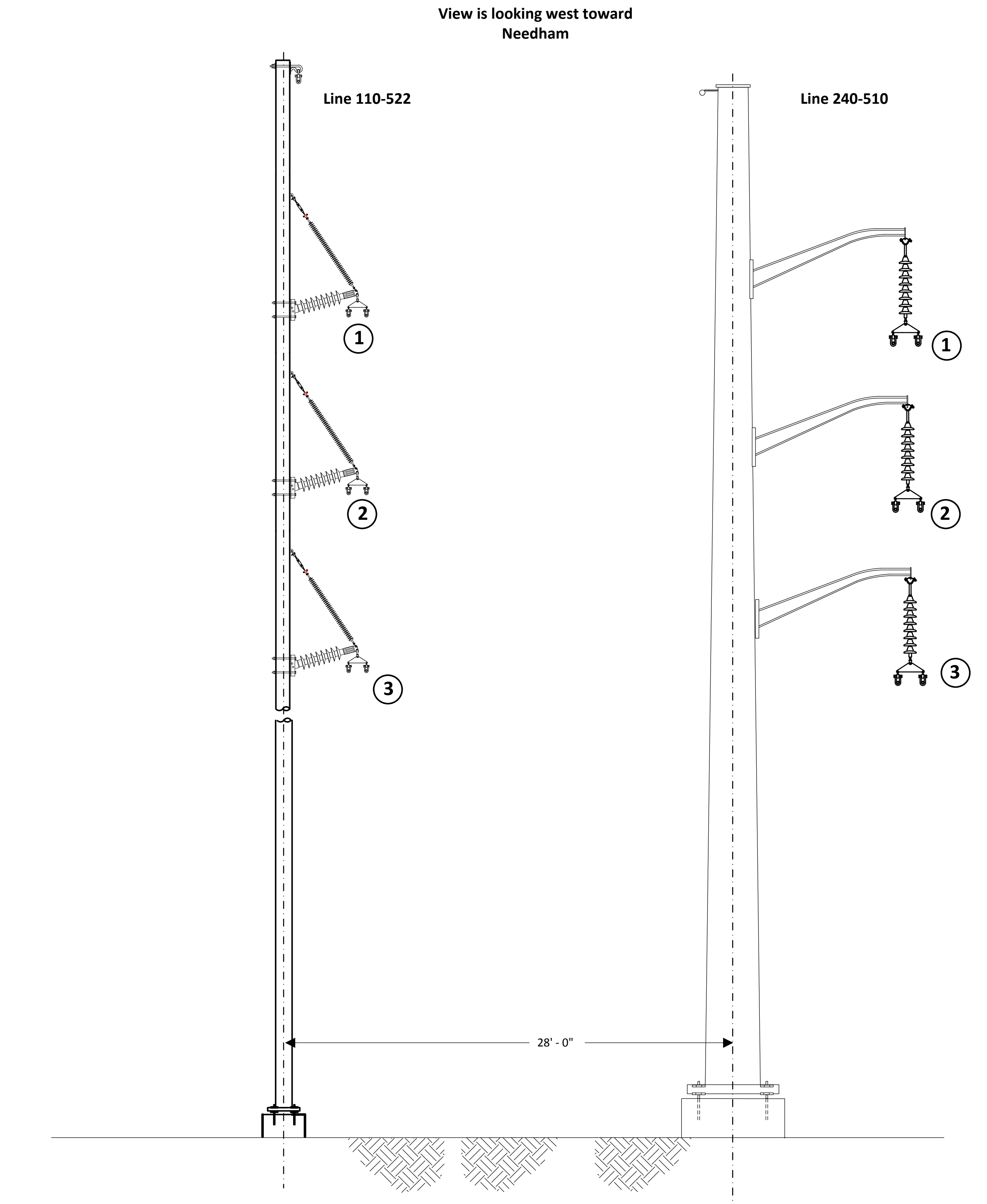
Conductor – 954 kcmil AAC, 37, “Magnolia”, two subconductors per phase
Subconductor spacing 18"; conductor diameter 1.124"

Static Wire – OPGW, diameter 0.646"

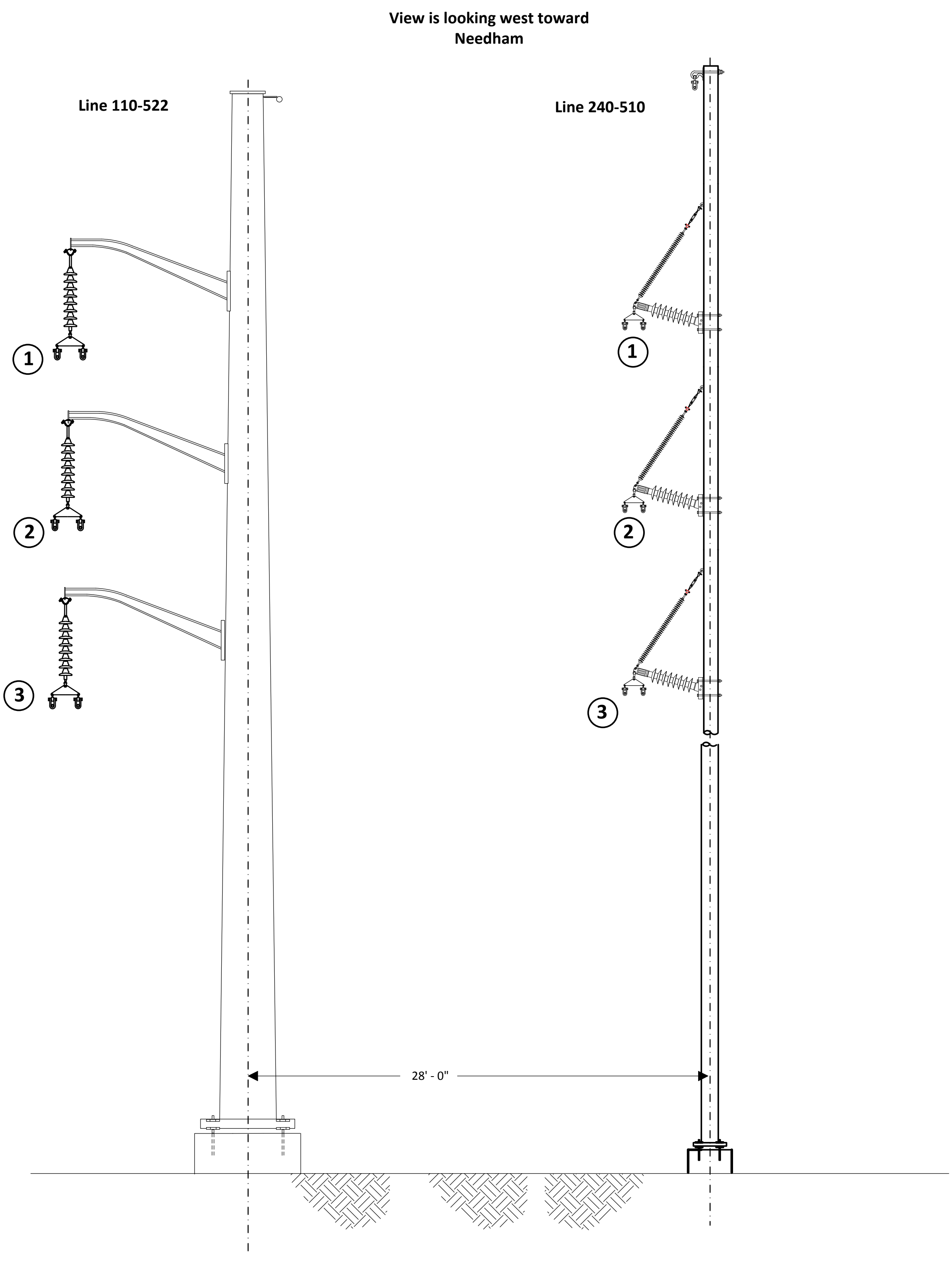
Line configuration is symmetrical on both sides

EVERSOURCE ENERGY

Baker to Needham DCT Split
Configuration of Existing Lines
For EMF and Permitting Only



Baker to Needham DCT Split
Proposed Construction – West of Gardner Street
For EMF and Permitting Only

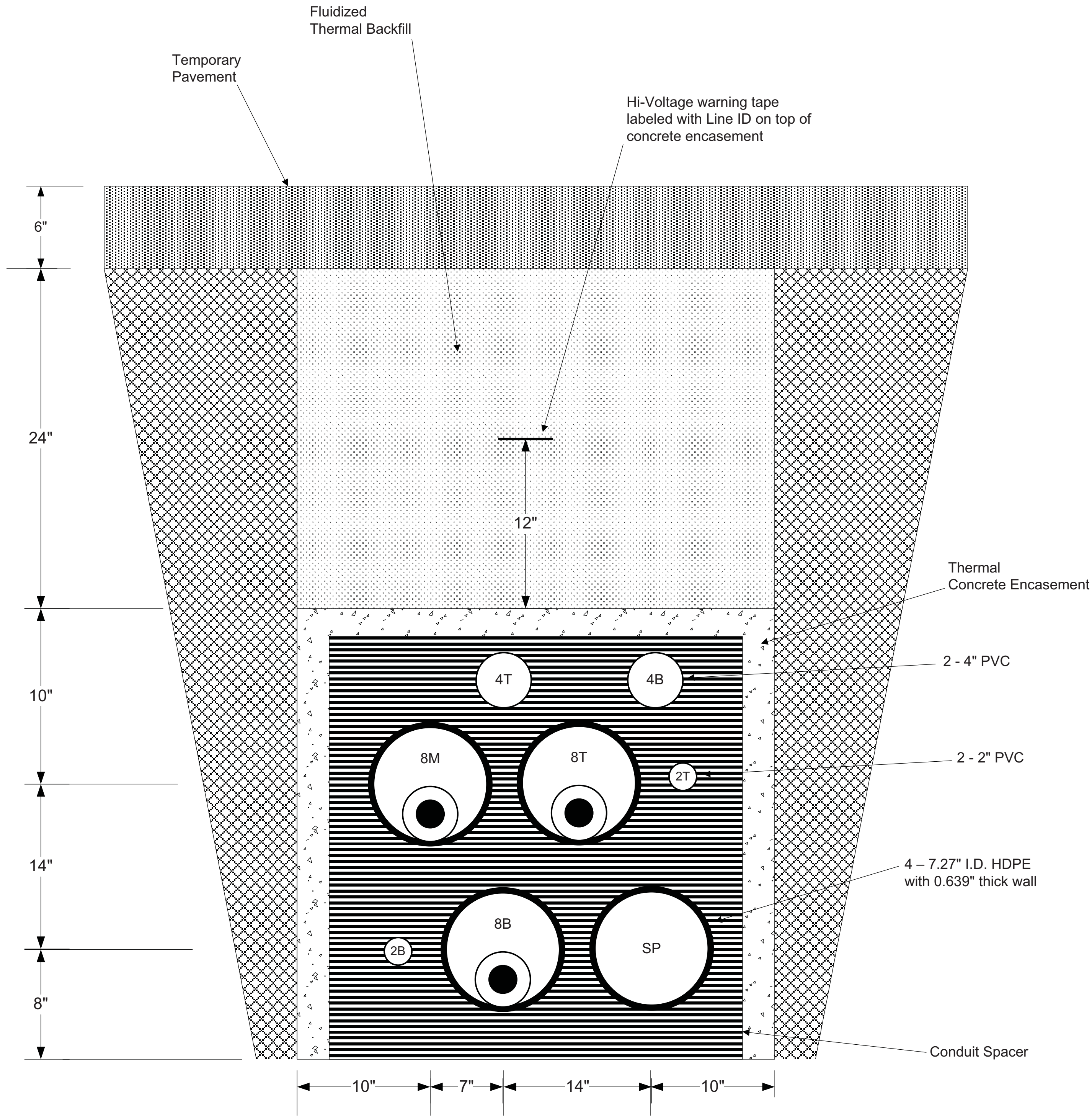


EVERSOURCE ENERGY

Baker to Needham DCT Split
Proposed Construction – East of Gardner Street
For EMF and Permitting Only

Appendix C

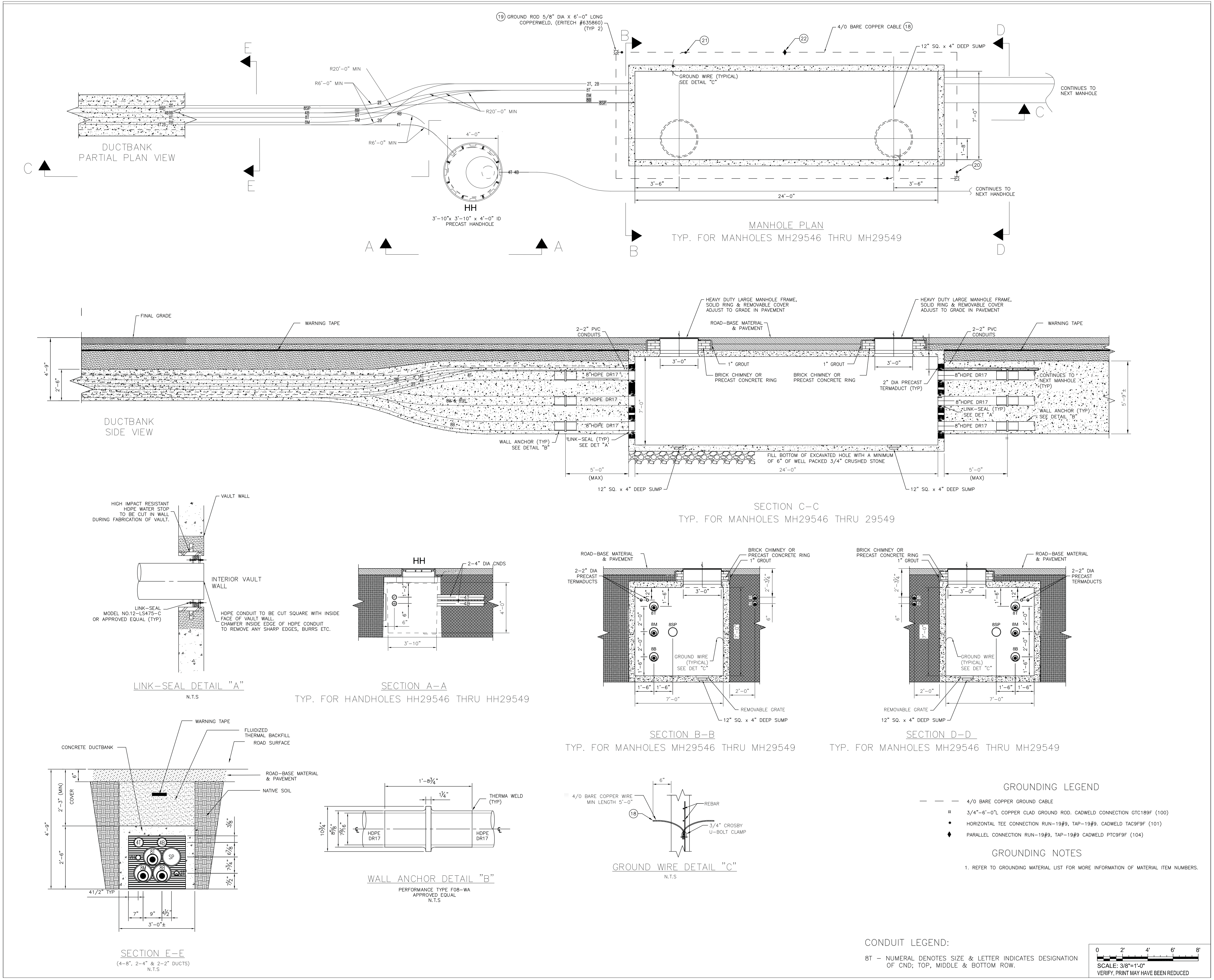
Cross-sections of West Roxbury to Needham Reliability Project Underground 115-kV Transmission Line Duct Bank and Manhole Sections



NOTE: Not to Scale

0	XX/XX/XX	Issued
Rev.	Date	Description

	115 KV / 345 KV XLPE Cross Section	Appendix XX Rev 0 Sheet X of X



NOTES:

1. DESIGN OF DUCT BANK IS BASED ON CLEAN AND STRUCTURALLY SOUND IN SITU CONDITIONS. IF ACTUAL CONDITIONS ARE DIFFERENT, CONTRACTOR SHALL NOTIFY ENGINEER TO DEVELOP APPROPRIATE MITIGATION PLAN.
2. LOCATION OF EXISTING UNDERGROUND UTILITIES IS BASED ON AVAILABLE INFORMATION. IN THE EVENT THAT OBSTACLES ARE ENCOUNTERED, CONTRACTOR SHALL NOTIFY ENGINEER TO DEVELOP APPROPRIATE MITIGATION PLAN.
3. DIG SAFE TO BE NOTIFIED PRIOR TO START OF CONSTRUCTION.

REV.	DATE	DESCRIPTION
B	9/19/12	REVISED SECTION E-E
A	9/10/12	95% IFR

VANDERWEIL POWER GROUP

R.G. Vanderweil Engineers, LLP 274 Summer Street Boston, MA 02210 617.423.7423 TEL 617.423.7401 FAX vanderweil.com

RGV Job No. 26991	Sheet 1 of 1
Drawn by:	JA
Checked by:	AJM
Date of Original:	9/4/12
Scale:	3/8"=1'-0"

Project

Title

345kV TRENCH MANHOLE SECTIONS AND DETAILS

E-001