APPLICATION TO THE

CONNECTICUT SITING COUNCIL

FOR A
CERTIFICATE OF ENVIRONMENTAL COMPATIBILITY
AND PUBLIC NEED FOR A 345-kV
ELECTRIC TRANSMISSION LINE FACILITY
AND ASSOCIATED FACILITIES

- **"ELECTRIC AND MAGNETIC FIELD ASSESSMENT: MIDDLETOWN-NORWALK TRANSMISSION REINFORCEMENT" BY EXPONENT**
- **"TUTORIAL – UNDERGROUND ELECTRIC POWER TRANSMISSION CABLE SYSTEMS" BY CABLE CONSULTING INTERNATIONAL**
- **"EVALUATION OF POTENTIAL 345-kV AND 115-kV CABLE SYSTEMS AS PART OF THE MIDDLETOWN-NORWALK PROJECT-SEPTEMBER 30, 2003" BY POWER DELIVERY CONSULTANTS, INC.**
- **SINGER SUBSTATION SITE SELECTION STUDY**

VOLUME 6 OF 12

Connecticut Light & Power
The Northeast Utilities System

The United Illuminating Company

Exponent®

Electric and Magnetic Field Assessment: Middletown—Norwalk Transmission Reinforcement

Exponent®

Electric and Magnetic Field Assessment: Middletown—Norwalk Transmission Reinforcement

Prepared for

Northeast Utilities
P.O. Box 270
Hartford, CT 06141

The United Illuminating Company
157 Church Street
New Haven, CT 06510

Prepared by

Exponent
420 Lexington Ave
Suite 408
New York, NY 10170

October 3, 2003

NY10132.000 C0T0 1003 WB24

Contents

Page

List of Figures v

List of Tables ix

Executive Summary x

1 Introduction 1

2 Project Effect on Electric and Magnetic Fields 2

2.1 Electric and Magnetic Fields from Power Lines and Other Sources 2

2.2 Magnetic Fields Encountered in Everyday Environments 4

2.3 Sources of Electric and Magnetic Fields 4

2.3.1 Proposed Route 4

2.3.2 Alternative A Route 6

2.3.3 Alternative B Route 6

2.3.4 Overview of Structure Configurations and EMF Profiles 6

2.4.1 Methods for Measuring Fields near Overhead Transmission Lines 8

2.4.2 Methods for Calculating Field from Overhead Transmission Lines 8

2.4.3 Methods for Calculating Fields from Underground Transmission Lines 9

2.5 Electric and Magnetic Field Measurements of Overhead Transmission Lines 12

2.5.1 Scovill Rock Switching Station, Middletown 13

2.5.2 Black Walnut Drive, Durham 15

2.5.3 Carpenter Lane (Proposed Beseck Substation Site) 16

2.5.4 Route 114, Woodbridge (near Jewish Community Center) 17

2.5.5 Route 152, Orange (High Plains Community Center) 18

2.5.6 Plains Road, Milford (Proposed site of East Devon Substation) 19

2.5.7 Atlantic and Main in Bridgeport (Proposed Singer Substation Site) 20

2.5.8 Norwalk Substation 22

2.6 Calculated Electric and Magnetic Fields from Transmission Lines 23

Cross Section 1 31

Cross Section 2 33

Cross Section 3 35

Cross Section 4 37

Cross Section 5 39

Cross Section 6 41

Cross Sections 7 and 7A 43

Cross Section 7B 45
Cross Sections 8 and 8B 47
Cross Section 8A 49
Cross Sections 9 and 9A 52
Cross Section 10 55
Cross Section 11 57
Cross Section 12 59
Cross Section 13 61
Cross Section 14 63
Cross Section 15 65
Cross Section 16 67
Cross Section 17 69
Cross Section 18 71
Cross Section 19 73
Cross Section 20 75
Cross Section 21 77
Cross Section 22 79

3 EMF Research 81

3.1 Epidemiology Studies of Cancer 81
3.1.1 Studies of Children 82
3.1.2 Studies of Adults 86

3.2 Laboratory Studies of Cancer 87

3.3 Summary of Research on Cancer 88

3.4 Research Related to Reproduction 89

3.5 Research Related to Neurobiological Effects and Neurological Diseases 90

3.6 Research Regarding Exposure to Appliances 91

3.7 Power Line Electric Fields and Airborne Particles 92

3.8 Reviews of EMF Research by Scientific Panels 93
3.8.1 International Agency for Research in Cancer (IARC) 93
3.8.2 Neutra et al. 93
3.8.3 Conclusions of Other National and International Organizations 94

4 Overall Project EMF Assessment 96

5 References 98

Appendix

List of Figures

		Page
Figure 1.	Electric and magnetic field levels in the environment	3
Figure 2.	Typical personal exposures to magnetic fields	5
Figure 3.	Trench cross section of 345-kV HPFF cable system with two cables per phase	10
Figure 4.	Trench cross section of 345-kV XLPE cable system, horizontal configuration, with two cables per phase	12
Figure 5.	Sketch of the Scovill Rock Switching Station perimeter and labeled measurement locations	13
Figure 6.	Plot of the electric and magnetic field around the perimeter of the Scovill Rock Switching Station	14
Figure 7.	Magnetic field profile from south to north for the transmission lines passing over Black Walnut Drive	15
Figure 8.	Electric field profile from south to north for the transmission lines passing over Black Walnut Drive	15
Figure 9.	Sketch of the site for the proposed Beseck Substation	16
Figure 10.	Magnetic field profile around the perimeter of the proposed site of the Beseck Substation.	17
Figure 11.	Magnetic field profile from south to north for the transmission lines passing over Route 114 (Center Road) in Woodbridge	17
Figure 12.	Electric field profile from south to north for the transmission lines passing over Route 114 (Center Road) in Woodbridge	18
Figure 13.	Magnetic field profile from south to north for the transmission lines adjacent to the High Plains Community Center in Orange	18
Figure 14.	Sketch of the proposed site for the East Devon Substation	19
Figure 15.	Magnetic field profile around the perimeter of the proposed site of the East Devon Substation	20
Figure 16.	Sketch of the proposed site of the Bridgeport Substation along Atlantic, Main, and Whiting Streets	21
Figure 17.	Magnetic fields along the perimeter of the Bridgeport Substation site	21

Figure 18. Sketch of the Norwalk Substation 22

Figure 19. Magnetic field measurements around the perimeter of the Norwalk Substation 23

Figure 20. Proposed route: Middletown Substation to East Devon Substation (overhead); Devon Substation to Norwalk Substation (underground) on modified Connecticut circuit map 27

Figure 21. "Supported Changes" to proposed route: Middletown Substation to East Devon Substation (overhead); East Devon Substation to Singer Substation to Hawthorne Transfer Station (underground); to Norwalk Substation (overhead) on *modified* Connecticut circuit map 28

Figure 22. Alternative A route: Middletown Substation to East Devon Substation (overhead); East Devon Substation to Singer Substation to Hawthorne Transfer Station (underground); to Norwalk Substation (overhead) on *modified* Connecticut circuit map 29

Figure 23. Alternative B route: Middletown Substation to East Devon Substation (overhead); East Devon Substation to Trumbull Junction (overhead); to/from Seaview Substation (underground); to Norwalk Substation (overhead) on *modified* Connecticut circuit map 30

Figure 24. Cross section 1 - Scovill Rock Substation to Chestnut Junction (Middletown) 31

Figure 25. Electric and magnetic field profiles for cross section 1 32

Figure 26. Cross section 2 - Oxbow Junction to Beseck Substation (Haddam, Durham, Middlefield, Wallingford, Middletown) 33

Figure 27. Electric and magnetic field profiles for cross section 2 34

Figure 28. Cross section 3 - Black Pond Junction to East Meriden Substation (Meriden) 35

Figure 29. Electric and magnetic field profiles for cross section 3 36

Figure 30. Cross section 4 - East Meriden Substation to Beseck Substation (Wallingford, Meriden) 37

Figure 31. Electric and magnetic field profiles for cross section 4 38

Figure 32. Cross section 5 - Beseck Substation to East Wallingford Junction (Wallingford) 39

Figure 33. Electric and magnetic field profiles for cross section 5 40

Figure 34. Cross section 6 - East Wallingford Junction to Wallingford Junction (Wallingford) 41

Figure 35. Electric and magnetic field profiles for cross section 6 42

Figure 36. Cross section 7 - Wallingford Junction to Cook Hill Junction (Wallingford) Cross section 7A - Wallingford Junction to Cheshire Town Line (Wallingford) 43

Figure 37. Electric and magnetic field profiles for cross sections 7 and 7A 44

Figure 38. Cross section 7B - Wallingford Town Line to Cook Hill Junction (Cheshire) 45

Figure 39. Electric and magnetic field profiles for cross section 7B 46

Figure 40. Cross section 8 - Cook Hill Junction to East Devon Substation (Cheshire, Hamden, Bethany, Woodbridge, Orange, West Haven, Milford) Cross section 8B - Cheshire Town Line to East Devon Substation (Hamden, Bethany, Woodbridge, Orange, West Haven, Milford) 47

Figure 41. Electric and magnetic field profiles for cross sections 8 and 8B 48

Figure 42. Cross section 8A - Cook Hill Junction to Hamden Town Line (Cheshire) 49

Figure 43. Electric and magnetic field profiles for overhead lines in cross section 8A 50

Figure 44. Electric and magnetic field profiles for overhead lines in cross section 8A 51

Figure 45. Cross section 9 - underground HPFF transmission line from East Devon to Singer to Norwalk Substations Cross section 9A - underground XLPE transmission line from Singer to Hawthorne Substations in Alternative A (Stratford, Fairfield, Westport, Milford, Bridgeport, Norwalk) 52

Figure 46. Magnetic field profile for cross section 9 from East Devon Substation to Singer Substation 53

Figure 47. Magnetic field profile for cross section 9 from Singer Substation to Norwalk Substation 53

Figure 48. Magnetic field profile for cross section 9A from Singer Substation to Hawthorne Substation (Alternative A) 54

Figure 49. Cross section 10 - Underground from Seaview Transfer Station to Singer Substation (Bridgeport) 55

Figure 50. Magnetic field profile for cross section 10 from Singer Substation to Seaview Transition Station and return (Alternative B) 56

Figure 51. Cross section 11 - Housatonic River Crossing (Stratford, Milford) 57

Figure 52. Electric and magnetic field profiles for cross section 11 (Alternative B) 58

Figure 53. Cross section 12 - Housatonic River to West Devon Junction (Stratford) 59

Figure 54. Electric and magnetic field profiles for cross section 12 (Alternative B) 60

Figure 55. Cross section 13 - West Devon Junction to Trumbull Junction (Stratford, Trumbull) 61

Figure 56. Electric and magnetic field profiles for cross section 13 (Alternative B) 62

Figure 57. Cross section 14 - Trumbull Junction to Seaview Transfer Station (Stratford, Trumbull) 63

Figure 58. Electric and magnetic field profiles for cross section 14 (Alternative B) 64

Figure 59. Cross section 15 - Trumbull Junction to Seaview Transfer Station (Stratford, Bridgeport) 65

Figure 60. Electric and magnetic field profiles for cross section 15 (Alternative B) 66

Figure 61. Cross section 16 - Trumbull Junction to Old Town Substation (Trumbull, Bridgeport) 67

Figure 62. Electric and magnetic field profiles for cross section 16 for typical alignment of proposed structure (Alternative B) 68

Figure 63. Cross section 17 - Old Town to Hawthorne to Weston Substations (Fairfield, Easton, Weston, Bridgeport) 69

Figure 64. Electric and magnetic field profiles for cross section 17 (Alternatives A and B) 70

Figure 65. Cross section 18 - Weston Substation to Norwalk Junction (Weston, Wilton) 71

Figure 66. Electric and magnetic field profiles for cross section 18 (Alternatives A and B) 72

Figure 67. Cross section 19 - Norwalk Junction to Norwalk Substation (Wilton) 73

Figure 68. Electric and magnetic field profiles for cross section 19 (Alternatives A and B) 74

Figure 69. Cross section 20 - Norwalk Junction to Norwalk Substation (Wilton) 75

Figure 70. Electric and magnetic field profiles for cross section 20 (Alternatives A and B) 76

Figure 71. Cross section 21 - Norwalk Junction to Norwalk Substation (Norwalk) 77

Figure 72. Electric and magnetic field profiles for cross section 21 (Alternatives A and B) 78

Figure 73. Cross section 22 - Norwalk Junction to Norwalk Substation (Norwalk) 79

Figure 74. Electric and magnetic field profiles for cross section 22 (Alternatives A and B) 80

List of Tables

		Page
Table 1.	Summary of magnetic fields measured in a Connecticut town (Bethel)	4
Table 2.	Sections included in possible routes	7
Table 3.	Measured electric field – perimeter of Norwalk Substation	22
Table 4.	Edge of right-of-way electric field values for existing, proposed and alternative line configurations in 2007	25
Table 5.	Edge of right-of-way magnetic field values for existing, proposed, and alternative line configurations	26
Table 6.	Conclusions of international agencies and scientific groups	95

Executive Summary

The Connecticut Light and Power Company (CL&P) and The United Illuminating Company (UI) propose to enhance the electric reliability in Southwestern Connecticut by extending a 345,000 Volt (345-kV) transmission line from the Scovill Rock Switching Station in the City of Middletown to the Norwalk Substation in the City of Norwalk. The project will require the addition of 345-kV lines and equipment to existing rights-of-way. The project also involves the construction of two new substations in the cities of Milford and Bridgeport; a new switching station in the city of Wallingford; and upgrades to the existing substation in Norwalk and the switching station in Middletown. An underground design has been proposed for the route between the East Devon Substation and Norwalk Substation.

This report describes the effect of the proposed project on existing levels of electric and magnetic fields (EMF) at the power frequency and evaluates health research on EMF, including reviews of the literature published by scientific advisory organizations.

Over the last 30 years, research has been conducted in the United States and around the world to examine whether exposures to EMF have health or environmental effects. These fields are produced by both natural and man-made sources that surround us in our daily lives. They are found throughout nature and in our own bodies, and the earth itself. The earth produces a static direct current magnetic field – it is this field that is used for compass navigation.

Man-made EMF is found wherever electricity is generated, delivered, or used. Power lines, wiring in homes, workplace equipment, electrical appliances, and motors produce EMF. EMF from such alternating current sources in the US changes direction and intensity 60 times per second—a frequency of 60 Hertz (Hz). Fields at this frequency differ significantly from fields at the higher frequencies characteristic of radio and television signals, microwaves from ovens, cellular phones, and radar (which can have frequencies up to billions of Hz).

The proposed project will affect ambient levels of electric and magnetic fields, with the greatest effect within the boundaries of the Middletown-Norwalk right-of-way. Outside the boundaries of the rights-of-way and substations, the effect of the project on EMF levels will be limited. At distances greater than approximately 100 feet from edges of the proposed right-of-way, the differences between the levels of fields produced by existing and future line configurations become smaller for this and other route sections under consideration. This results from the overall design and the location of the proposed facilities, the proposal to expand the right-of-way in some sections, and the placement of the 345-kV line underground between the East Devon and Norwalk Substations.

The consensus of scientists who have reviewed the literature for scientific and regulatory organizations including the International Agency for Research on Cancer (IARC), the National Institute of Environmental Health Sciences (NIEHS), the Health Council of the Netherlands (HCN), and the National Radiological Protection Board of Great Britain (NRPB) is that no cause and effect relationship between EMF from any source and ill health has been established at the levels generally found in residential environments. Moreover, the information provided in this report demonstrates that the proposed project complies with the Connecticut Siting Council's Electric and Magnetic Field Best Management Practices.

1 Introduction

The Connecticut Light & Power (CL&P) and The United Illuminating Company (UI) must support an increasing demand for power and increase the reliability of service in Southwest Connecticut. To accomplish these goals, CL&P and UI have proposed to extend the existing 345-kV system by adding a new 345-kV circuit between Middletown and Norwalk. The proposed project consists of 45.7 miles of 345-kV overhead transmission lines (primarily within existing ROWs and 23.6 miles of 345-kV underground cables (primarily within existing roadways). The addition of a new circuit would require the widening of some portions of the overhead ROW along the route. This proposed route is shown in Figure 20. Based on input from citizens, public meetings, and towns, some changes to the configuration of facilities on this route could be accommodated as shown in Figure 21. Two alternative routes were also investigated (Figure 22 and Figure 23).

This report describes electric and magnetic fields (EMF) associated with existing facilities and evaluates how the addition of a new 345-kV circuit would affect existing levels of EMF along the Middletown-Norwalk right-of-way and at the terminal substations. The magnetic field from an underground transmission design for a portion of the route is also presented (Section 2). Because of questions that have been raised about EMF in relation to health, this report also provides an up-to-date assessment of current research on EMF (Section 3). Finally, the report provides an overall assessment that relates the project's effects on EMF levels to potential effects and relevant guidelines and standards (Section 4).

2 Project Effect on Electric and Magnetic Fields

2.1 Electric and Magnetic Fields from Power Lines and Other Sources

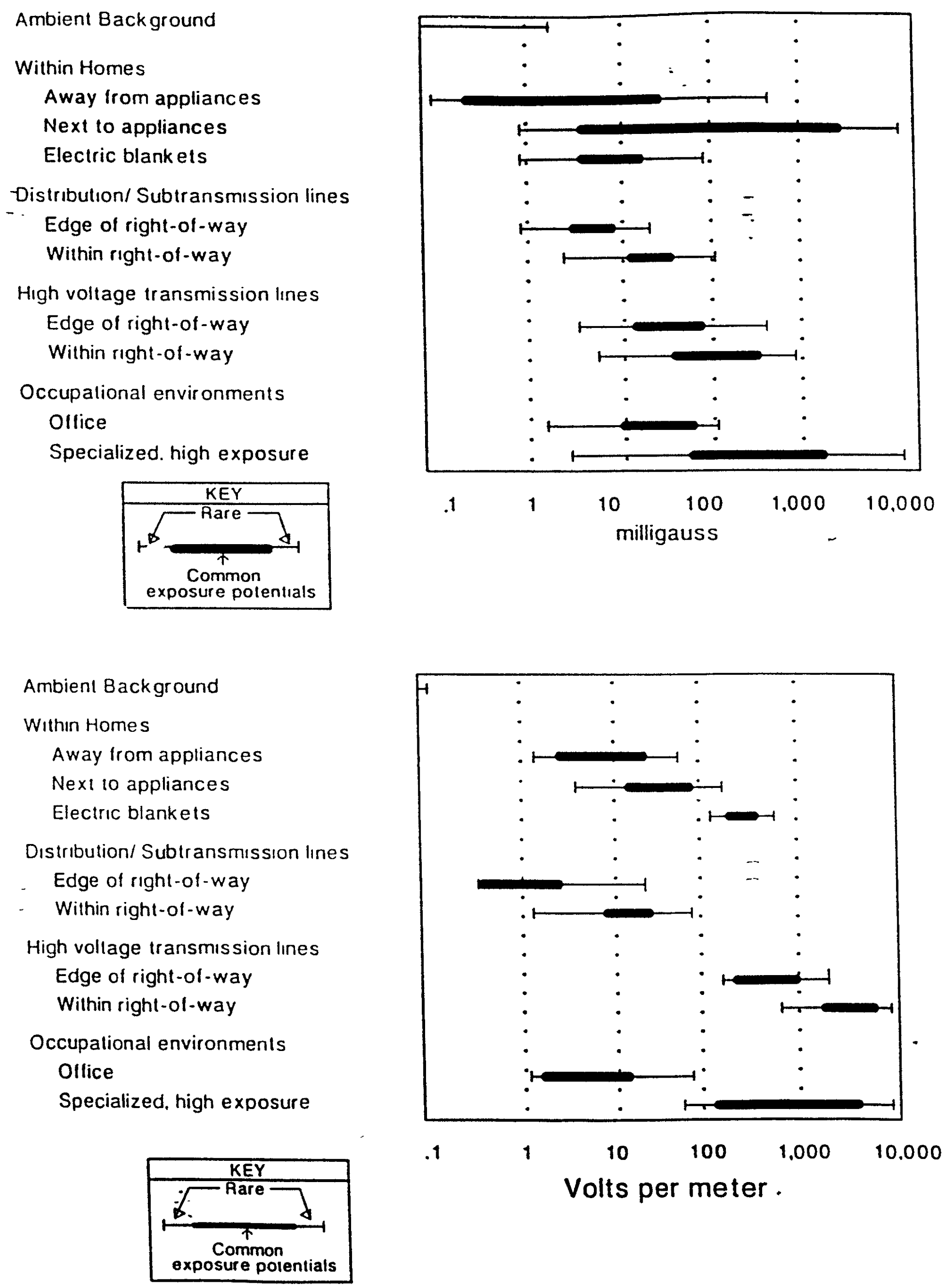
Electricity in our homes and workplaces is transmitted over considerable distances from generation sources to transmission and distribution systems. Electricity is transmitted as alternating current (AC) to all homes and to the electric lines that deliver power to our neighborhoods, factories and commercial establishments. The power provided by electric utilities in North America oscillates 60 times per second, i.e., at a frequency of 60 hertz (Hz).

Electric fields are the result of voltages applied to electrical conductors and equipment and are quite stable over time. The electric field is expressed in measurement units of volts per meter (V/m) or kilovolts per meter (kV/m); a kilovolt per meter is equal to 1000 V/m. Most objects including fences, shrubbery, and buildings easily block electric fields. Therefore, certain appliances within homes and the workplace are the major sources of electric fields indoors, while power lines are the major sources of electric fields outdoors (Figure 1, lower panel).

Magnetic fields are produced by the flow of electric currents and therefore vary over time; however, unlike electric fields, most materials do not readily block magnetic fields. The level of magnetic fields is commonly expressed as magnetic flux density in units called gauss, or in milligauss (mG), where 1 G = 1000 mG[1]. The level of the magnetic field at any point depends on characteristics of the source, including the arrangement of conductors, the amount of current flow through the source, and its distance from the point of measurement. The intensity of both electric and magnetic fields diminishes with increasing distance from the source.

In most of our homes, background AC magnetic field levels average about 1 mG, even when not near a particular source such as an appliance. Higher magnetic field levels are measured in the vicinity of distribution lines, subtransmission lines, transmission lines and appliances (Figure 1, upper panel).

[1] Scientists more commonly refer to magnetic flux density at these levels in units of microtesla (μT). Magnetic flux density in milligauss units can be converted to μT by dividing by 10, i.e., 1 milligauss = 0.1 μT.



Source: Savitz et al, 1989

Figure 1. Electric and magnetic field levels in the environment

The strongest sources of AC magnetic fields that we encounter indoors in residential settings are electrical appliances (fields near appliances vary over a wide range, from a fraction of a milligauss to a thousand milligauss or more). For example, Gauger (1985) reports the maximum AC magnetic field at 3 cm from a sampling of appliances as 3,000 mG (can opener), 2,000 mG (hair dryer), 5 mG (oven), and 0.7 mG (refrigerator). Similar measurements have shown that there is a tremendous variability among appliances made by different manufacturers.

2.2 Magnetic Fields Encountered in Everyday Environments

Considering EMF from a perspective of specific sources or environments, as in Figure 1, does not fully describe the variations in a person's personal exposure encountered in everyday life. To illustrate this, magnetic field measurements recorded by a meter worn at the waist while going about daily activities in a Connecticut town for two hours are shown in Figure 2. Activities included a visit to the post-office, the library, walking along the street, getting ice cream, browsing in the bicycle shop, stopping in the chocolate shop, going to the bank/ATM, driving along streets, shopping in a supermarket, stopping for gas, and getting something to eat at a fast food restaurant. This figure shows that we encounter magnetic fields whose intensity varies over a wide range from moment to moment in everyday life. The maximum average and median magnetic field levels encountered are listed in Table 1 below.

Table 1. Summary of magnetic fields measured in a Connecticut town (Bethel)

Magnetic Field Levels (milligauss, mG)		
Maximum	Average	Median
97.55*	4.57	1.10

*Maximum occurred in the supermarket. Still higher levels can occur in other community and residential settings.

2.3 Sources of Electric and Magnetic Fields

The major power frequency sources of EMF associated with the project are the transmission lines on the proposed Middletown to Norwalk right-of-way and the transformers and other equipment within the associated substations. The maps previously cited (Figures 21,22, 23, 24) identify sections of the proposed and alternative routes by number. The typical characteristics of the existing and proposed transmission lines in these sections differ with respect to the design characteristics of the facilities and/or the width of the ROW. However, within each section these characteristics are generally similar along the route.

2.3.1 Proposed Route

Existing transmission lines on segments of the proposed right-of-way between Middletown and Middlefield are the 345-kV transmission line, Line 387, out of Scovill Rock Switching Station in Middletown, and 115-kV transmission lines, Line 1975 and Line 1466, going into Middlefield/Meriden. The 345-kV transmission line 387 continues from Middlefield to the East Wallingford Junction area where 115-kV line 1655 joins the right-of-way. Lines 1630 and 1640 continue from the East Wallingford Junction to the Cook Hill Junction in Cheshire where Line 1640 continues south and is joined by 115-kV lines 1610 and 1690. Line 1610 becomes Line 1685 and Lines 1640, 1690, and 1685 then continue south to the proposed East Devon Substation. The primary route under consideration would continue underground from East Devon to the proposed Singer Substation in Bridgeport and finally to the existing Norwalk

Substation. (See also H.5.1. in Application.) The portion of the proposed route that incorporates changes developed through the Municipal Consultation Process and supported by the companies is described in Section I of the Application.

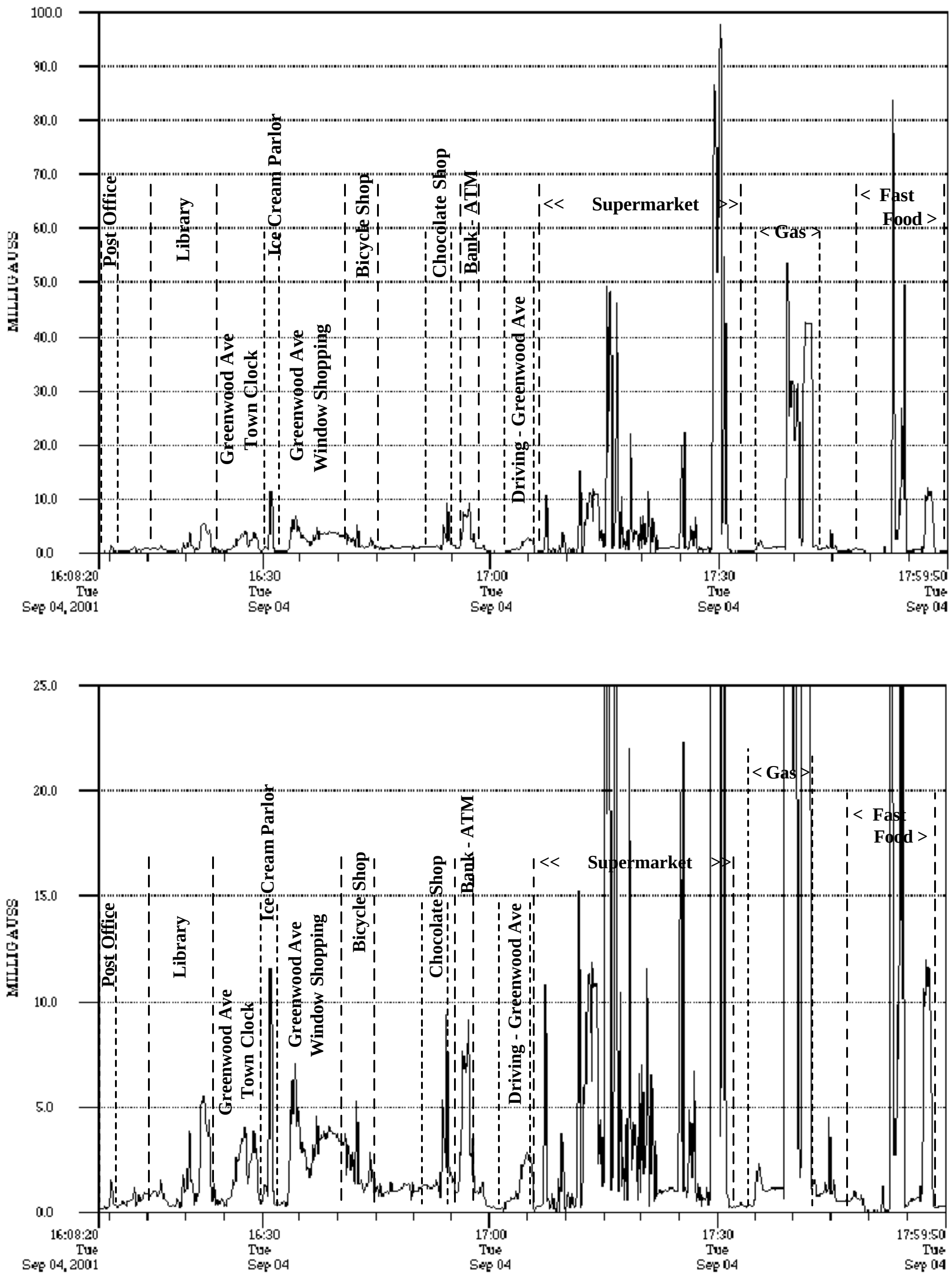


Figure 2. Typical personal exposures to magnetic fields

The modifications to the existing power lines on the Middletown-Norwalk right-of-way include: the removal of existing H-frame and latticework 115-kV poles/towers; the relocation of 115-kV lines to steel poles; and the addition of a 345-kV circuit. The proposed modification to the Scovill Rock Switching Station that would most affect fields at the periphery of the site is the addition of a new 345-kV circuit. Similarly, at the Norwalk Substation changes in EMF levels would be associated with changes to the 1720 and 1470 lines entering the substation, the elimination of Line 1637, and the addition of the 345-kV line. More precise estimates of field levels at the boundary of the site would depend upon the heights, alignments and interconnections of the circuits to structures within the substation.

2.3.2 Alternative A Route

An alternate route, Alternative A, has the same initial overhead routing from Middletown to East Devon and then is routed underground to the Singer Substation. From Singer Substation, the underground line would go northwest underground to the Hawthorne Transition Station, a new station at Hawthorne Substation, where the proposed line switches back to overhead and joins existing lines 1720 and 1730. From the Hawthorne Transition Station the proposed line continues west within the ROW through Weston where line 1730 becomes line 1637. The proposed line then continues with existing lines 1720 and 1637 through Wilton to Norwalk Substation.

2.3.3 Alternative B Route

Another alternate route, Alternative B, is primarily overhead. Again the initial overhead routing from Middletown to Devon is the same as previously described. The alternative overhead right-of-way continues west from the Devon area with 115-kV lines 1710, 1730, 1580, 1570, and 1574. Lines 1710 and 1730 continue on west to Trumbull Junction where the proposed right-of-way loops south to the Seaview Transition Station and then completes an underground loop to the Singer Substation. The proposed right-of-way then goes underground back north along the same route to the Seaview Switching Station where it returns to overhead and continues back to Trumbull Junction and it continues west with existing lines 1710 and 1730. Along the route, Line 1710 is replaced by Line 1222, which is later replaced by Line 1720. North of Norwalk, in Weston, Line 1730 is replaced by Line 1637. The lines then drop south into Norwalk Substation.

2.3.4 Overview of Structure Configurations and EMF Profiles

The configurations of the lines and calculated electric and magnetic field profiles on the Middletown-Norwalk right-of-way for the proposed route are shown in Section 2.6 in Figure 24 through Figure 47. The configurations of the lines on the Alternative A are shown in Figure 48 and Figure 63 through Figure 74, and Alternative B are shown in above figures, along with Figure 51 through Figure 62. These cross sections are also reproduced with greater clarity in Volume 10 of the Application. For ease of reference, the sections comprising each of the four routes that have been evaluated are listed below.

Table 2. Sections included in possible routes
(Numbers refer to cross sections shown on map Figures 21-24 and are listed in order of occurrence from Middletown to Norwalk)

Proposed (Figure 20)	**"Supported Changes"** (Figure 21)	**Alternative A** (Figure 22)	**Alternative B** (Figure 23)
1	1	1	1
2	2	2	2
3	3	3	3
4	4	4	4
5	5	5	5
6	6	6	6
7	7A	7A	7A
8	7B	7B	7B
9 East Devon to Singer	8A	8A	8A
9 Singer to Norwalk	8B	8B	8B
		9 East Devon to Singer	11
		9A Singer to Hawthorne	12
		17	13
		18	14
		19	15
		20	10
		21	16
		22	17
			18
			19
			20
			21
			22

2.4 Overhead Transmission Lines Measurements and Calculation Methods

Measurements were taken around the boundaries of the Scovill Rock Switching Station in January 2003 and Norwalk Substation on in June 2001 to characterize existing levels of EMF at these sites. Measurements were also taken at selected locations along and adjacent to the Middletown-Norwalk right-of-way in January 2003. Additional measurements were made around the proposed sites of the Beseck Switching Station, East Devon Substation, and Singer Substation in 2003, and at locations near the proposed route in September 2003. Estimates of present day and post-construction EMF levels were also obtained from calculations based upon the operating characteristics of these field sources.

2.4.1 Methods for Measuring Fields near Overhead Transmission Lines

Measurements were taken 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. 644-1994b). Both electric and magnetic fields were expressed as the total field computed as the resultant of field vectors measured in the x, y, and z-axes (rms[2]). The electric field was measured in units of kV/m with a single-axis field sensor and meter (Electric Field Measurements, Inc.) at five- or ten-foot intervals. The magnetic field was measured in units of milligauss (mG) in x, y and z-axes by orthogonally mounted sensing coils whose output was logged by a digital recording meter (Dexil Corp) at one-foot intervals. Measurements were taken along a transect perpendicular to transmission lines and around the perimeter of substation and switching station sites. Personal exposure measurements were taken at 10-second intervals. These instruments meet the IEEE instrumentation standard for obtaining valid and accurate field measurements at power line frequencies (IEEE Std.1308-1994a). The meters were calibrated by the manufacturers by methods like those described in IEEE Std. 644-1994b.

It is important to remember that measurements of the magnetic field present a ‘snapshot’ of the conditions at a point in time. Within a day, or over the course days, months, and even seasons, the magnetic field can change depending upon the amount and the patterns of power demand within the state and surrounding region. In contrast, the unperturbed electric field is quite stable over time.

2.4.2 Methods for Calculating Field from Overhead Transmission Lines

Pre- and post-construction EMF levels were calculated using a computer program developed by the Bonneville Power Administration, an agency of the U.S. Department of Energy (BPA, 1991). This program has been shown to accurately predict electric and magnetic fields measured near power lines. The inputs to the program are data regarding voltage, current flow, phasing, and conductor configurations. The fields associated with power lines were estimated along profiles perpendicular to lines at the point of lowest conductor sag, i.e., closest to the ground or opposite points of interest. All calculations were referenced to a height of 1 m (3.28 ft) above ground according to standard practice (IEEE-644, 1994b). The program assumed balanced currents on phases, horizontal conductors, and flat terrain. Northeast Utilities (NU) provided the conductor heights and other data pertaining to the configuration of existing and proposed lines. The height of the conductors above ground has a strong influence on the magnitude of the fields close to the edge of the ROW. In the early stage of project development, NU estimated the height of the conductors by the average conductor height within

[2] Root-mean-square (rms) refers to the common mathematical method of defining the effective voltage, current, or field of an alternating current (ac) system.

a section. NU provided conductor heights obtained by this method to Exponent for calculating EMF levels included in the Municipal Consultation draft. With the further developments in the project design, NU was able to estimate conductor heights for the shortest, not the average, distance between structures, which results more conservative estimates of representative field levels for both existing and proposed lines. Further changes were made to the phasing of adjacent lines in one section to achieve optimum field cancellation, and to the configuration of lines on some other sections. The electric field from the overhead conductors was also calculated at the point of lowest conductor sag, at a voltage assumed to be 5% above nominal values, to take into account situations where the operating voltage may be slightly higher than nominal values. Magnetic field levels were calculated for the average load flows modeled for existing and proposed circuits. The loadings on the circuits were based upon a representative system model developed by NU to reflect a typical day under estimated average system load conditions (15 gigawatt [GW] case). Fluctuations in current flow on these lines could result in higher or lower magnetic field levels over short periods. A rare system peak loading case (27.7 GW, the highest expected system loading during an hour in 2007) was also modeled for the proposed route.

2.4.3 Methods for Calculating Fields from Underground Transmission Lines

Power Delivery Consultants, Inc. (PDC) performed calculations of the above ground magnetic fields that will be produced by two different types of underground transmission lines under consideration.

2.4.3.1 High-Pressure Fluid-Filled (HPFF) Transmission Cable System

The 345-kV HPFF underground transmission lines will be constructed with two, three-phase HPFF transmission cable systems in parallel. The 345-kV HPFF cables will be manufactured with compact-segmental copper conductors and 0.6-inch Laminated Paper Polypropylene (LPP) high voltage insulation. Three of the HPFF cables will be installed in each of the two eight-inch carbon steel pipes. The horizontal separation between the centerlines of the two pipes will be 24 inches. The depth from the surface of the ground to the centerlines of the eight-inch pipes will vary between 20 and 60 inches along the alignment of the cable trench depending on local construction conditions.

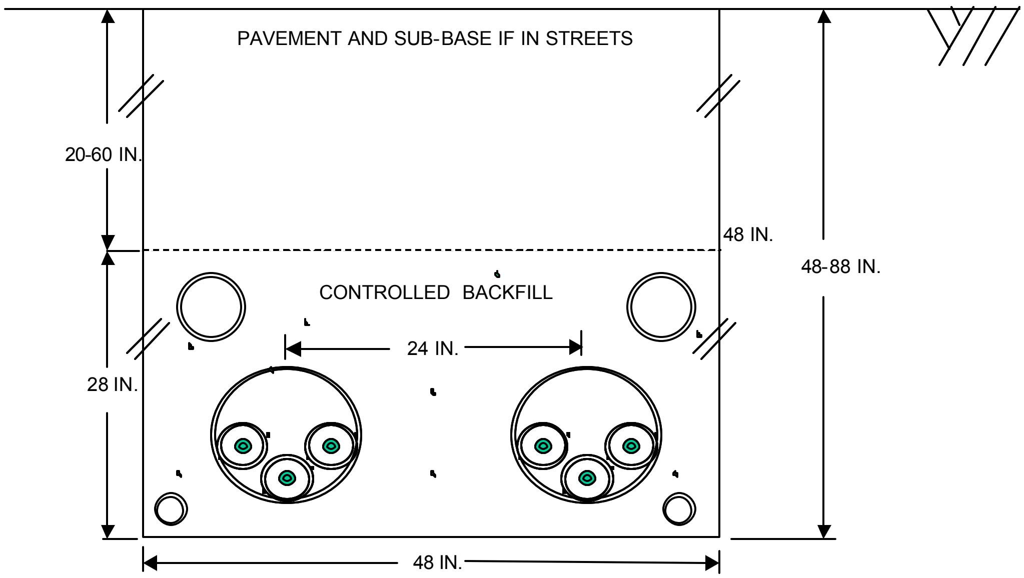


Figure 3. Trench cross section of 345-kV HPFF cable system with two cables per phase

The above ground values of the magnetic field for the HPFF underground lines were calculated using a computer program developed by PDC for HPFF cable systems, PTMF. This computer program calculates the magnetic field at a specified distance above ground level, then calculates the steel pipe attenuation factor based on procedures described in the report, *Handbook of Shielding Principles for Power Systems Magnetic Fields* (EPRI, 1994) and multiplies the unshielded magnetic field times the shielding factor. The magnetic permeability of steel pipe varies with the intensity of the magnetic field produced by the current produced by the power cables.

The currents flowing in each of the HPFF cables reflect one half of the total phase current that will flow in each of the two parallel HPFF cable systems.

The following assumptions were made concerning installation and operating conditions for the 345-kV HPFF underground transmission line lines.

- The copper conductor 345-kV HPFF cables will be installed in a 8-inch carbon steel pipe with a wall thickness of one quarter inch (Schedule 20 pipe).
- The magnetic properties of the carbon steel pipes vary depending on carbon content as well as the manufacturing process. The magnetic field calculations assume typical magnetic field properties for the carbon steel pipes.
- The currents flowing in the 345-kV underground transmission line will be balanced three-phase currents (i.e. the zero sequence current would be negligible).

The accuracy of the PTMF calculation results have been verified by comparison with field measurements that were performed in Honolulu Hawaii, Baltimore Maryland, and Bayonne New Jersey.

2.4.3.2 XLPE Underground Cable Systems

The second type of underground transmission line considered will be constructed using cross-linked polyethylene (XLPE) transmission cables rated at 345 kV (primary route) or 115 kV ("Supported Changes" to proposed route). The cables will be installed in concrete encased duct banks.

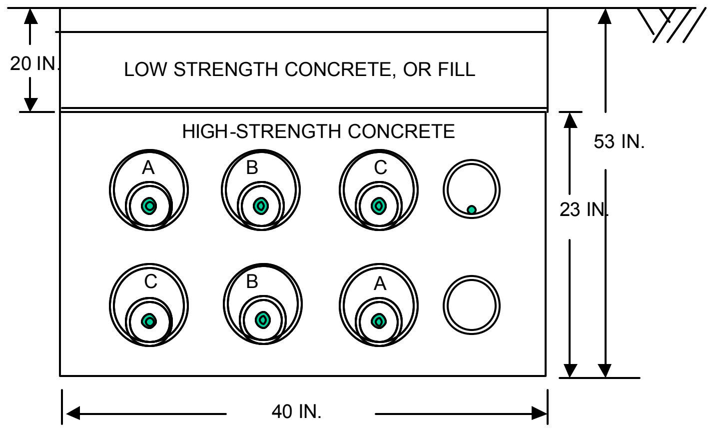


Figure 4. Trench cross section of 345-kV XLPE cable system, horizontal configuration, with two cables per phase

PDC's computer program, CableEMF, was used to model the above ground magnetic field produced by the XLPE underground transmission cables. This program is based on the Biot Savart law of fundamental magnetic field theory and application of Biot – Savart's described in the *Underground Transmission Systems Reference Book* (EPRI, 1992).

The accuracy of the CableEMF magnetic field calculations was verified by field measurements performed in the vicinity of 138-kV XLPE transmission lines in Honolulu, Hawaii and Baltimore Maryland.

2.5 Electric and Magnetic Field Measurements of Overhead Transmission Lines

Measurements of the magnetic field were made around the perimeter of the Scovill Rock Switching Station, along a profile perpendicular to existing transmission lines along Black Walnut Drive in Durham, around the proposed site of the Beseck Substation, along a profile perpendicular to existing transmission lines along Center Road in Woodbridge (Jewish Community Center), along a profile perpendicular to existing transmission lines near Route 152 (Center Road) in Orange (High Plains Community Center), around the perimeter of the proposed East Devon Substation in Milford, and around the perimeter of the proposed Singer Substation site in Bridgeport near Atlantic and Main Street.

Measurements of the electric field were made at locations around the perimeter of the Scovill Rock Switching Station, along a profile perpendicular to existing transmission lines along Black Walnut Drive in Durham, along a profile perpendicular to existing transmission lines along Center Road in Woodbridge, and at locations perpendicular to the existing transmission lines near Route 152 (Center Road) in Orange. Additional measurements of electric and magnetic fields at locations recommended by the Connecticut Siting Council (CSC, 2003) are summarized in the Appendix.

2.5.1 Scovill Rock Switching Station, Middletown

Magnetic and electric fields were measured around the perimeter of Scovill Rock Switching Station. A sketch of the substation and key locations around its perimeter is provided in Figure 5. The electric and magnetic fields are plotted in the upper and lower panels of Figure 6, going clockwise around the station perimeter from the northwest corner. The highest magnetic field measured around the perimeter of the substation was 70 mG and occurred near the northeast corner of the station and was associated with the 345-kV transmission line passing overhead into the station.

The electric fields were measured at locations around the perimeter of the station and are plotted in the upper panel of Figure 6. The electric fields were measured at the four corners of the station and at the approximate midpoints. Measurements were also made under the transmission lines entering the station. The highest electric field measured was 1.32 kV/m and occurred along the east side of the station. The field was associated with a 345-kV transmission line passing overhead into the station.

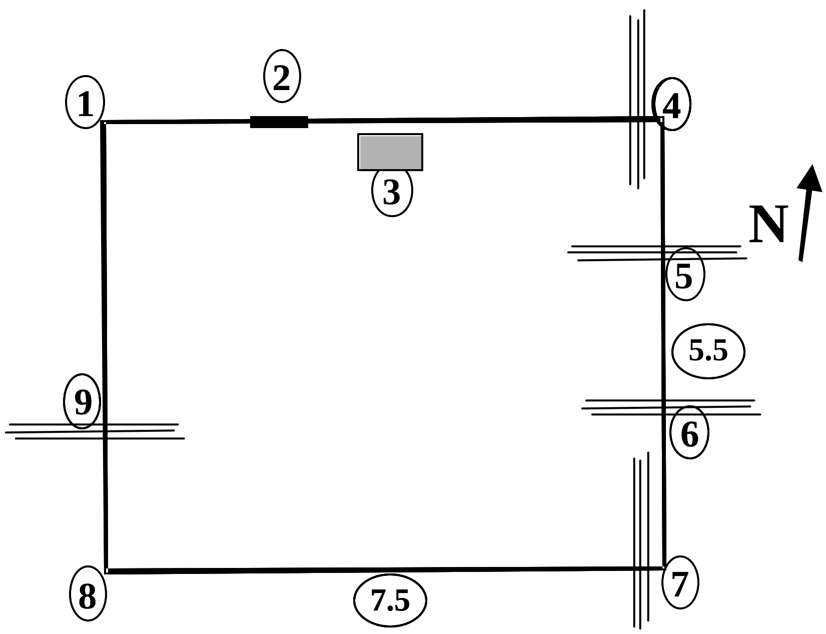
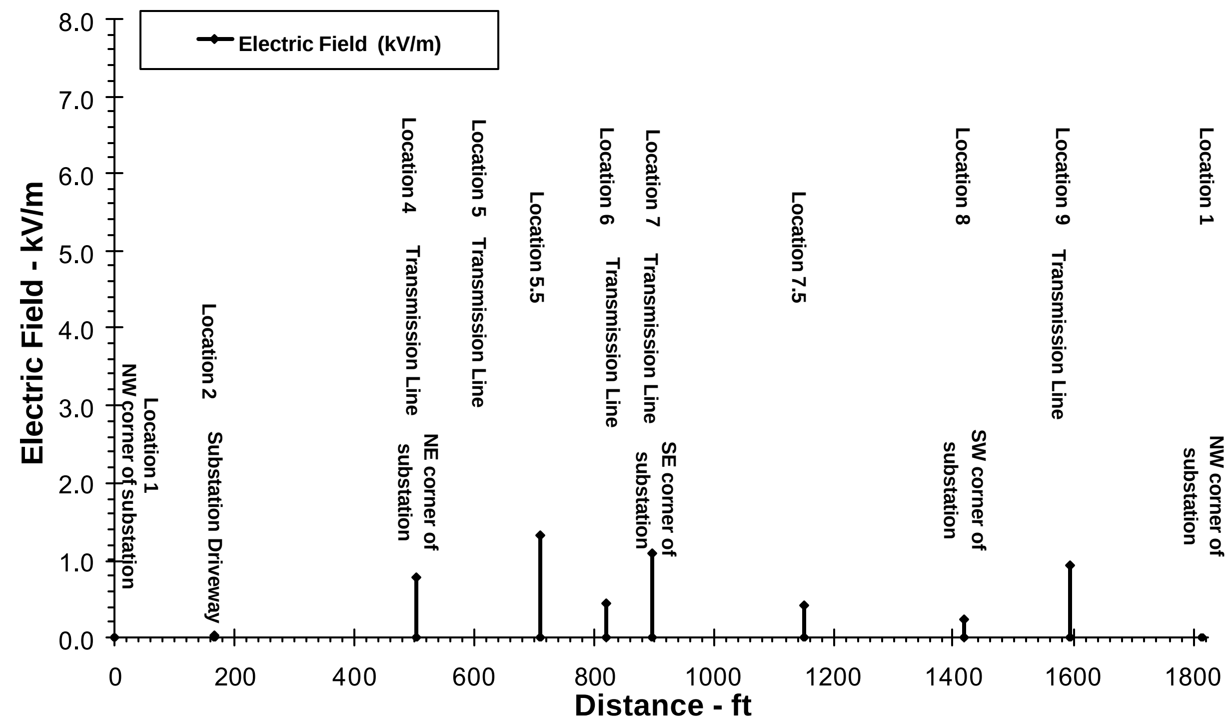


Figure 5. Sketch of the Scovill Rock Switching Station perimeter and labeled measurement locations
(Lines indicate approximate locations of existing 345-kV transmission lines.)



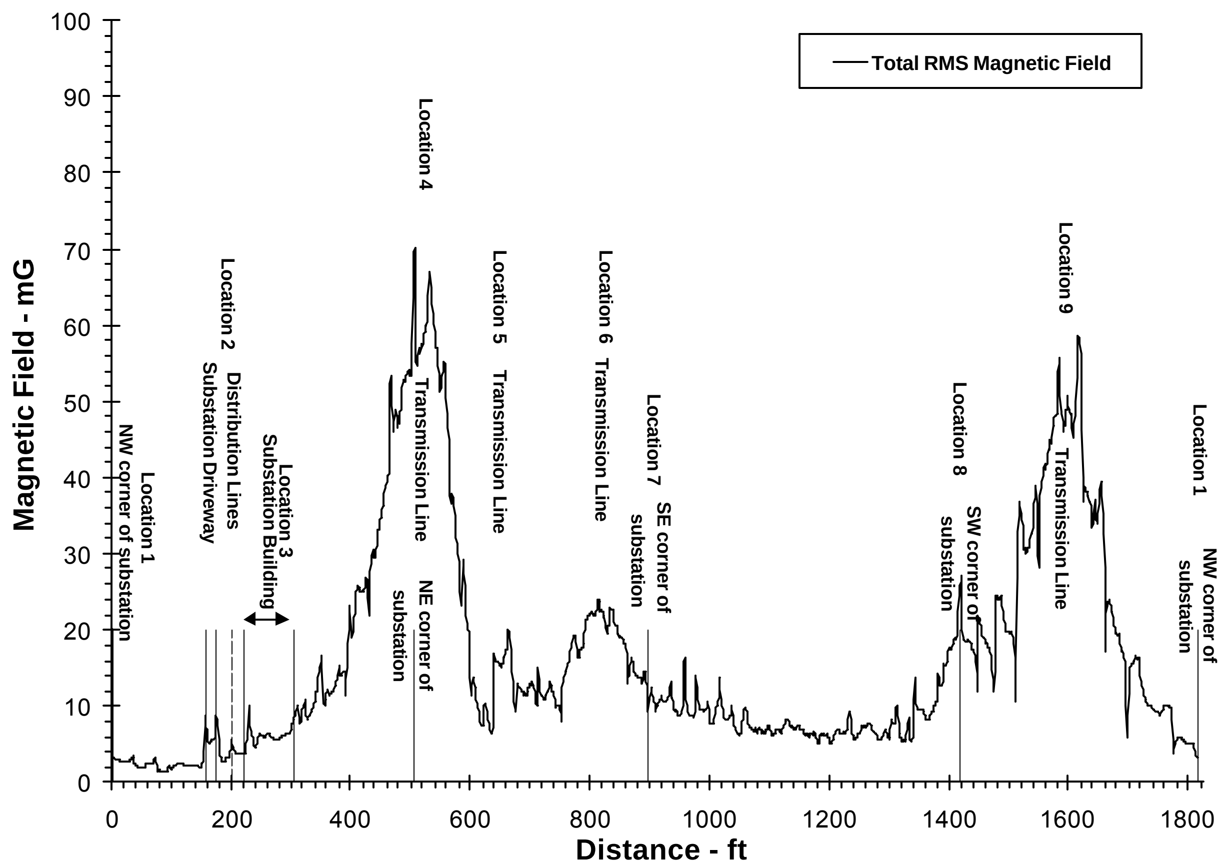


Figure 6. Plot of the electric and magnetic field around the perimeter of the Scovill Rock Switching Station

NY10132.000 C0T0 1003 WB24

2.5.2 Black Walnut Drive, Durham

Magnetic field measurements were taken along a profile from south to north perpendicular to the existing 115-kV transmission lines. The highest magnetic field measured was 14.6 mG and occurred under the transmission lines. The magnetic field profile is plotted in Figure 7.

Electric field measurements were also made along the profile perpendicular to the transmission lines. The highest electric field measured was 1.45 kV/m and occurred under the transmission lines. The electric field profile is plotted in Figure 8.

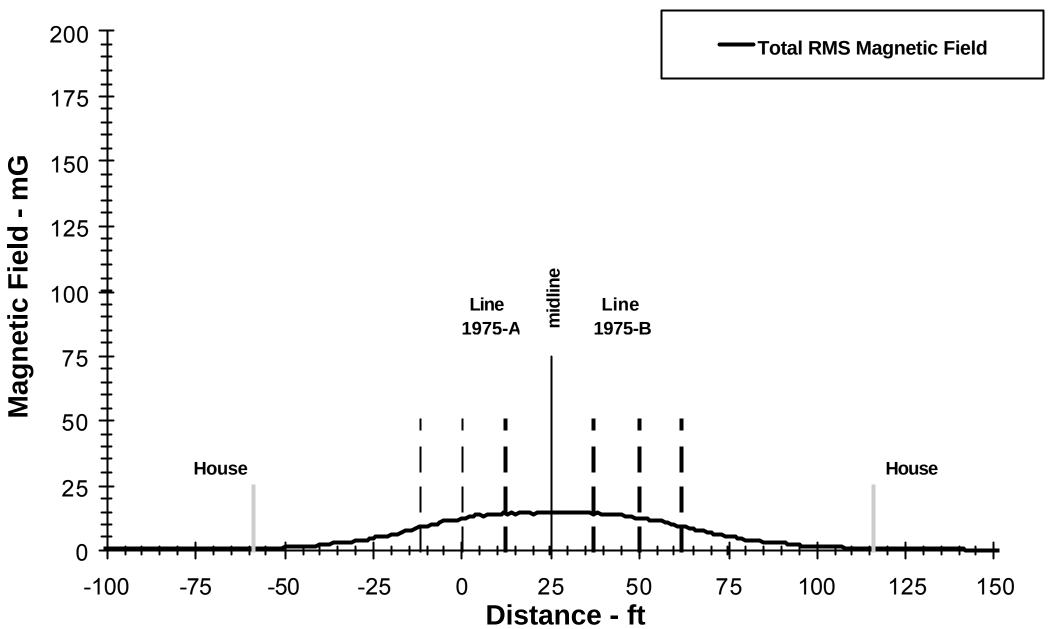


Figure 7. Magnetic field profile from south to north for the transmission lines passing over Black Walnut Drive

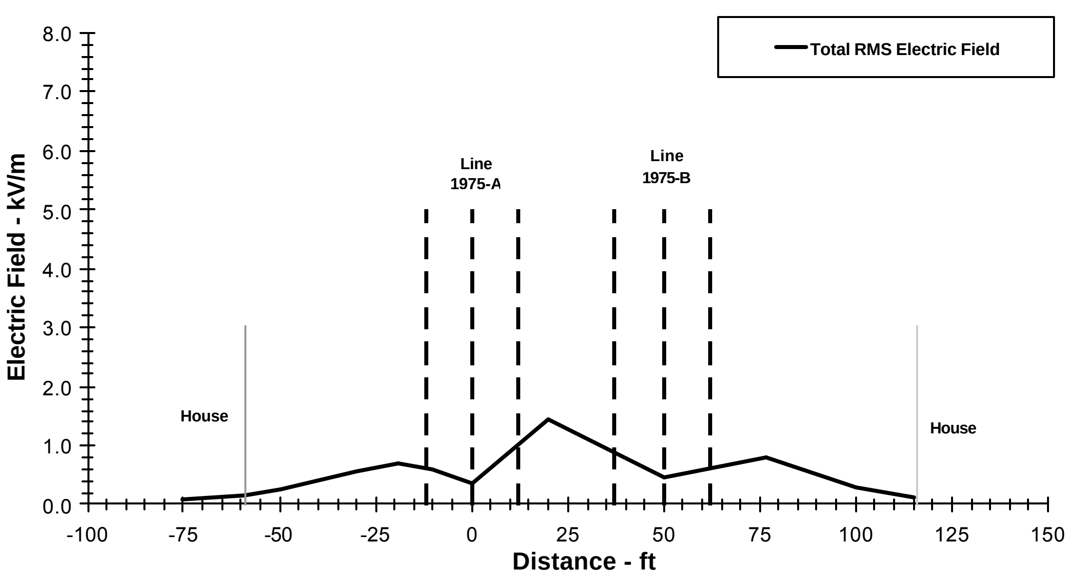


Figure 8. Electric field profile from south to north for the transmission lines passing over Black Walnut Drive

2.5.3 Carpenter Lane (Proposed Beseck Substation Site)

Measurements of the electric field and magnetic field were taken at the site of the proposed Beseck Substation. The site is part of a larger tract owned by Northeast Utilities, north of Carpenter Lane and east of High Hill Road. A sketch of the Beseck site is shown in Figure 9. Existing transmission lines are located on the north and east side of the proposed site as shown in Figure 9. Nearby trees on the site and along its perimeter perturbed the electric field measurements.

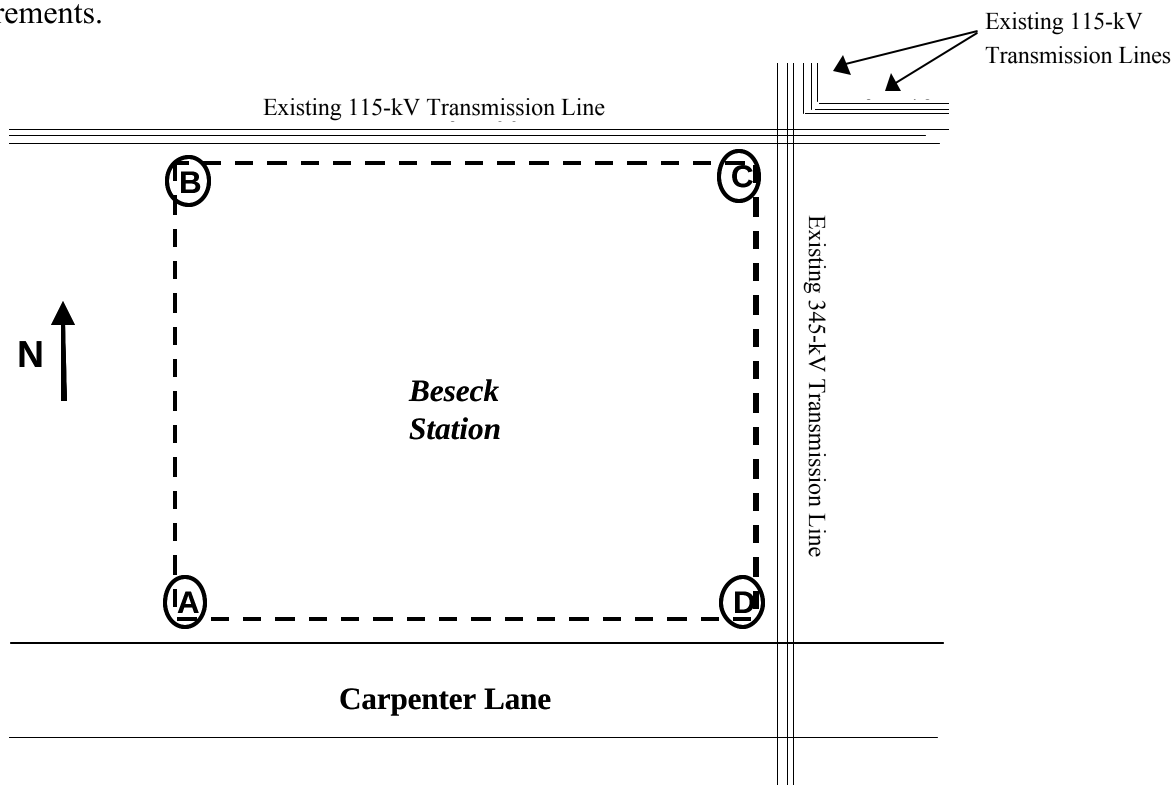


Figure 9. Sketch of the site for the proposed Beseck Substation

The magnetic field was measured around the perimeter of the site indicated by the dashed line on Figure 9. The perimeter profile started at Location A and proceeded clockwise around the site from A to B to C to D, and back to A. The magnetic field profile is plotted in Figure 10. The highest value, measured at Location D, was influenced by the nearby 115-kV and 345-kV lines that meet at Carpenter Junction.

The electric field was measured at the four corners of the proposed site, labeled A, B, C and D on Figure 9. The field values are annotated on Figure 10.

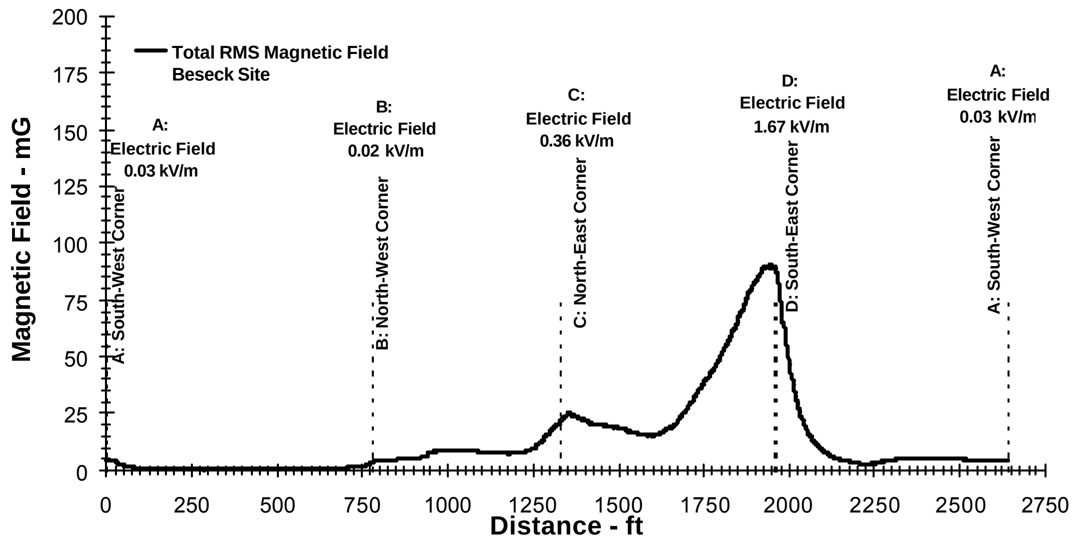


Figure 10. Magnetic field profile around the perimeter of the proposed site of the Beseck Substation.
The profile starts at the southwest corner of the site and proceeds clockwise around the site from Location A to B to C to D and back to A (see Figure 9)

2.5.4 Route 114, Woodbridge (near Jewish Community Center)

Magnetic field measurements were taken along a profile from east to west perpendicular to the existing 115-kV transmission lines. The highest magnetic field measured was 18.8 mG and occurred under the transmission lines. The magnetic field profile is plotted in Figure 11.

Electric field measurements were also made along the profile perpendicular to the transmission lines. The highest electric field measured was 1.36 kV/m and occurred under the transmission lines. The electric field profile is plotted in Figure 12.

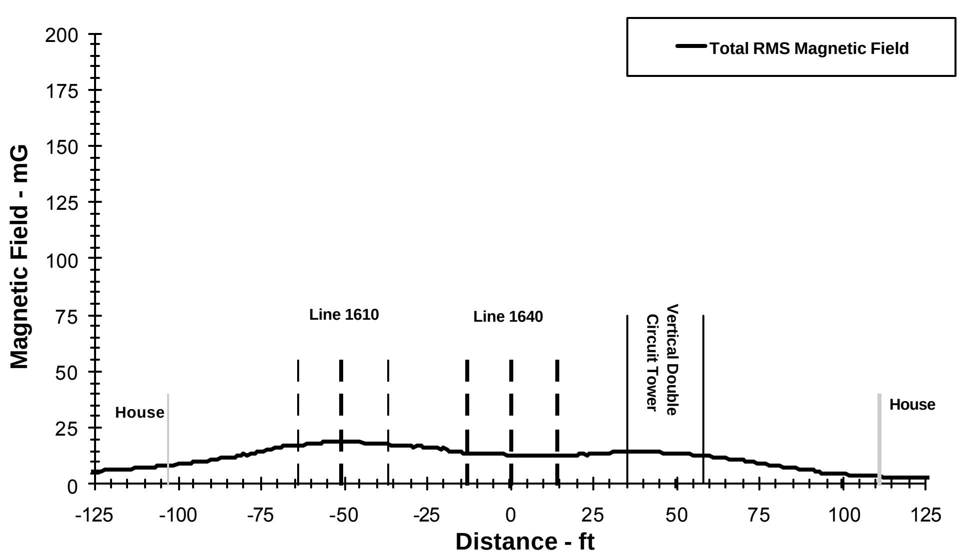


Figure 11. Magnetic field profile from south to north for the transmission lines passing over Route 114 (Center Road) in Woodbridge

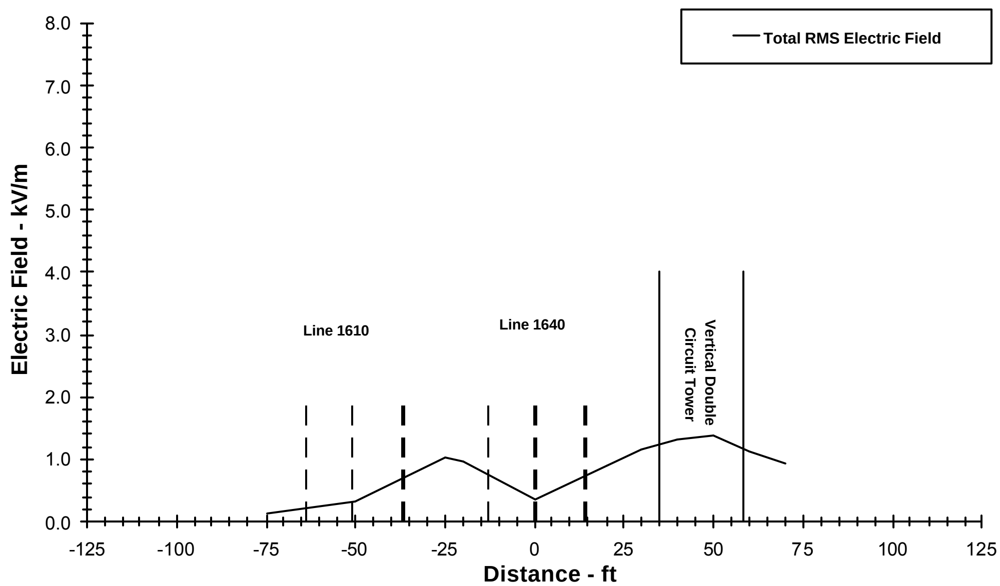


Figure 12. Electric field profile from south to north for the transmission lines passing over Route 114 (Center Road) in Woodbridge

2.5.5 Route 152, Orange (High Plains Community Center)

Magnetic field measurements were taken along a profile from south to north perpendicular to the existing 115-kV transmission lines. The highest magnetic field measured was 16.2 mG and occurred under the transmission lines. The magnetic field profile is plotted in Figure 13.

Electric field measurements were also taken at the location of the highest electric field, which occurred under the double circuit lines, and at the fence line of the playground at its closest approach to the transmission lines. The highest electric field under the transmission lines was 0.90 kV/m. The electric field at the fence line was 0.18 kV/m.

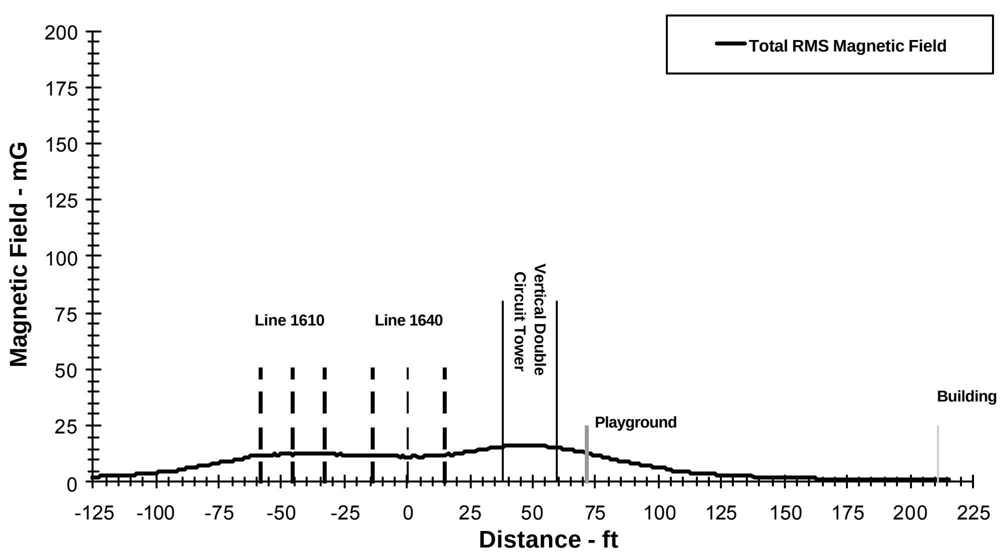


Figure 13. Magnetic field profile from south to north for the transmission lines adjacent to the High Plains Community Center in Orange

2.5.6 Plains Road, Milford (Proposed site of East Devon Substation)

Measurements of the electric field and magnetic field were taken at the site of the proposed East Devon Substation. The site is north of the Milford Power generating plant and east of Oronoque Road. A sketch of the East Devon site is shown in Figure 14.

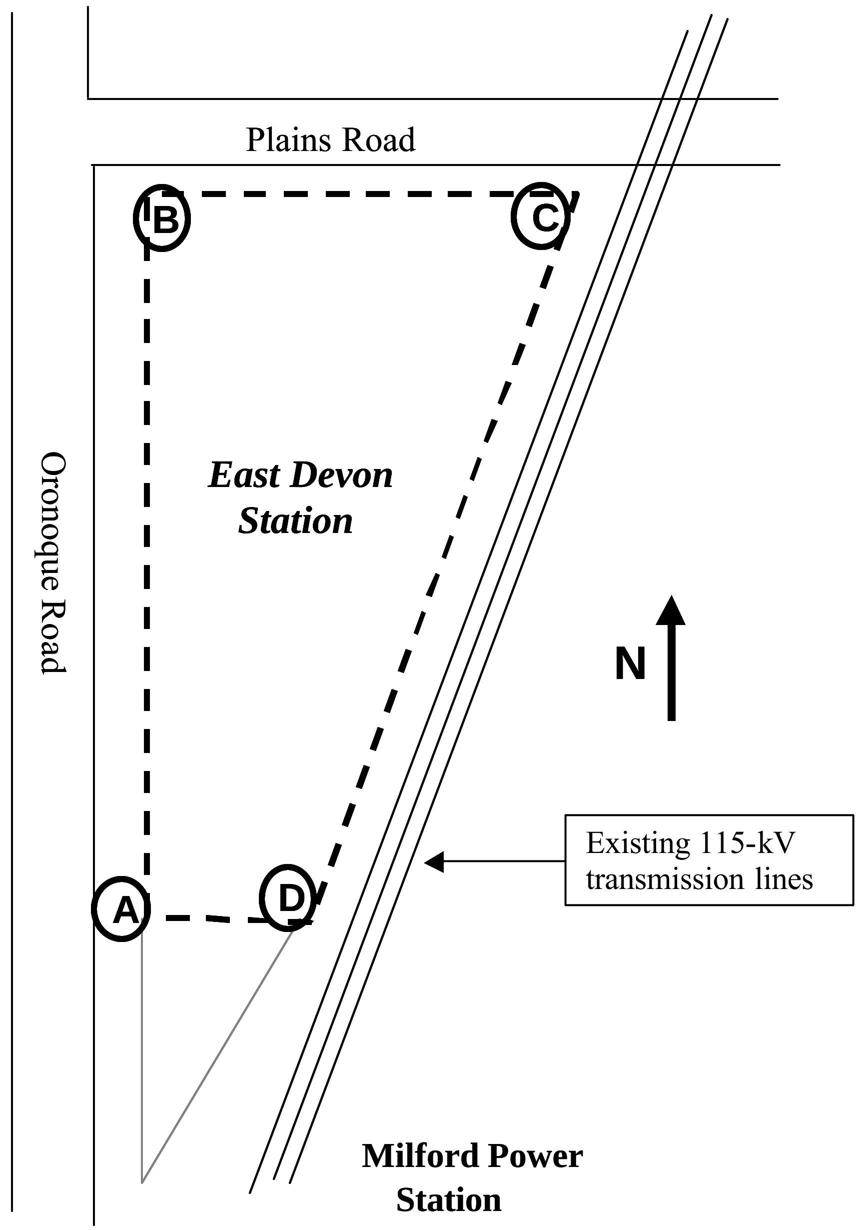


Figure 14. Sketch of the proposed site for the East Devon Substation

Existing transmission lines are located on the east side of the proposed site and the Milford Power station is located to the south of the site as shown in Figure 14. The magnetic field was measured around the perimeter of the site indicated by the dashed line. The perimeter profile started at Location A and proceeded clockwise around the site from A to B to C to D and back to A. The magnetic field profile is plotted in Figure 15.

Electric field measurements were made at the site corner locations identified as A, B, C and D. The values are annotated on Figure 15. Nearby trees on the site and along its perimeter perturbed the electric field measurements to varying degrees.

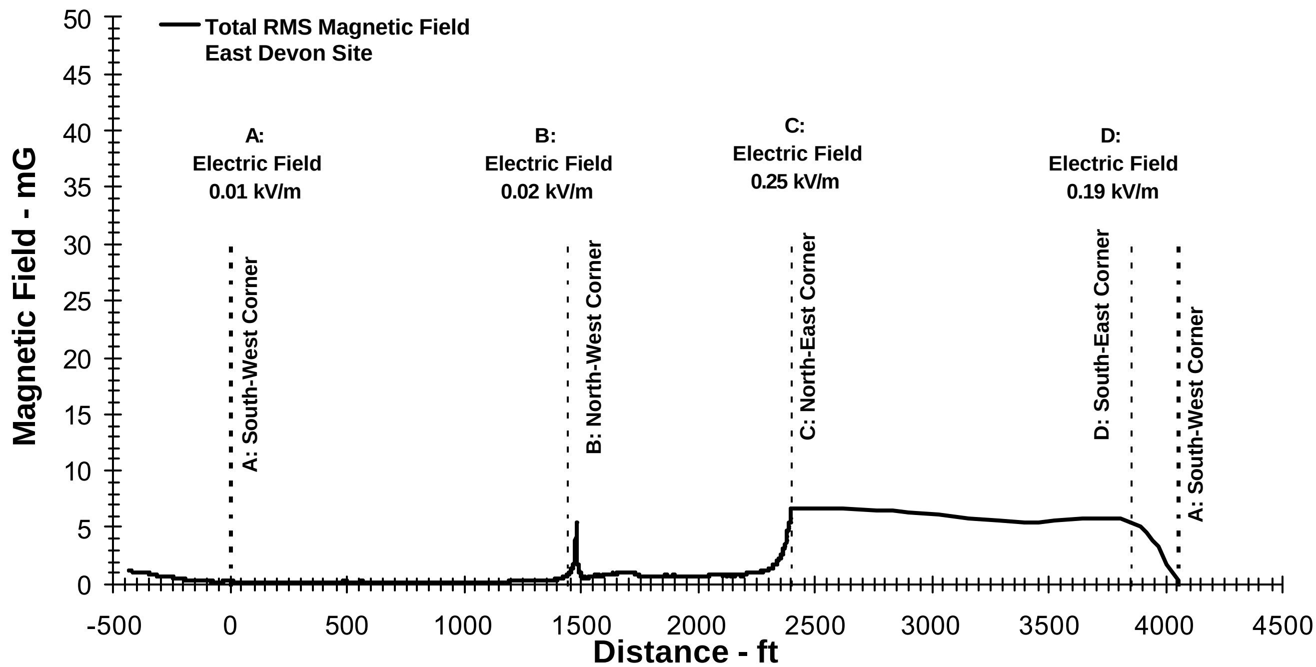


Figure 15. Magnetic field profile around the perimeter of the proposed site of the East Devon Substation
The profile starts at the southwest corner of the site and proceeds clockwise around the site from Location A to B to C to D and back to A (see Figure 14).

2.5.7 Atlantic and Main in Bridgeport (Proposed Singer Substation Site)

Magnetic field measurements were taken along the perimeter of a potential substation site along Main Street in Bridgeport bounded by Atlantic and Whiting Streets. Bridgeport Energy abuts the site on the fourth side. A sketch of the site is provided in Figure 16. The magnetic fields measured along the perimeter of the site are plotted in Figure 17. The highest magnetic field along the perimeter was 30.5 mG and occurred adjacent to the Bridgeport Energy fence line.

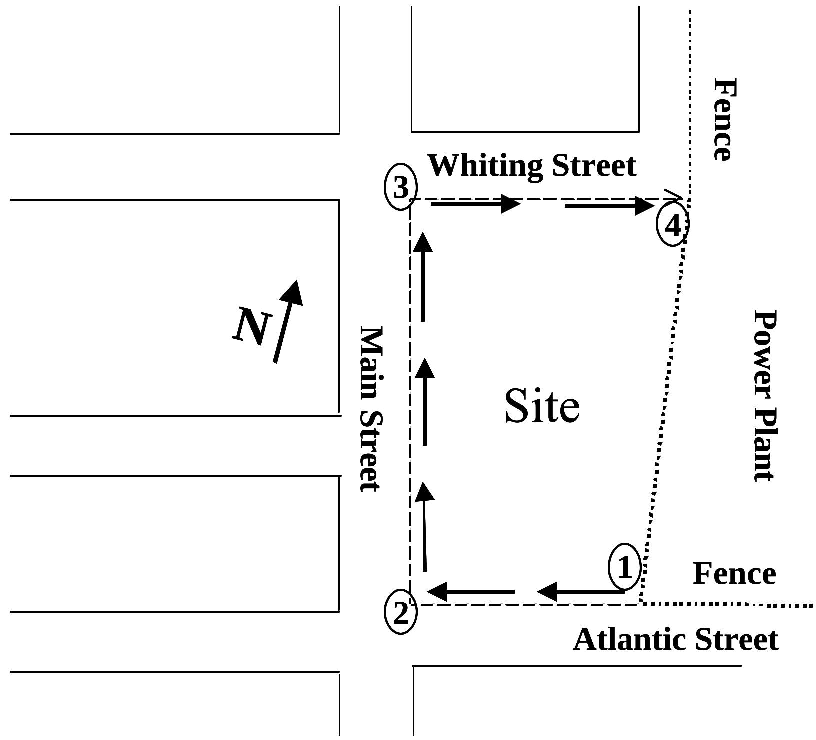


Figure 16. Sketch of the proposed site of the Bridgeport Substation along Atlantic, Main, and Whiting Streets

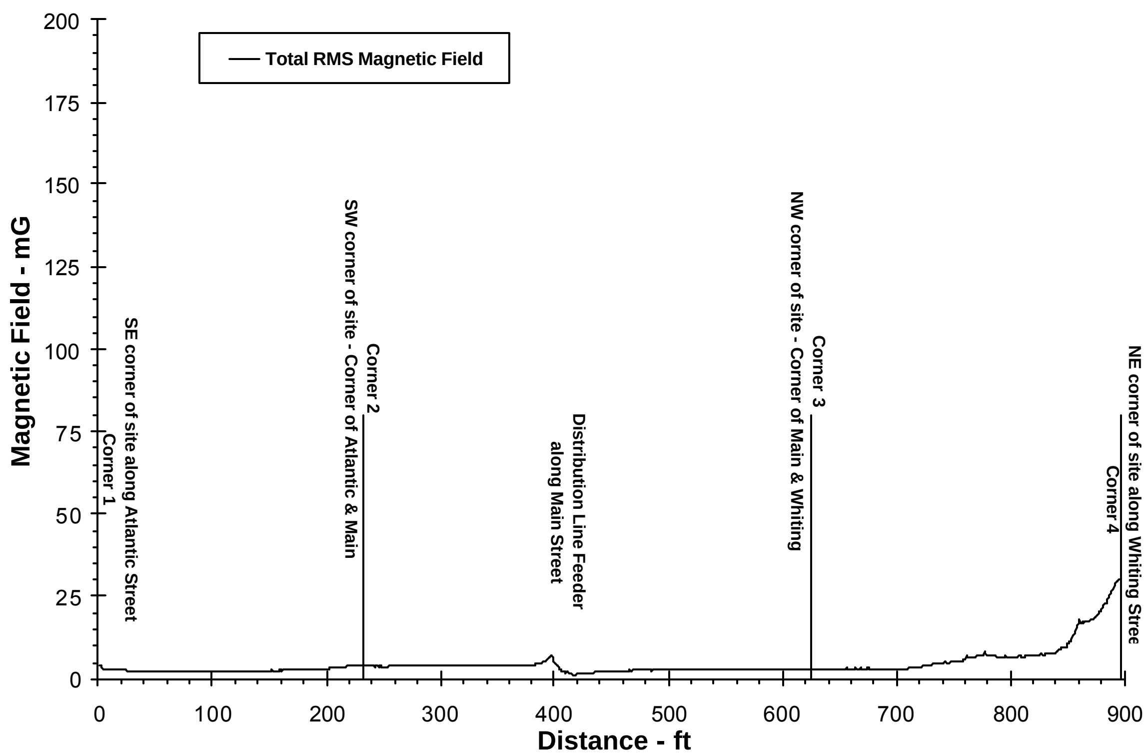


Figure 17. Magnetic fields along the perimeter of the Bridgeport Substation site

2.5.8 Norwalk Substation

A sketch of the perimeter of the Norwalk Substation is shown in Figure 18. The substation is located on the west side of Route 7 at the junction with Route 123. Electric field measurements were taken around the perimeter of the substation at locations B, E, F, H, J, and L shown in Figure 18. The measurements reflect existing conditions at this substation without the additions planned for the termination of the Bethel-Norwalk 345-kV line. There are trees and brush along the west side of the substation. Route 123 borders the south side of the substation. The east side of the substation borders a southbound exit ramp of Route 7. The north side of the substation is bordered by low brush on the right-of-way of several 115-kV transmission lines for the substation. The electric field measurements are summarized in Table 3.

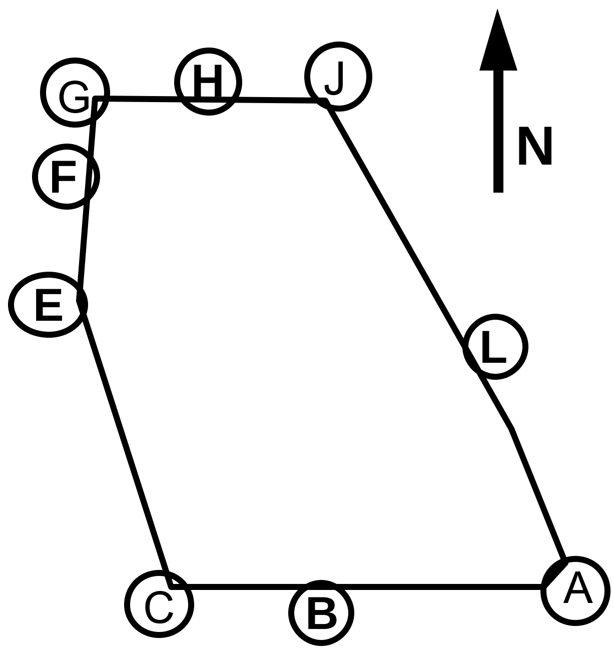


Figure 18. Sketch of the Norwalk Substation

Table 3. Measured electric field – perimeter of Norwalk Substation

Location	Electric Field (kV/m)
B: South Side	0.033
E: West Side (under line)	0.259
F: North West Side (parallel line)	0.628
H: North Side	0.160
J: North East Corner (under lines)	0.880
L: East Side	0.035

The magnetic field was also measured around the perimeter of the substation starting at the southeast corner (location C in Figure 18). The plot of the magnetic field around the perimeter of the substation is shown in Figure 19.

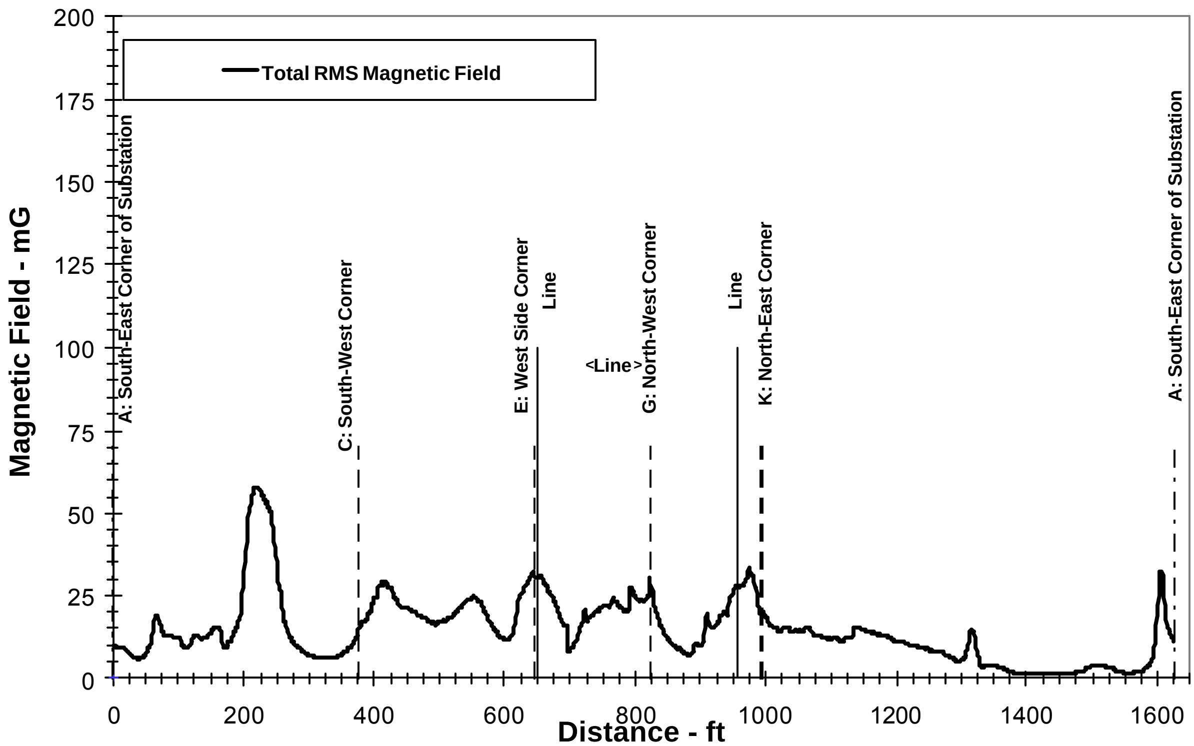


Figure 19. Magnetic field measurements around the perimeter of the Norwalk Substation starting at the substation's southeast corner (location C in Figure 18)

2.6 Calculated Electric and Magnetic Fields from Transmission Lines

When applying for a Certificate of Environmental Compatibility and Public Need (Certificate) before the Connecticut Siting Council (CSC), it is required that the applicant demonstrate that efforts are being taken to manage the electric and magnetic fields associated with those facilities as recommended in "Electric and Magnetic Field Best Management Practices" (CSC, 1993).

To this end, electric and magnetic fields were modeled for each section of proposed and alternative routes. For magnetic field calculations, the assumed loading on existing and the proposed lines was the "15 GW Case." The fields were calculated for both existing line cross sections along the route and for the cross sections after the proposed 345-kV transmission line. This "15 GW Case" conforms to an all New England average annual load of 15 GW that can be expected in the future. This case was developed by NU by modeling an average New England load of approximately 15 GW with representative generator dispatches for this load level in 2007. From this load flow modeling, average line loadings in the Connecticut region of interest were determined for the existing systems lines and for the system after the addition of the proposed 345-kV line. This provided a realistic comparison of the magnetic field along the proposed route before (without) and after (with) the proposed 345-kV transmission line for similar loading and generation conditions. Additional calculations for a 27 GW case reflecting peak system loadings that might occur for a single hour during the year are summarized in the Appendix. Calculated fields at locations near the proposed route in categories listed in Section N of Connecticut Siting Council Application Guide (CSC, 2003) are also provided in the Appendix.

The magnetic and electric field values associated with the operation of existing and proposed overhead and underground transmission lines for typical structure height are shown in Table 4 and Table 5, respectively. For overhead lines, the calculated values represent the highest field values, which are found midway between structures where the conductors are closest to the ground. The location of the sections of the primary route and the two alternative routes can be identified by the numbers of the sections on Figure 18 through Figure 21.

Following Figure 18, sketches of each cross section of the route segments are shown with the corresponding profiles of calculated electric and magnetic fields on the facing page. The cross section sketches represent typical structure heights and structures at specific locations may vary. The cross section sketches depict the typical configuration of the overhead or underground transmission lines considered for each section of the four proposed routes.

The differences in calculated field levels between the existing and proposed configurations shown in the profiles and in Tables 4 and 5 are similar to those reported in the Municipal Consultation draft. However, the use of conductor heights for the shortest span rather than the average span resulted in generally somewhat higher calculated field values in this report for both existing and proposed transmission lines (a. short span assumption will yield a more conservative estimate for the purposes of calculating electric and magnetic fields.) On one section, lower field levels resulted from optimizing the phasing of adjacent circuits to achieve maximum field cancellation. Other differences in field levels between those calculated for the Municipal Consultation draft and this report are the result of refinements in structure configuration, line placement, and other design factors.

Table 4. Edge of right-of-way electric field values for existing, proposed and alternative line configurations in 2007

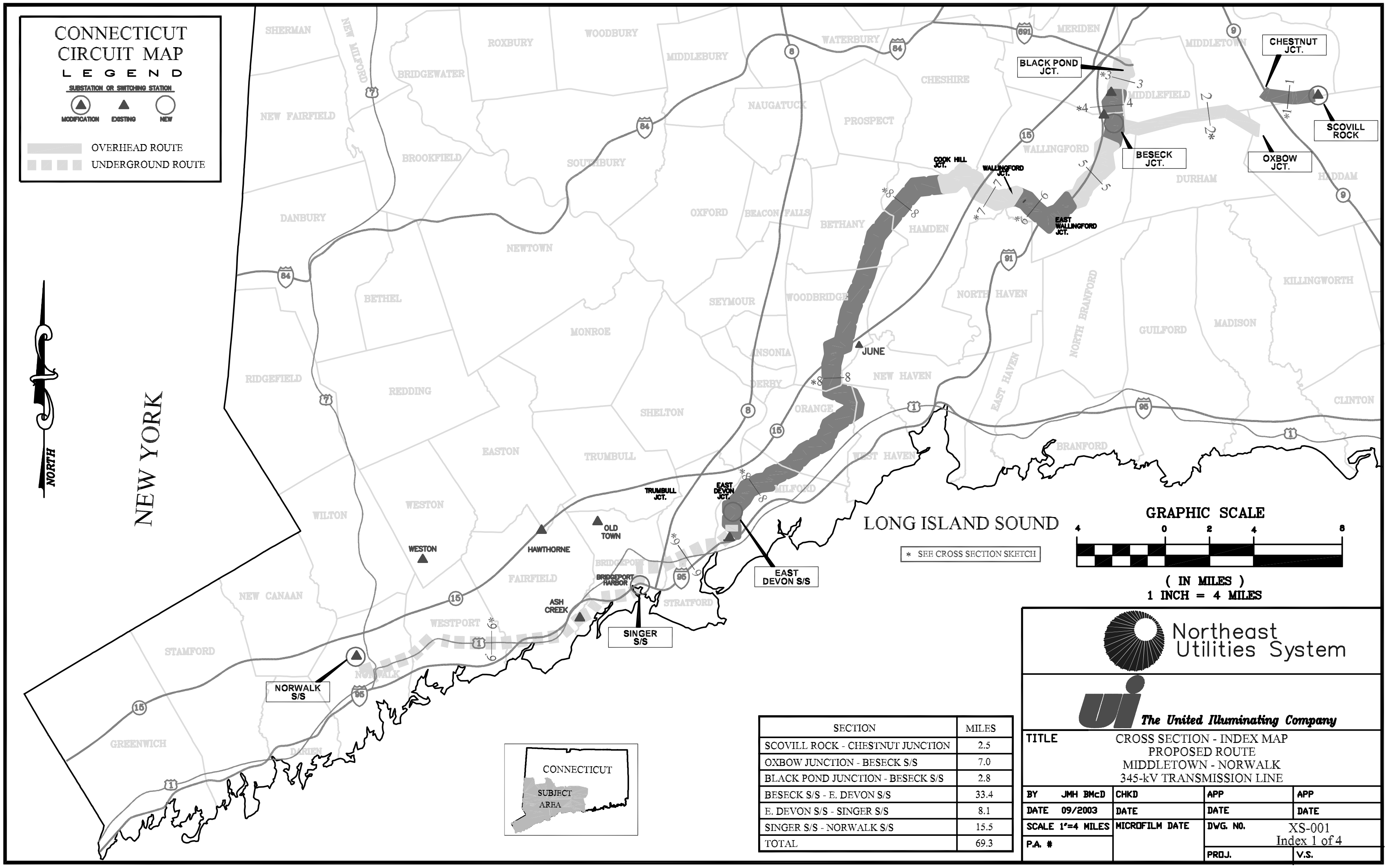
Cross Section	Existing Electric Field (kV/m) East/South*ROW	Existing Electric Field (kV/m) West/North**ROW	Proposed Electric Field (kV/m) East/South ROW	Proposed Electric Field (kV/m) West/North ROW
Proposed Primary 345-kV Overhead Route				
1	1.39	1.39	1.44	1.40
2	0.67	0.91	0.31	0.21
3	0.28	0.20	0.15	0.29
4	0.15	0.56	0.09	0.21
5	0.13	1.21	0.78	1.30
6	0.03	0.53	0.25	0.20
7 and 7A	0.01	0.09	0.75	0.10
8 and 8B	0.70	0.62	0.45	1.48
"Supported Changes" - 345-kV Overhead and Relocation of 115-kV to Underground				
7B *(225')****	0.01	0.09	0.21	0.15
8A *(-20')*****	0.70	0.62	0.16	0.31
*(-400')*****	0.70	0.62	0.16	0.31
Proposed and Alternative Underground Line Routes +				
9	- na -	- na -	- na -	- na -
9A (Alternative A)	- na -	- na -	- na -	- na -
10 (Alternative B)	- na -	- na -	- na -	- na -
Alternative Overhead Line Route				
11 (Alternative B)	0.04	0.18	0.11	0.29
12 (Alternative B)	0.87	0.08	0.23	0.10
13 (Alternative B)	0.10	0.06	0.21	0.31
14 (Alternative B)	0.22	0.07	0.31	0.37
15 (Alternative B)	0.57	0.57	0.31	0.20
16 (Alternative B)	0.29	0.27	0.21	0.31
17 (Alternative A & B)	0.39	0.39	0.21	0.31
18 (Alternative A & B)	0.16	0.76	0.21	0.31
19 (Alternative A & B)	1.01	2.49	1.57	1.57
20 (Alternative A & B)	0.62	1.46	2.94	1.66
21 (Alternative A & B)	0.20	1.51	2.51	1.66
22 (Alternative A & B)	0.67	1.59	2.94	1.66

* Identified in documentation as left ROW
** Identified in documentation as right ROW
*** Distance from edge of ROW. +25' indicates 25' outside of the right (West/North) ROW.
**** Distance from edge of ROW. -20' indicates 20' outside of the left (East/South) ROW
\+ Underground transmission lines do not produce a surface electric field
- na - Not applicable

Table 5. Edge of right-of-way magnetic field values for existing, proposed, and alternative line configurations
2007 annual average loading (15 GW)

	Existing Magnetic Field (mG)		Proposed Magnetic Field (mG)	
Cross Section	East/South* ROW	West/North** ROW	East/South ROW	West/North ROW
Proposed Primary 345-kV Overhead Route				
1	35.6	35.3	31.0	17.3
2	3.0	4.5	31.5	21.5
3	13.5	5.2	4.0	13.8
4	5.7	10.1	2.8	19.8
5	5.7	27.3	11.4	28.3
6	0.9	6.6	2.5	6.1
7 and 7A	0.5	6.7	6.5	9.6
8 and 8B	7.7	4.3	5.7	8.6
"Supported Changes" - 345-kV Overhead and Relocation of 115-kV to Underground				
7B *(25')****	0.5	6.7	4.3	15.4
8A *(-20')*****	7.7	4.3	2.1	7.6
*(-400')*****	7.7	4.3	1.7	7.5
Proposed and Alternative Underground Line Routes+				
9 (HPFF - East Devon to Singer)	- na -	- na -	0.1	0.1
9 (HPFF - Singer to Norwalk)	- na -	- na -	0.2	0.2
9A (Alternative A) (XLPE - Singer to Hawthorne)	- na -	- na -	2.9	2.7
10 (Alternative B) (XLPE - Singer to Seaview Loop)	- na -	- na -	1.7	2.8
Alternative 345-kV Overhead Line Route				
11 (Alternative B)	2.3	9.0	2.8	7.6
12 (Alternative B)	5.6	33.3	3.4	27.7
13 (Alternative B)	1.7	2.0	5.8	6.0
14 (Alternative B)	49.2	5.2	26.3	8.2
15 (Alternative B)	63.3	59.5	26.3	14.4
16 (Alternative B)	52.3	46.3	15.4	16.8
17 Alternative A & B)	34.4	34.6	11.4	22.3
18 (Alternative A & B)	17.0	27.4	16.1	26.2
19 (Alternative A & B)	37.3	38.4	23.9	8.6
20 (Alternative A & B)	43.8	23.9	59.5	8.1
21 (Alternative A & B)	13.8	21.1	35.5	8.1
22 (Alternative A & B)	32.5	18.7	59.5	8.1

* Identified in documentation as left ROW
** Identified in documentation as right ROW
*** Distance from edge of ROW. +25' indicates 25' outside of the right (West/North) ROW.
**** Distance from edge of ROW. -20' indicates 20' outside of the left (East/South) ROW
\+ ROW edge taken as –20' left (East/South) ROW and +20' right (West/North) ROW.
\- na - Not applicable

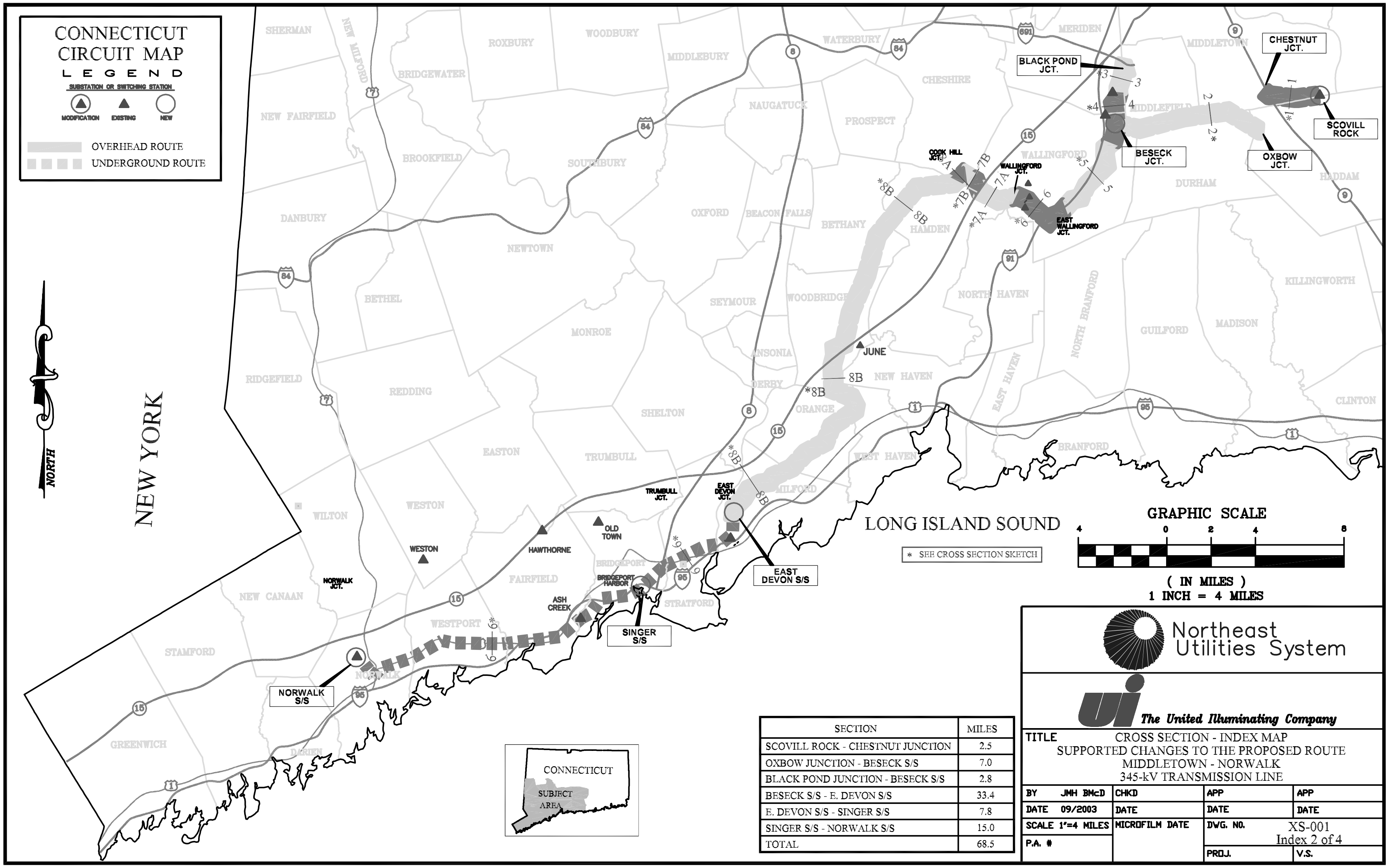


SECTION	MILES
SCOVILL ROCK - CHESTNUT JUNCTION	2.5
OXBOW JUNCTION - BESECK S/S	7.0
BLACK POND JUNCTION - BESECK S/S	2.8
BESECK S/S - E. DEVON S/S	33.4
E. DEVON S/S - SINGER S/S	8.1
SINGER S/S - NORWALK S/S	15.5
TOTAL	69.3

Figure 20. Proposed route: Middletown Substation to East Devon Substation (overhead); East Devon Substation to Norwalk Substation (underground) on *modified* Connecticut circuit map

Note: Shading of overhead line sections changes is to enhance discrimination between adjacent sections.

NY10132.000 C0T0 1003 WB24



SECTION	MILES
SCOVILL ROCK - CHESTNUT JUNCTION	2.5
OXBOW JUNCTION - BESECK S/S	7.0
BLACK POND JUNCTION - BESECK S/S	2.8
BESECK S/S - E. DEVON S/S	33.4
E. DEVON S/S - SINGER S/S	7.8
SINGER S/S - NORWALK S/S	15.0
TOTAL	68.5

Figure 21. "Supported Changes" to proposed route: Middletown Substation to East Devon Substation (overhead); East Devon Substation to Singer Substation to Hawthorne Transfer Station (underground); to Norwalk Substation (overhead) on *modified* Connecticut circuit map
Note: Shading of overhead line sections changes is to enhance discrimination between adjacent sections.

NY10132.000 C0T0 1003 WB24

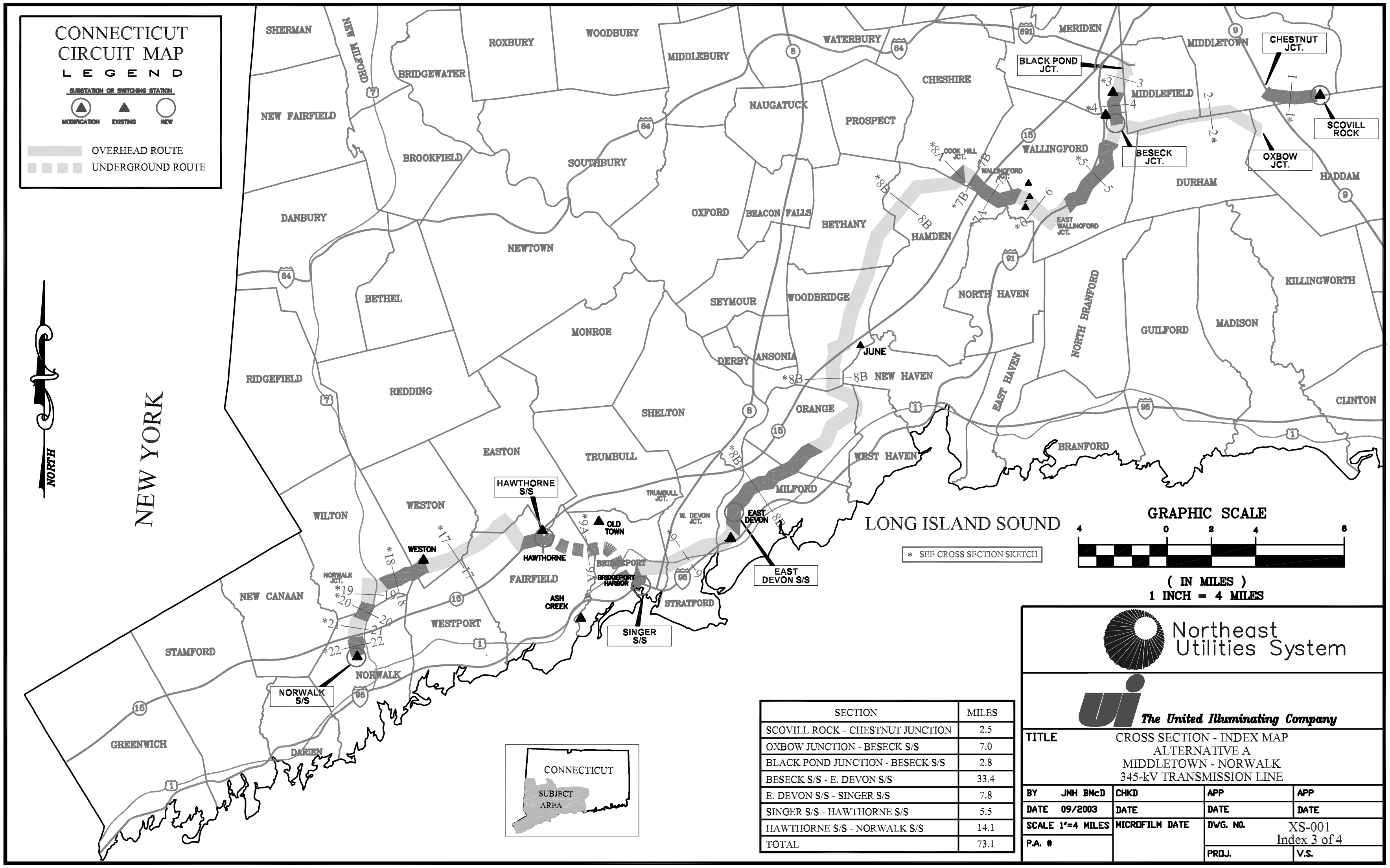
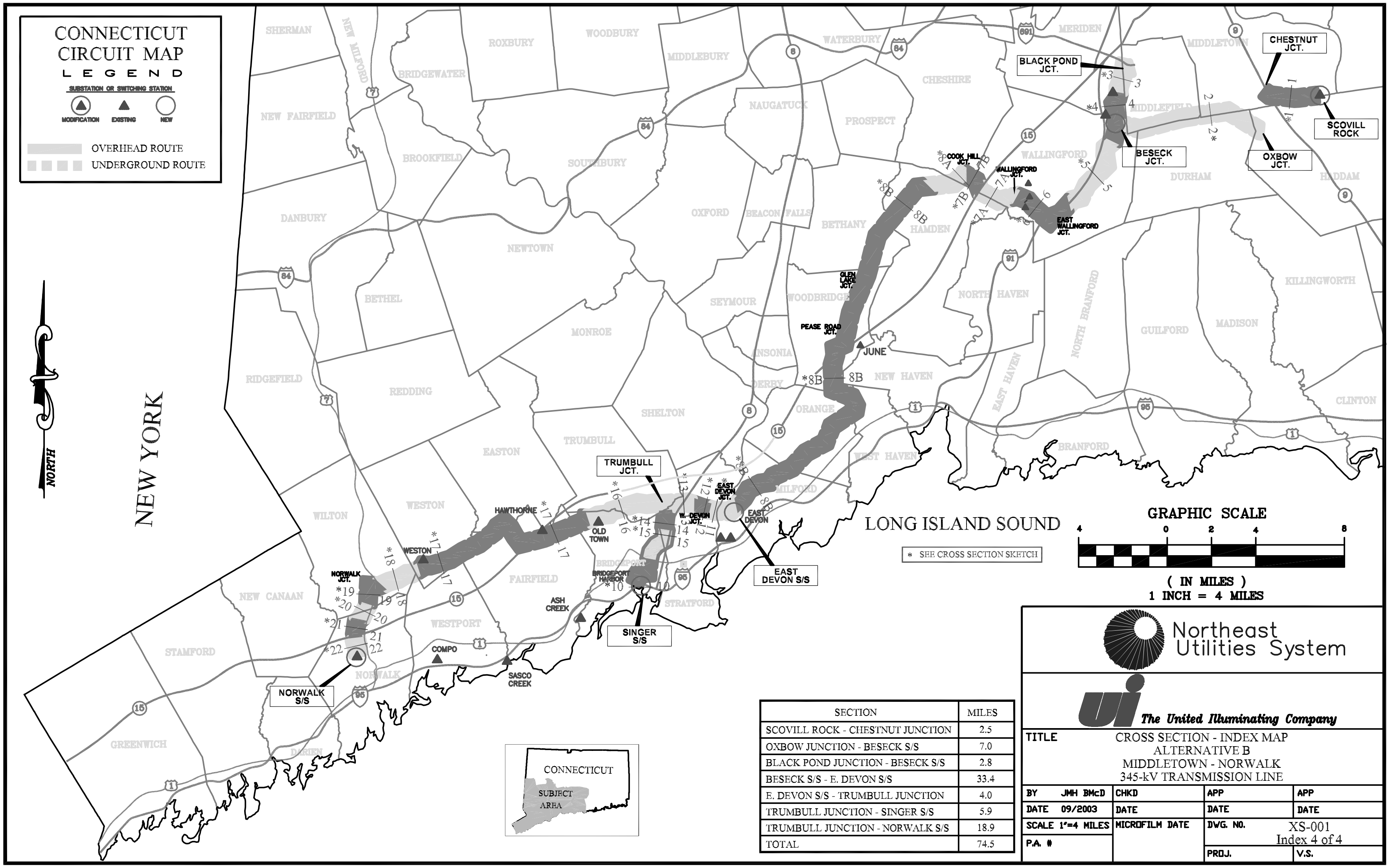


Figure 22. Alternative A route: Middletown Substation to East Devon Substation (overhead); East Devon Substation to Singer Substation to Hawthorne Transfer Station (underground); to Norwalk Substation (overhead) on *modified* Connecticut circuit map
Note: Shading of overhead line sections changes is to enhance discrimination between adjacent sections.

NY10132.000 C0T0 1003 WB24



SECTION	MILES
SCOVILL ROCK - CHESTNUT JUNCTION	2.5
OXBOW JUNCTION - BESECK S/S	7.0
BLACK POND JUNCTION - BESECK S/S	2.8
BESECK S/S - E. DEVON S/S	33.4
E. DEVON S/S - TRUMBULL JUNCTION	4.0
TRUMBULL JUNCTION - SINGER S/S	5.9
TRUMBULL JUNCTION - NORWALK S/S	18.9
TOTAL	74.5

Figure 23. Alternative B route: Middletown Substation to East Devon Substation (overhead); East Devon Substation to Trumbull Junction (overhead); to/from Seaview Substation (underground); to Norwalk Substation (overhead) on *modified* Connecticut circuit map
Note: Shading of overhead line sections changes is to enhance discrimination between adjacent sections.

NY10132.000 C0T0 1003 WB24

Cross Section 1

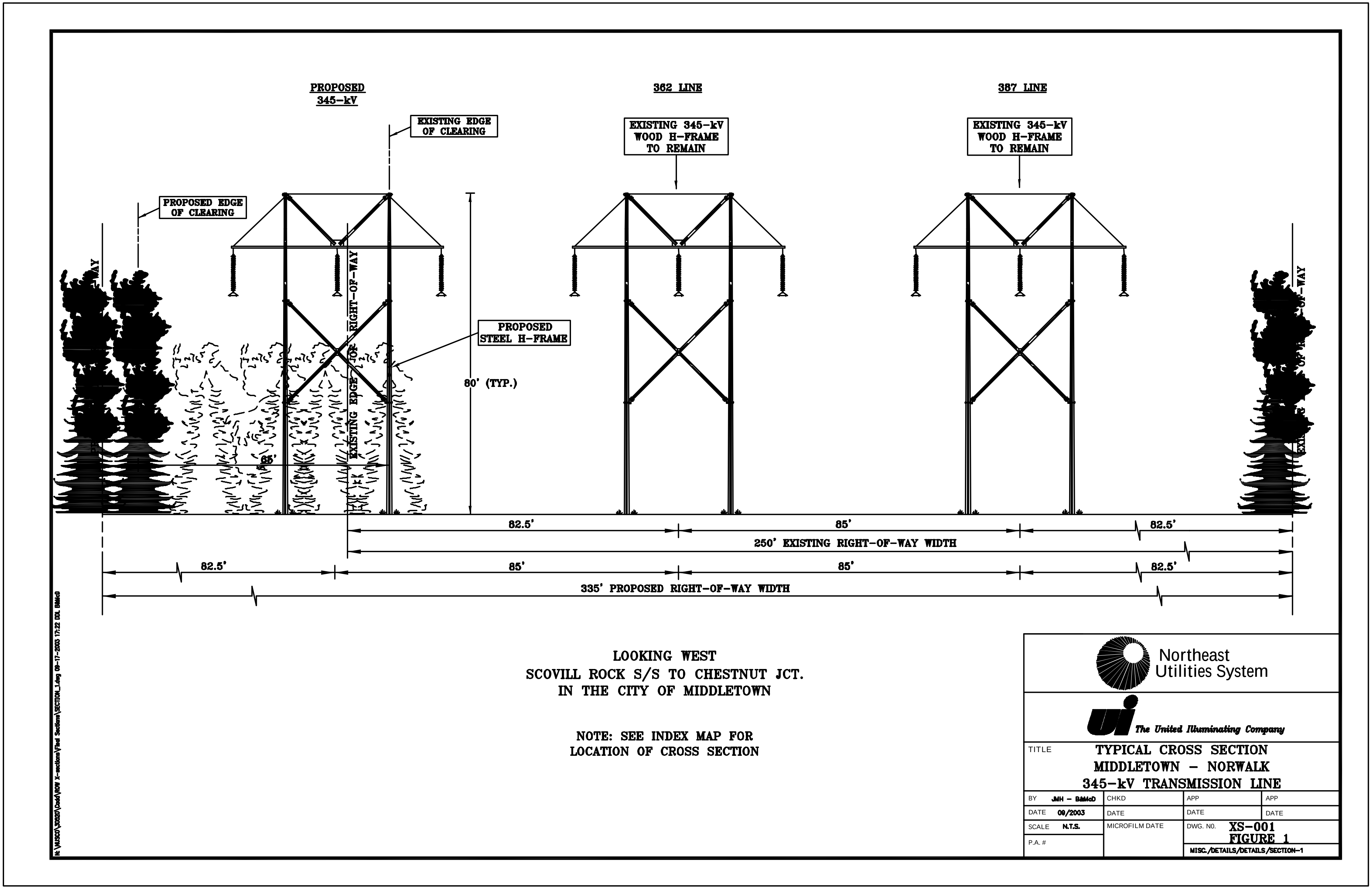
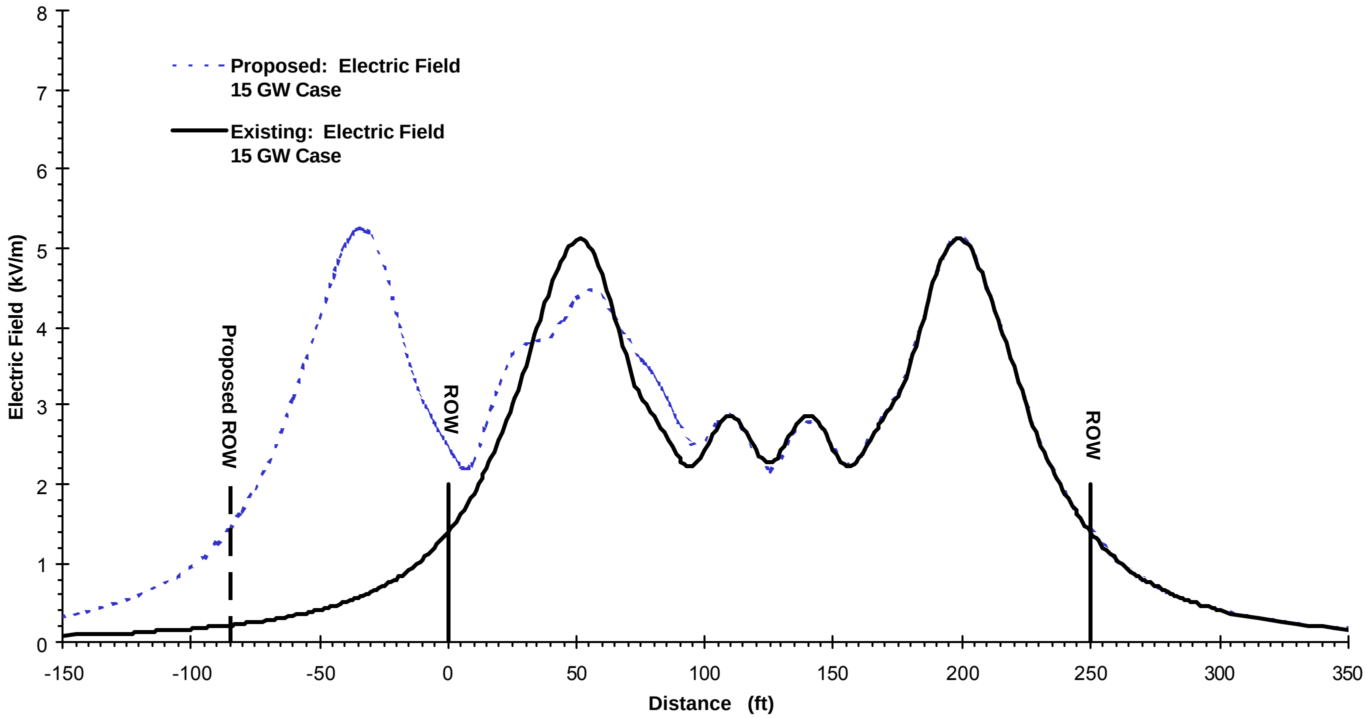


Figure 24. Cross section 1 - Scovill Rock Substation to Chestnut Junction (Middletown)



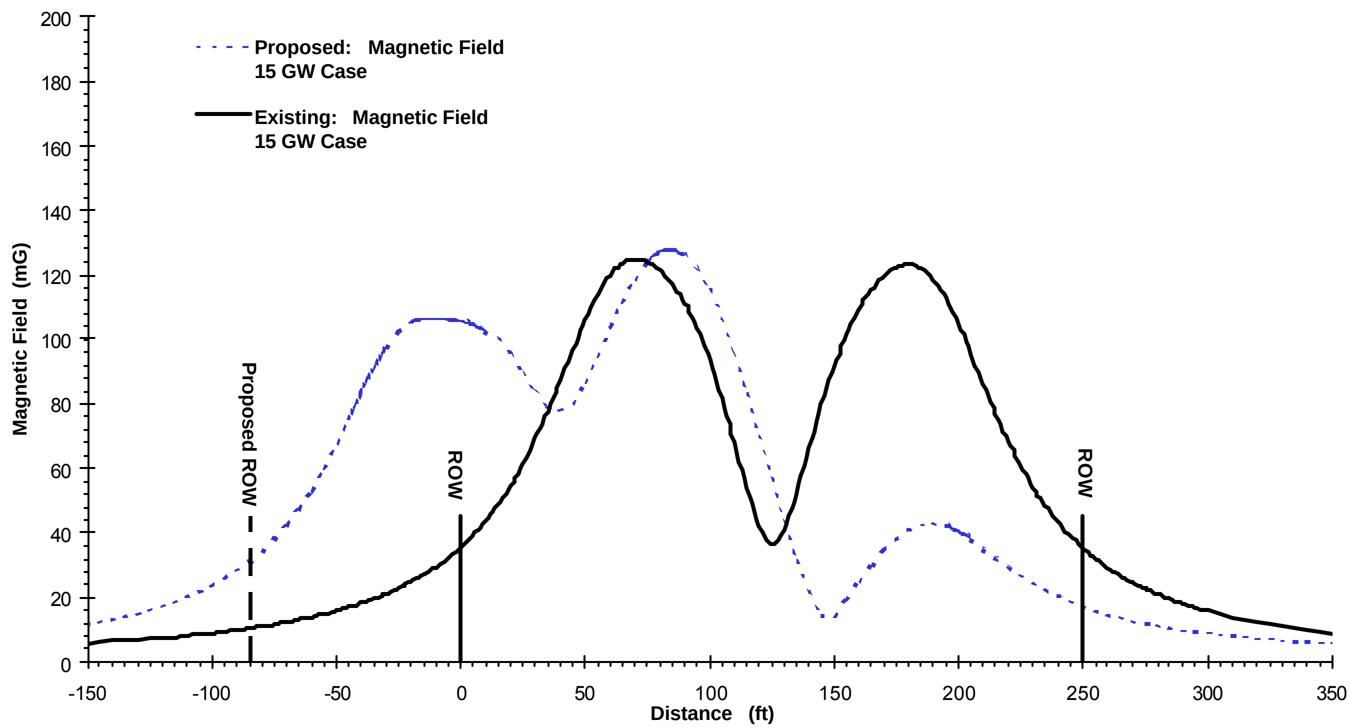


Figure 25. Electric and magnetic field profiles for cross section 1

NY10132.000 C0T0 1003 WB24

Cross Section 2

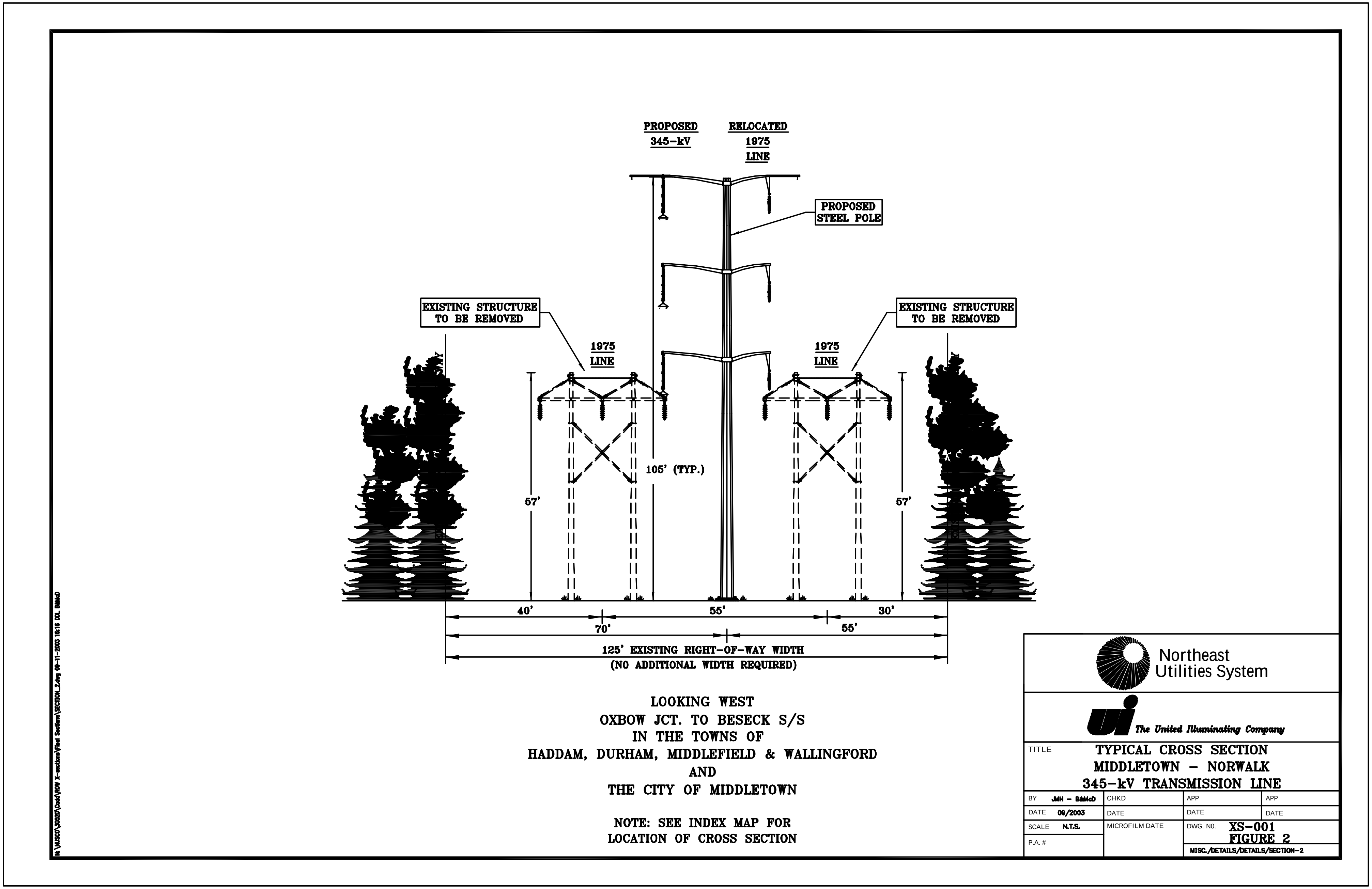
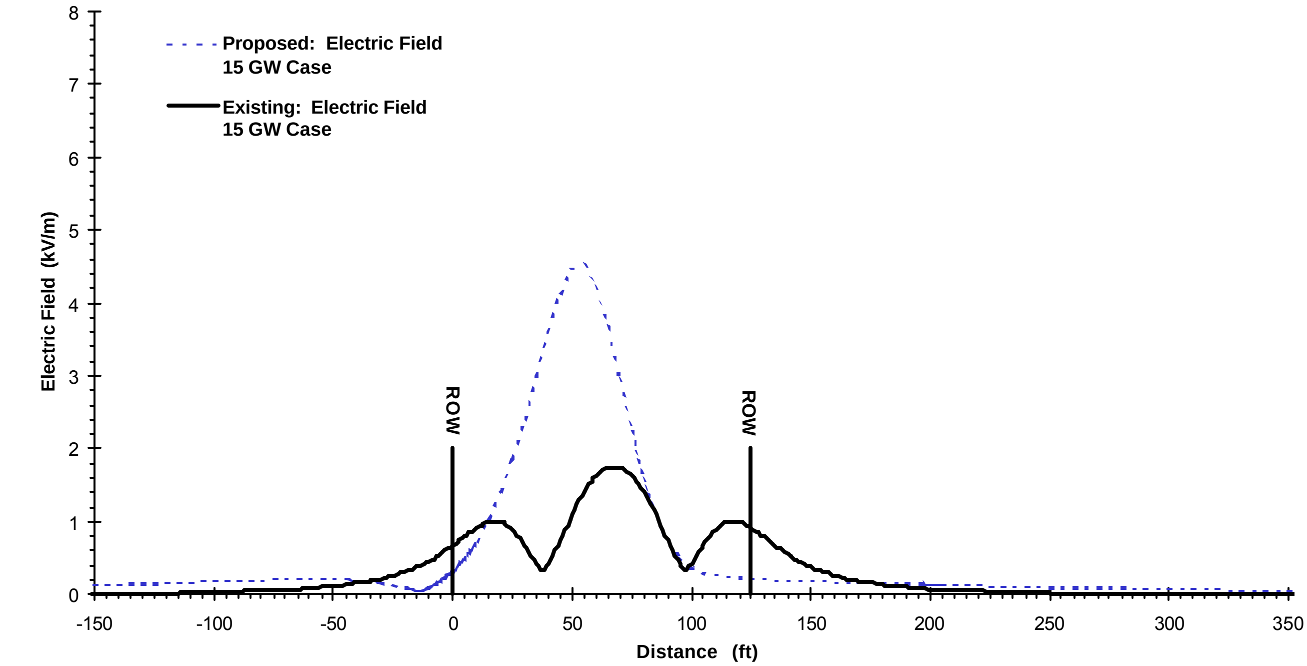


Figure 26. Cross section 2 - Oxbow Junction to Beseck Substation (Haddam, Durham, Middlefield, Wallingford, Middletown)



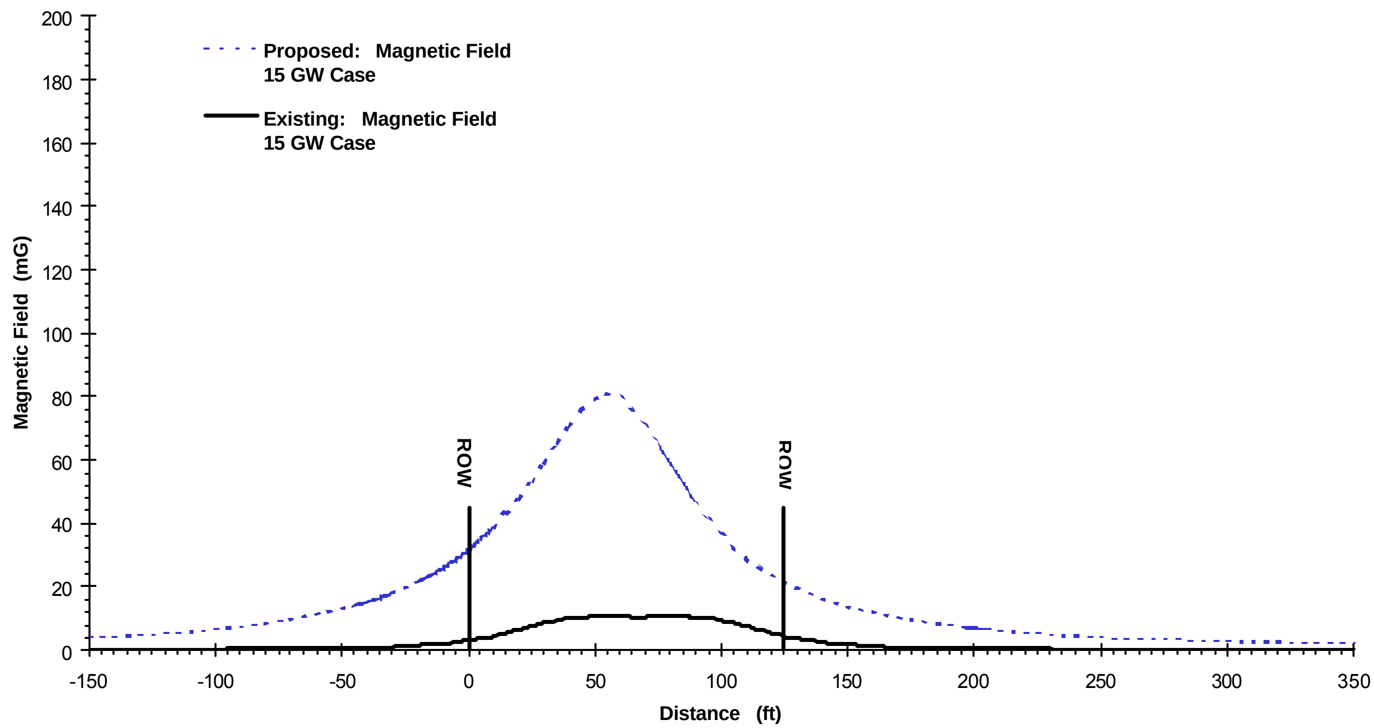


Figure 27. Electric and magnetic field profiles for cross section 2

Cross Section 3

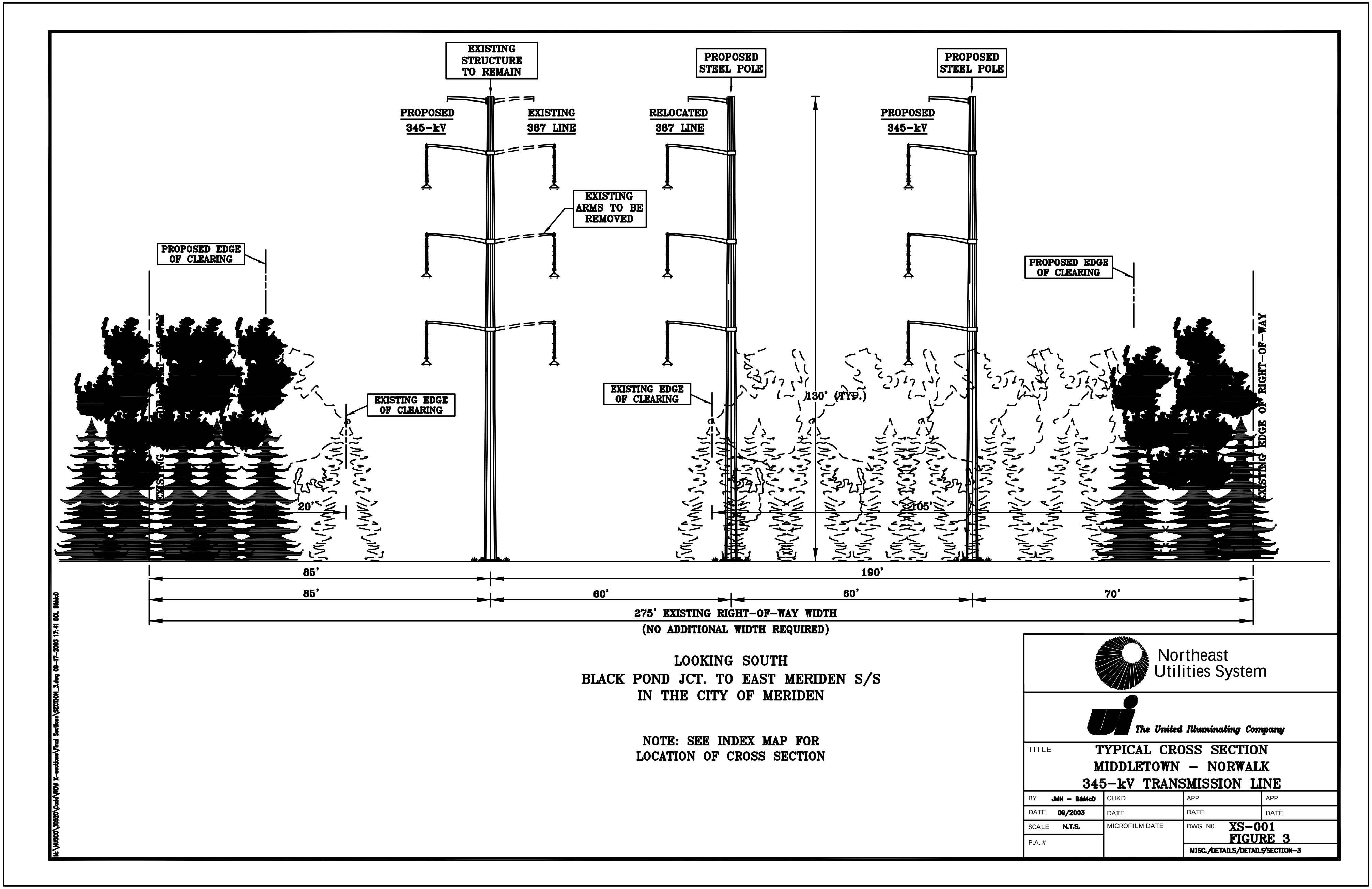
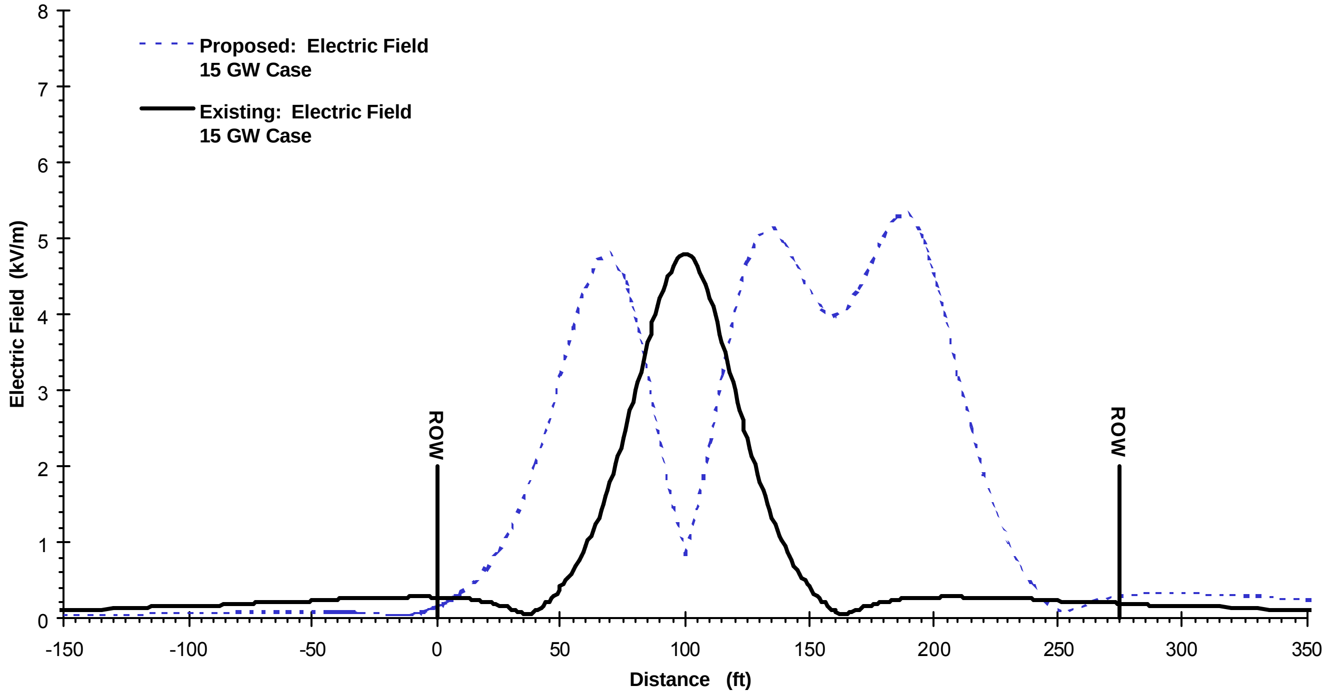


Figure 28. Cross section 3 - Black Pond Junction to East Meriden Substation (Meriden)



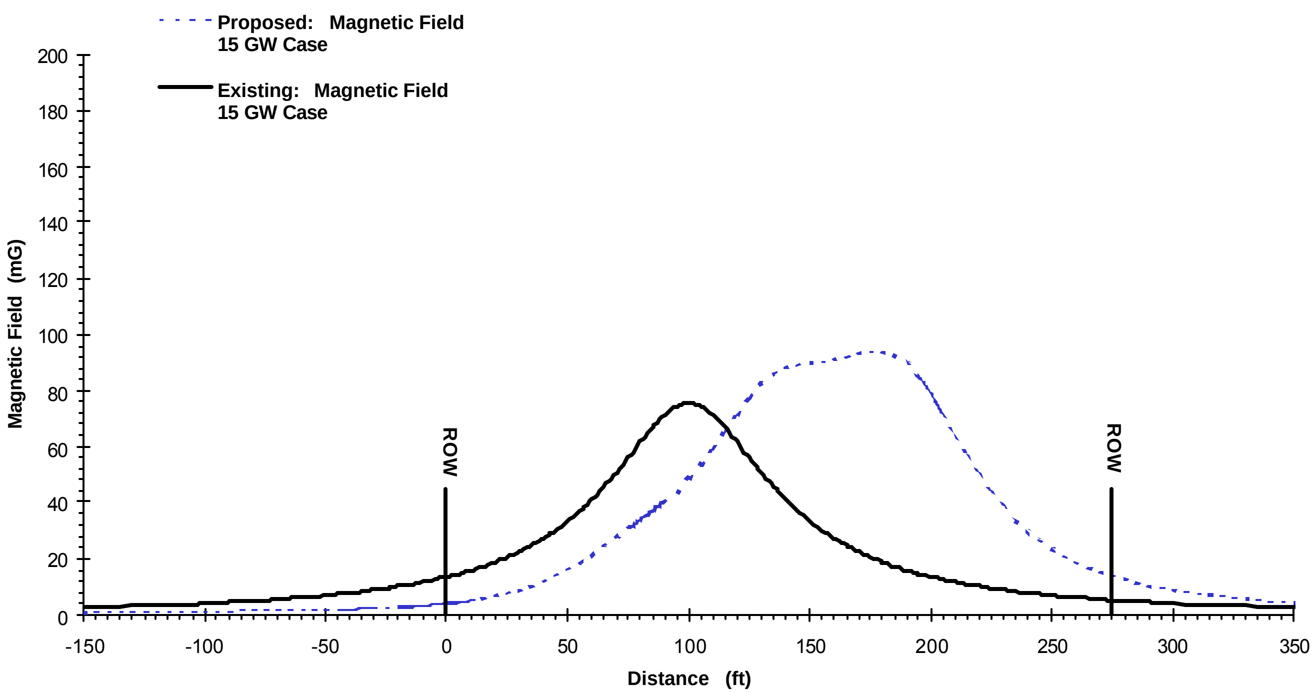


Figure 29. Electric and magnetic field profiles for cross section 3

Cross Section 4

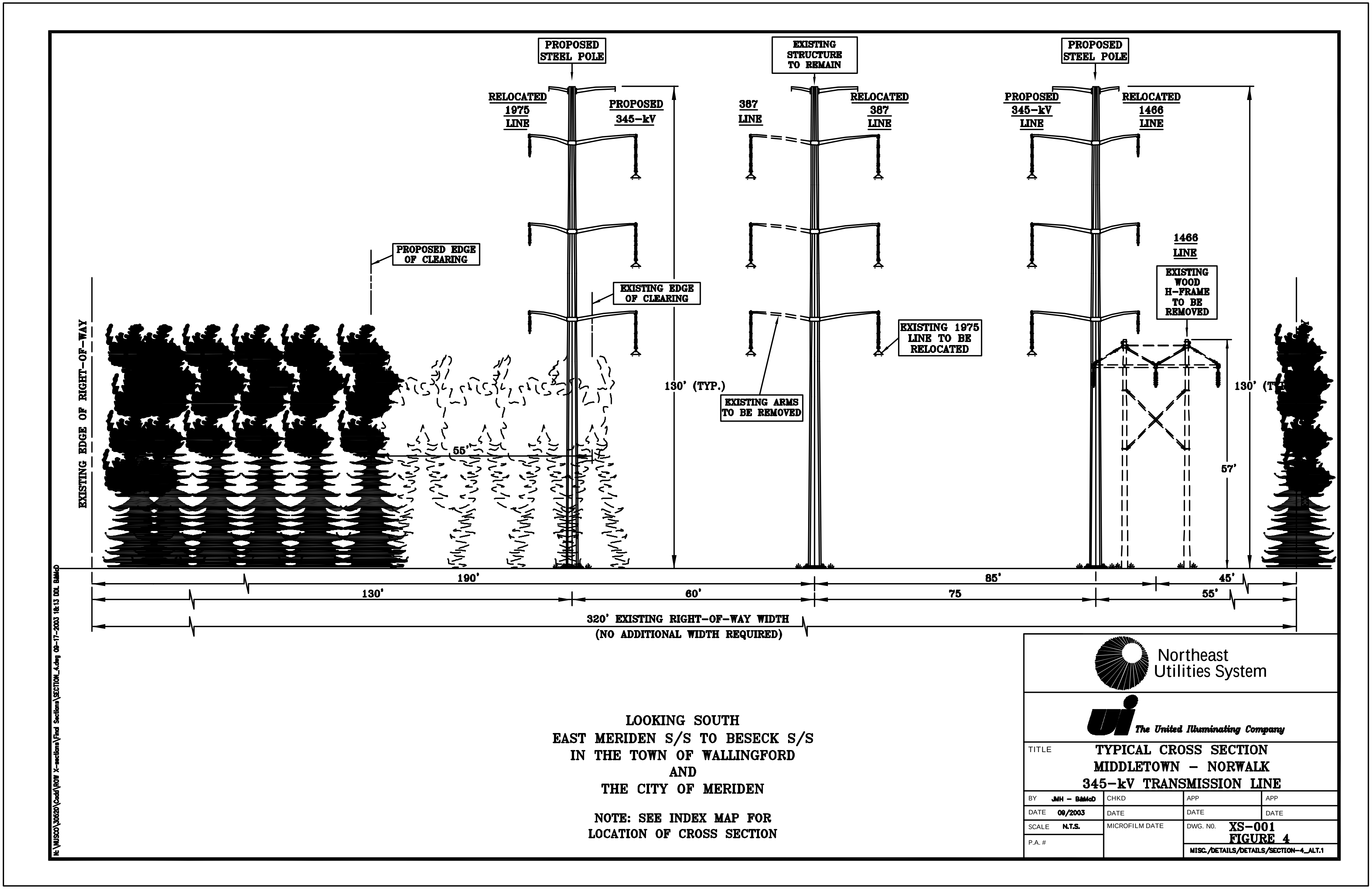
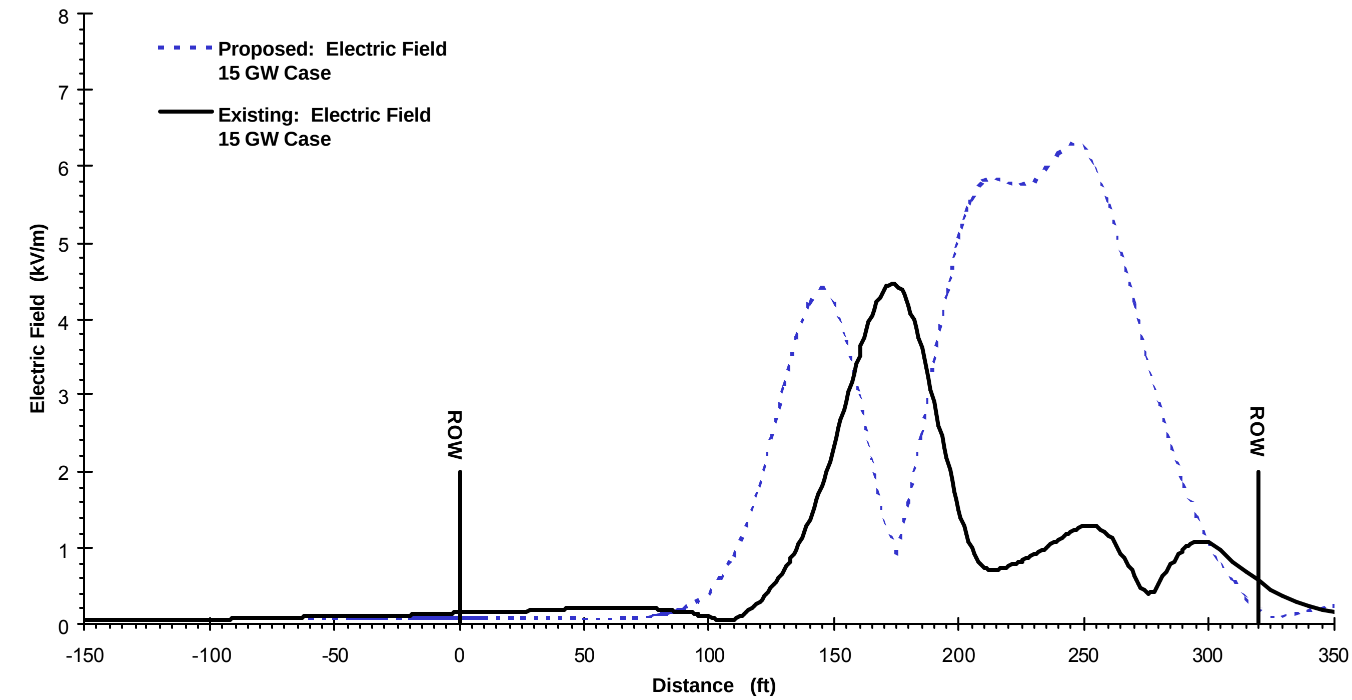


Figure 30. Cross section 4 - East Meriden Substation to Beseck Substation (Wallingford, Meriden)



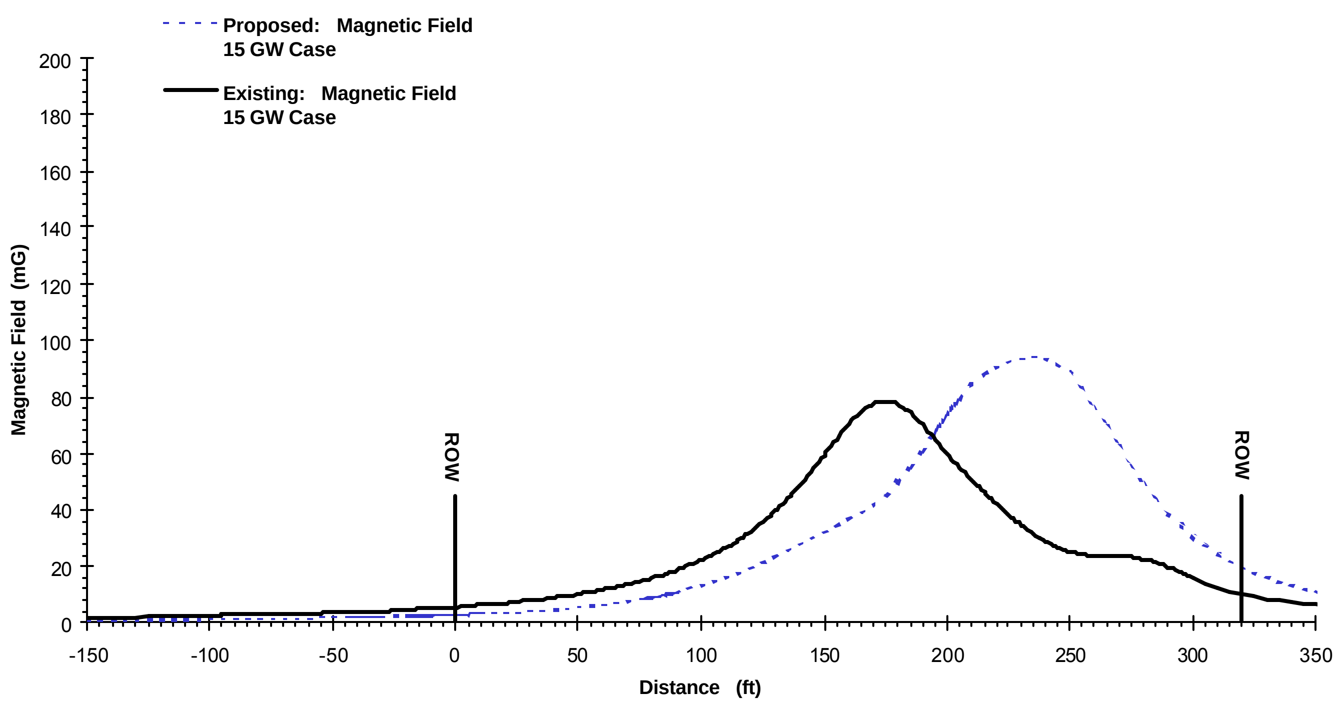


Figure 31. Electric and magnetic field profiles for cross section 4

Cross Section 5

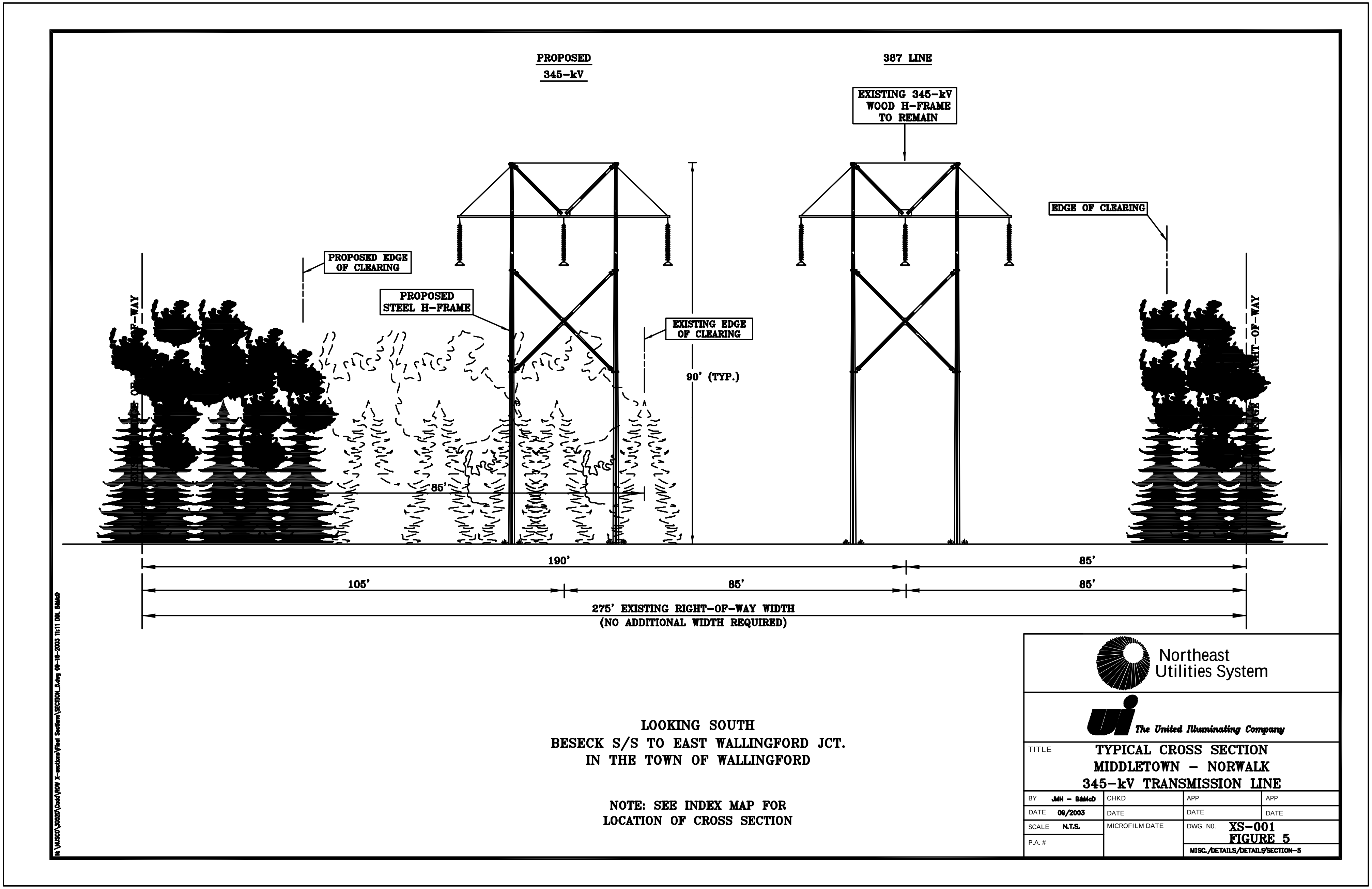
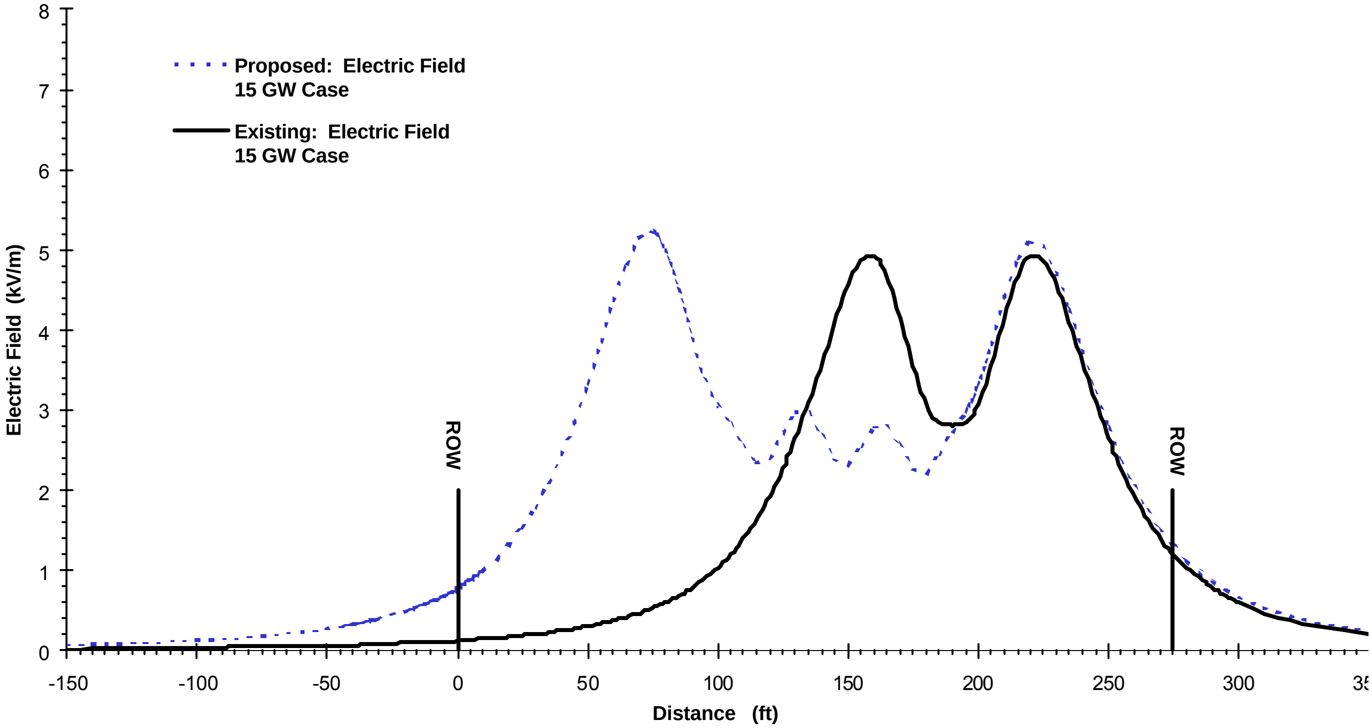


Figure 32. Cross section 5 - Beseck Substation to East Wallingford Junction (Wallingford)



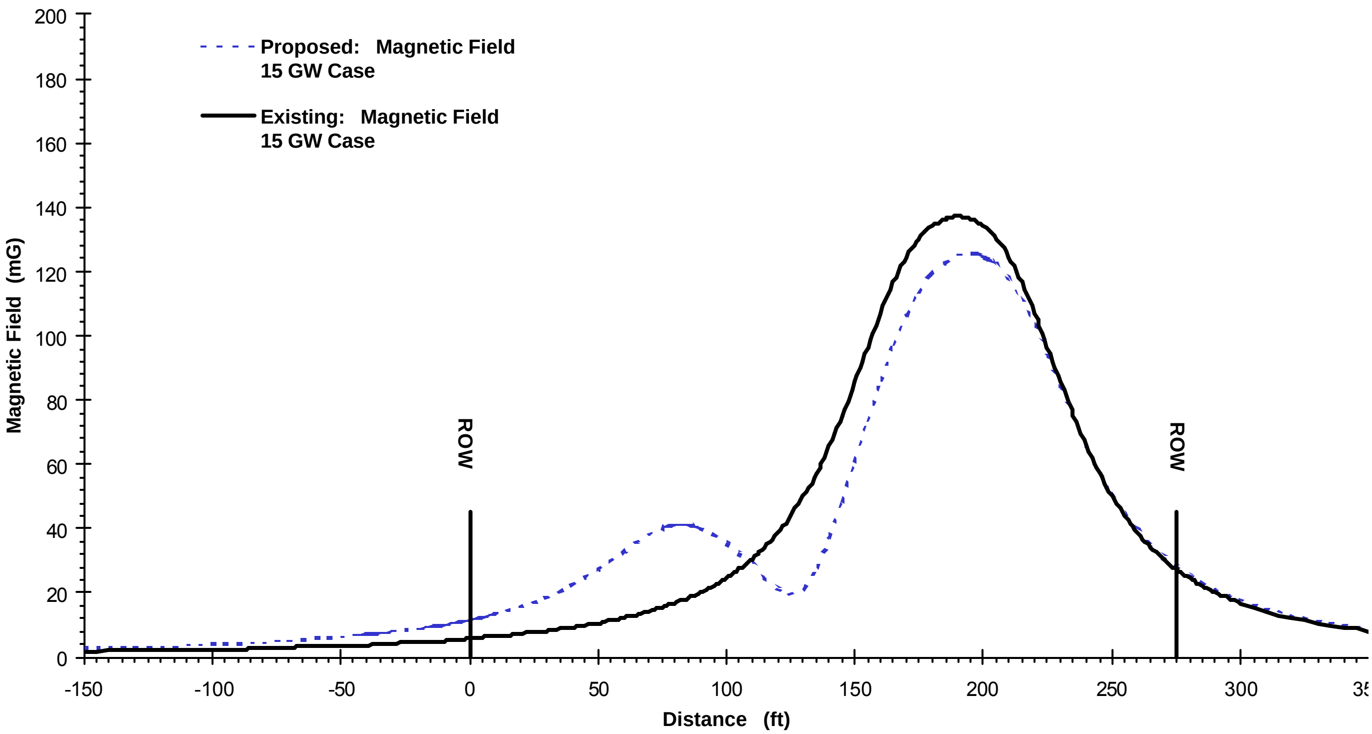


Figure 33. Electric and magnetic field profiles for cross section 5

Cross Section 6

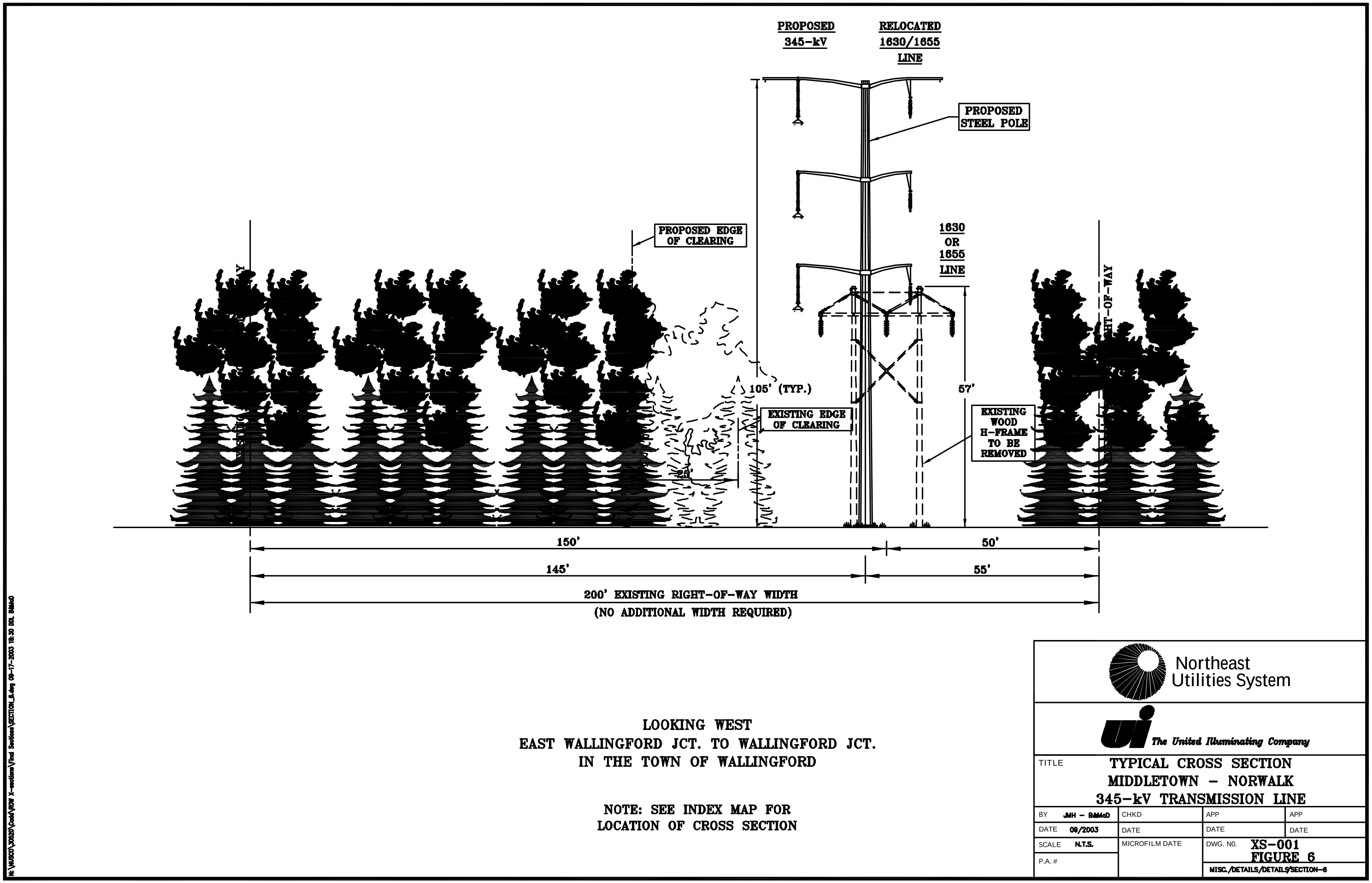


Figure 34. Cross section 6 - East Wallingford Junction to Wallingford Junction (Wallingford)

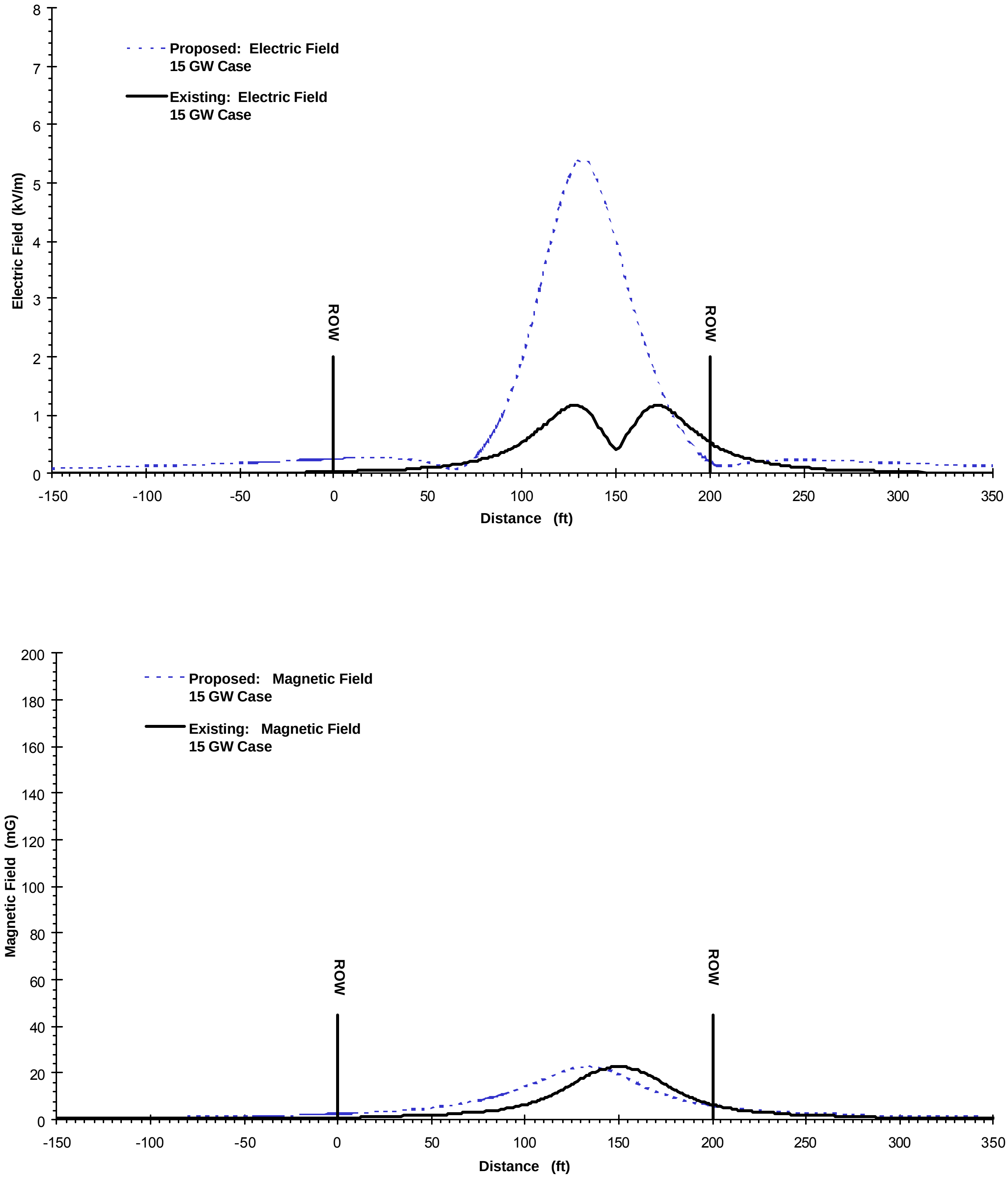


Figure 35. Electric and magnetic field profiles for cross section 6

Cross Sections 7 and 7A

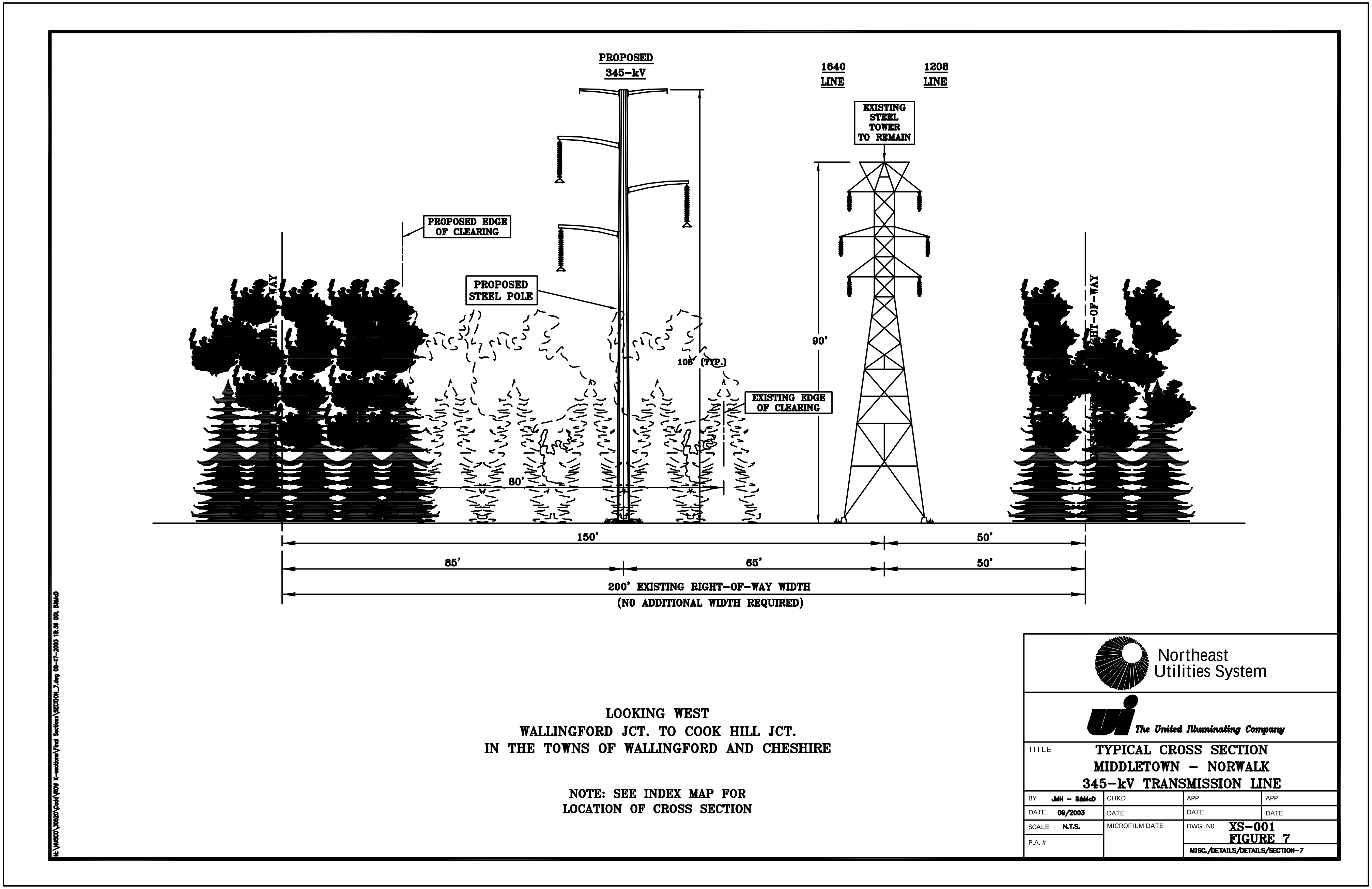
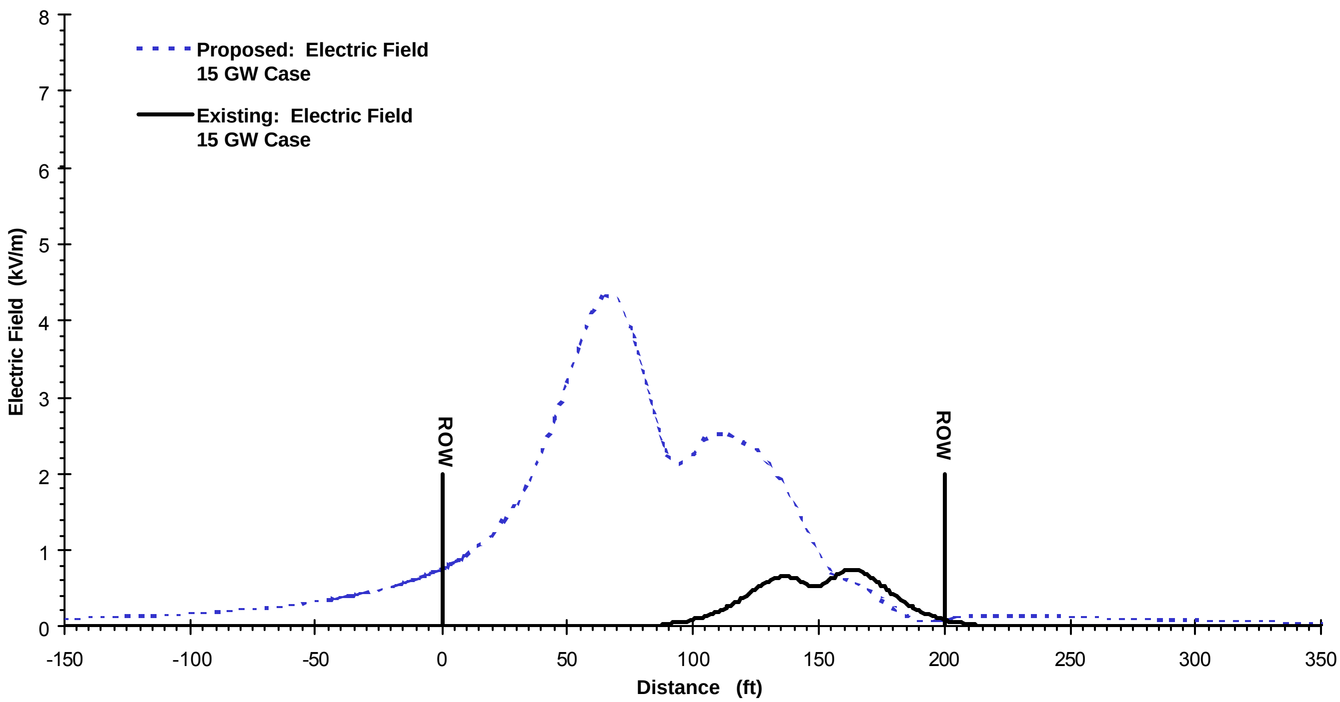


Figure 36. Cross section 7 - Wallingford Junction to Cook Hill Junction (Wallingford)
Cross section 7A - Wallingford Junction to Cheshire Town Line (Wallingford)



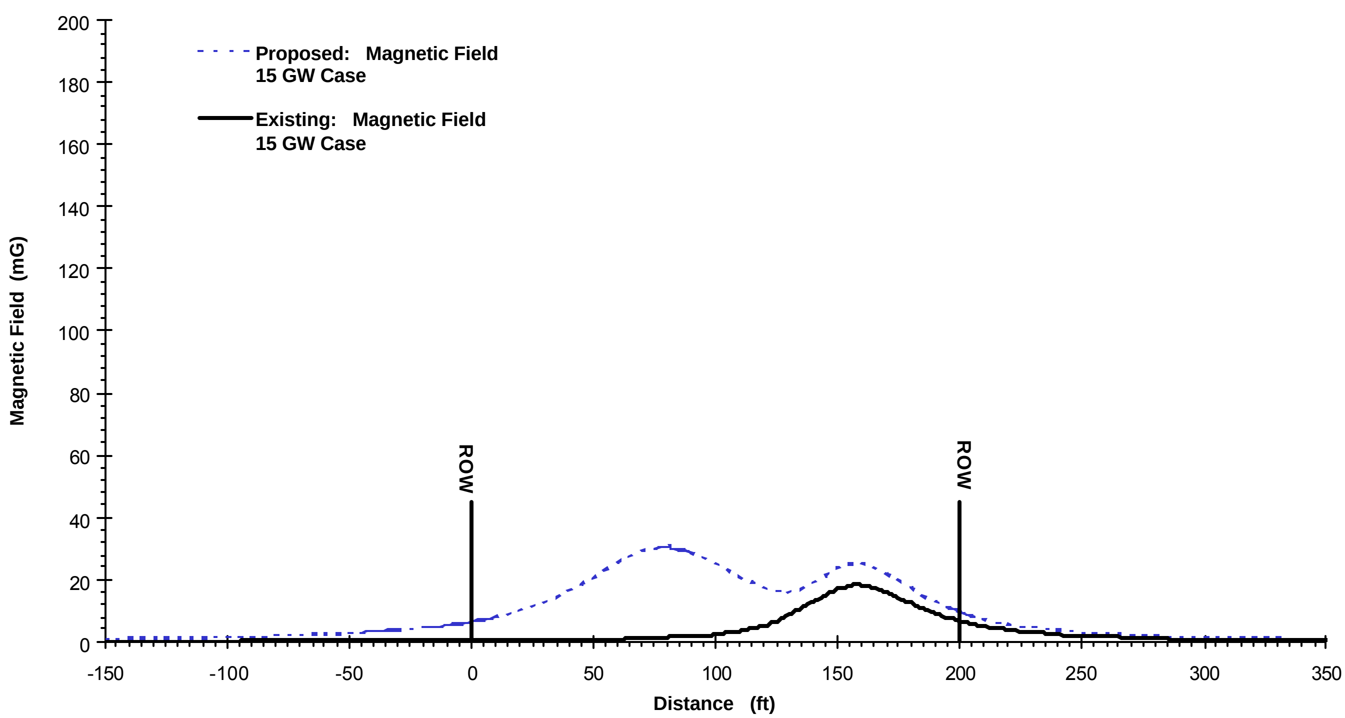


Figure 37. Electric and magnetic field profiles for cross sections 7 and 7A

NY10132.000 C0T0 1003 WB24

Cross Section 7B

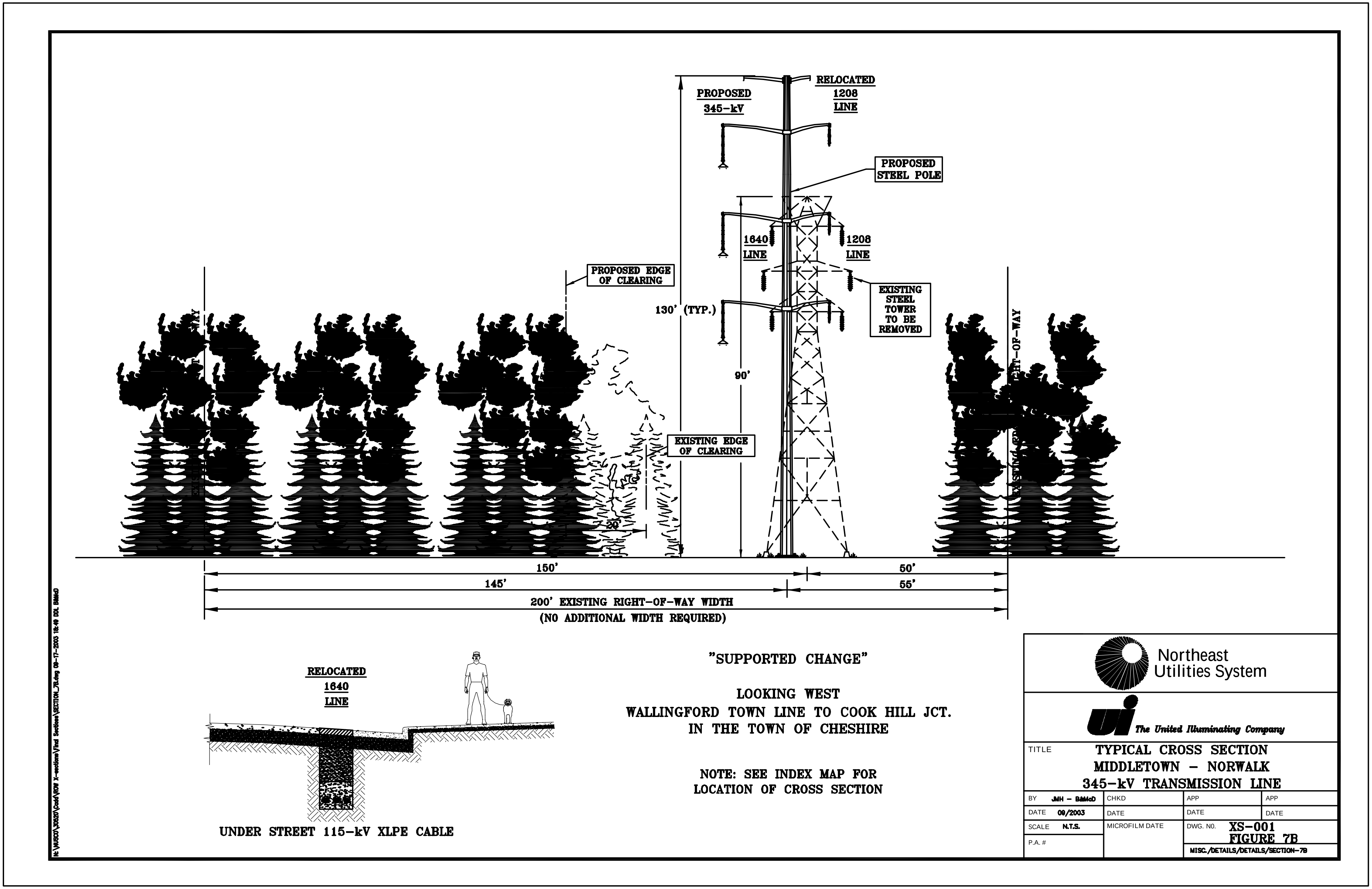
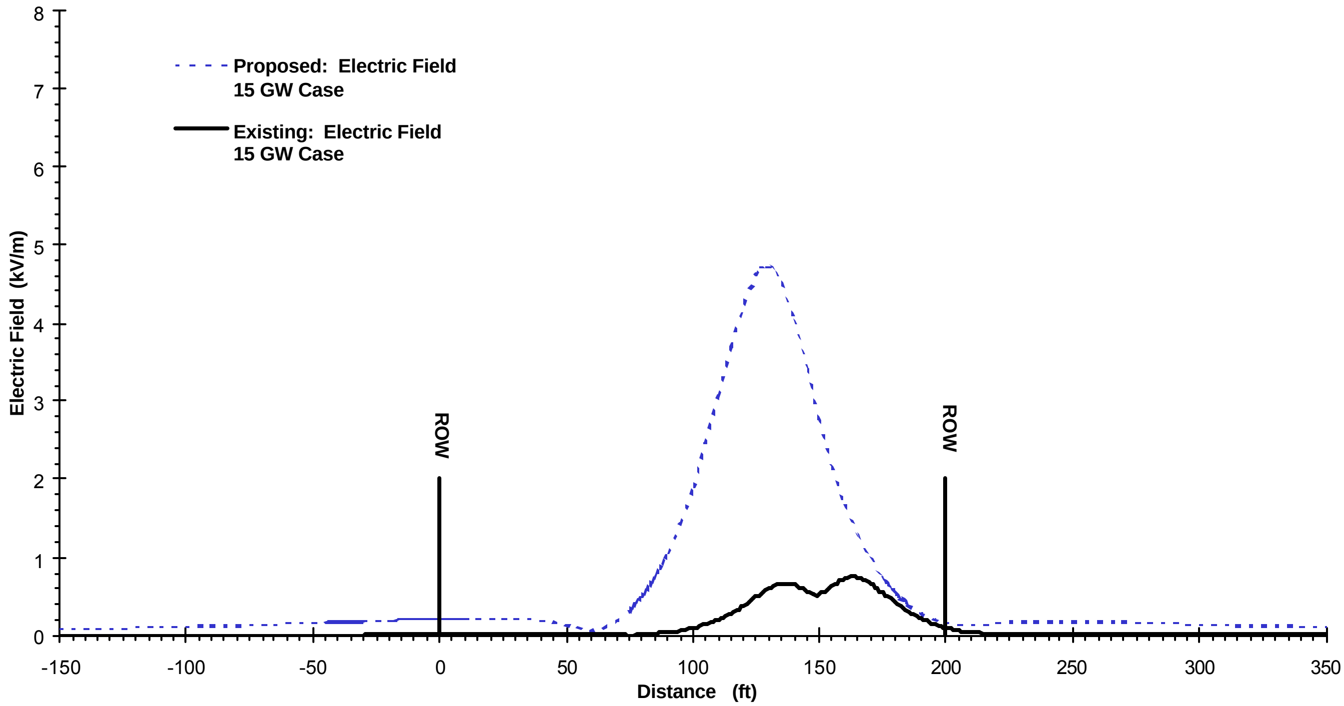


Figure 38. Cross section 7B - Wallingford Town Line to Cook Hill Junction (Cheshire)
(Underground 115-kV line located 25 feet to the right (north) of the 345-kV line)



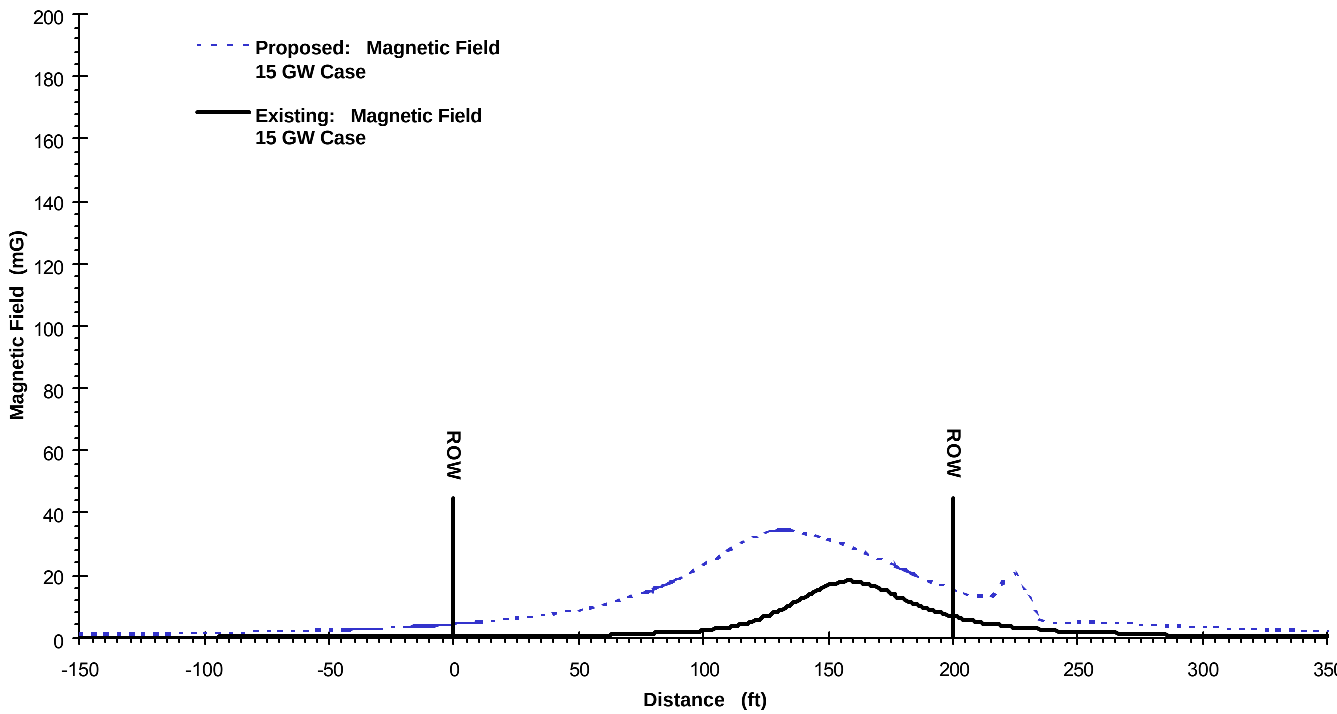


Figure 39. Electric and magnetic field profiles for cross section 7B

NY10132.000 C0T0 1003 WB24

Cross Sections 8 and 8B

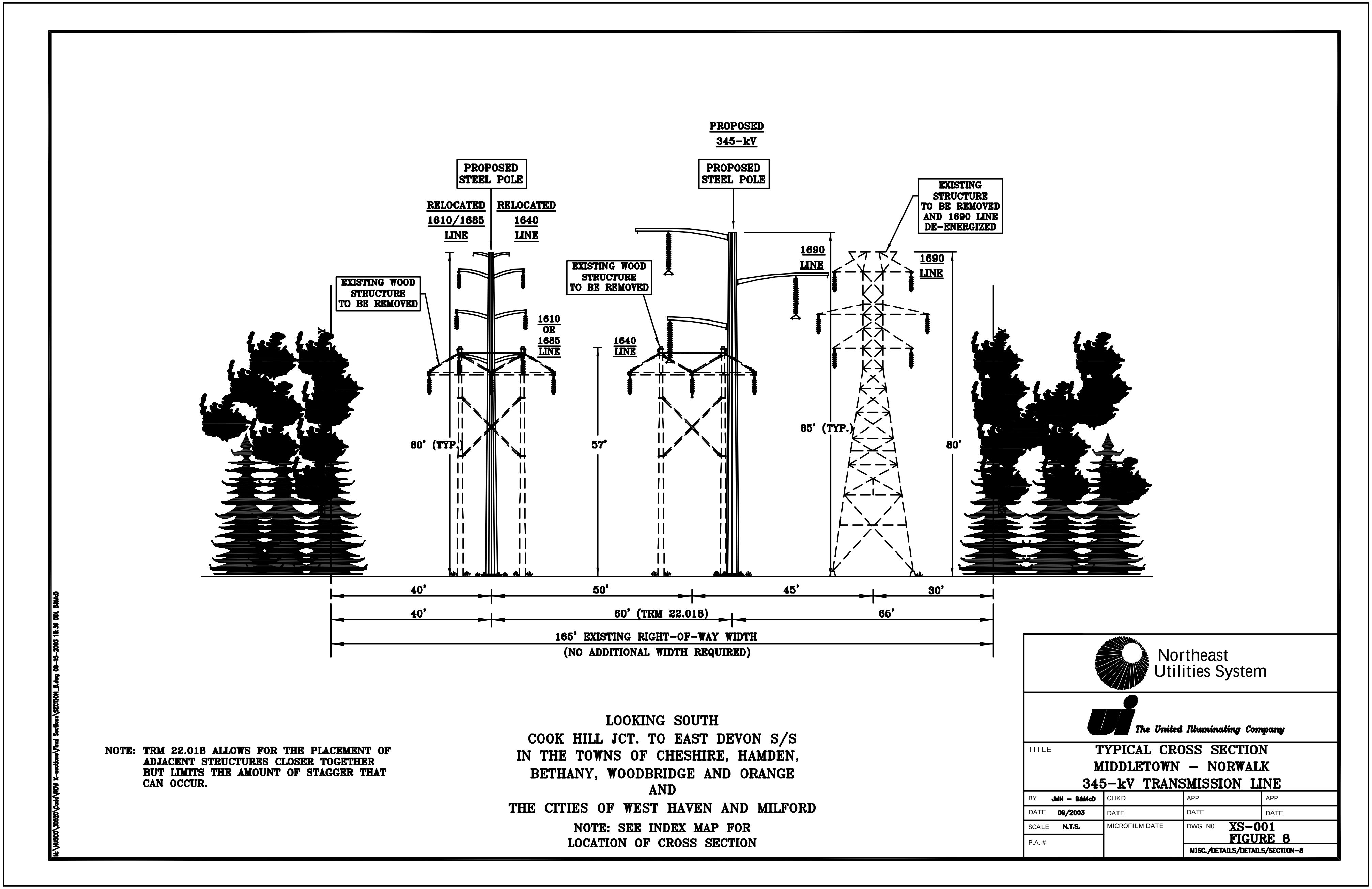


Figure 40. Cross section 8 - Cook Hill Junction to East Devon Substation (Cheshire, Hamden, Bethany, Woodbridge, Orange, West Haven, Milford)
Cross section 8B - Cheshire Town Line to East Devon Substation (Hamden, Bethany, Woodbridge, Orange, West Haven, Milford)

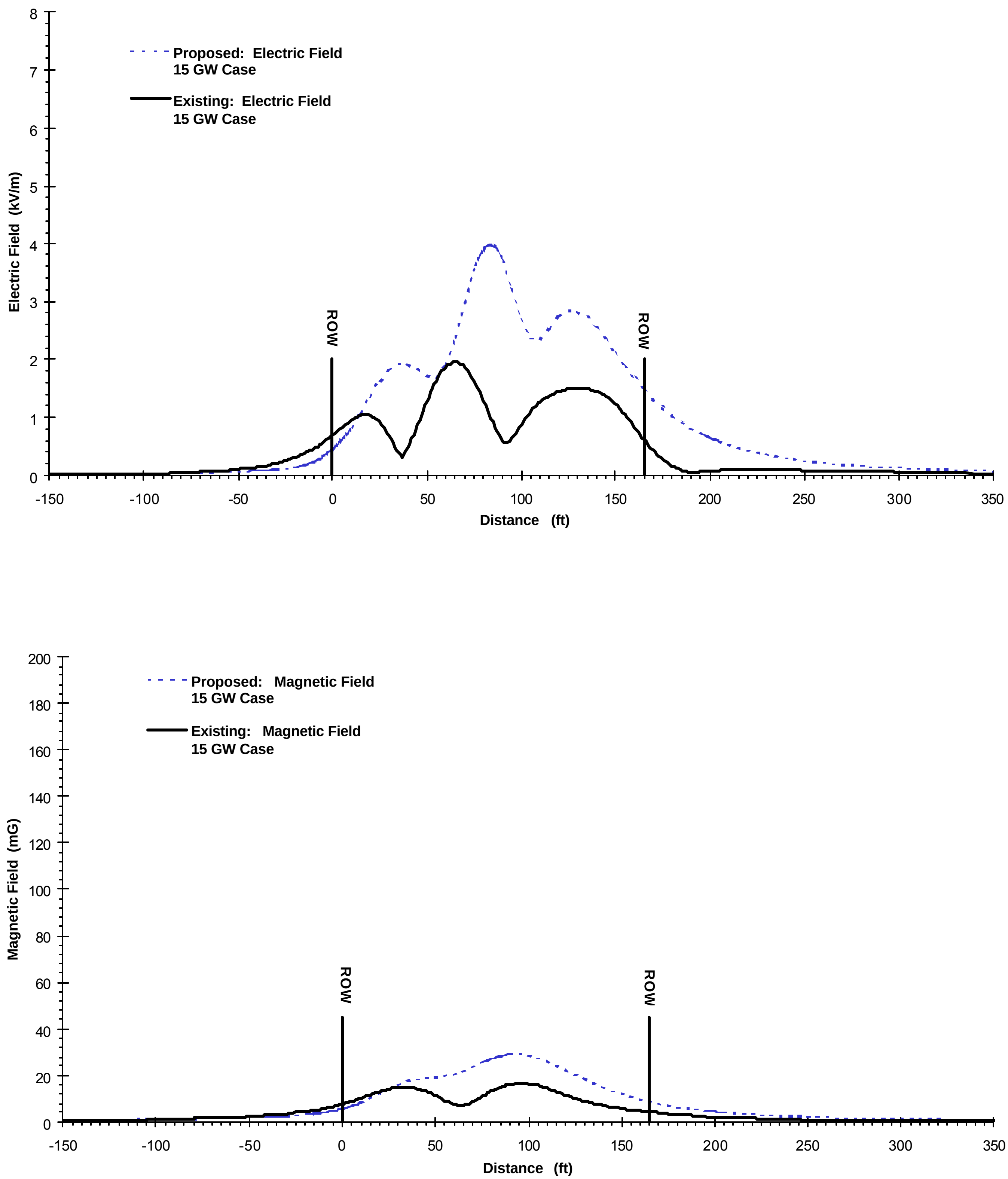


Figure 41. Electric and magnetic field profiles for cross sections 8 and 8B

NY10132.000 C0T0 1003 WB24

Cross Section 8A

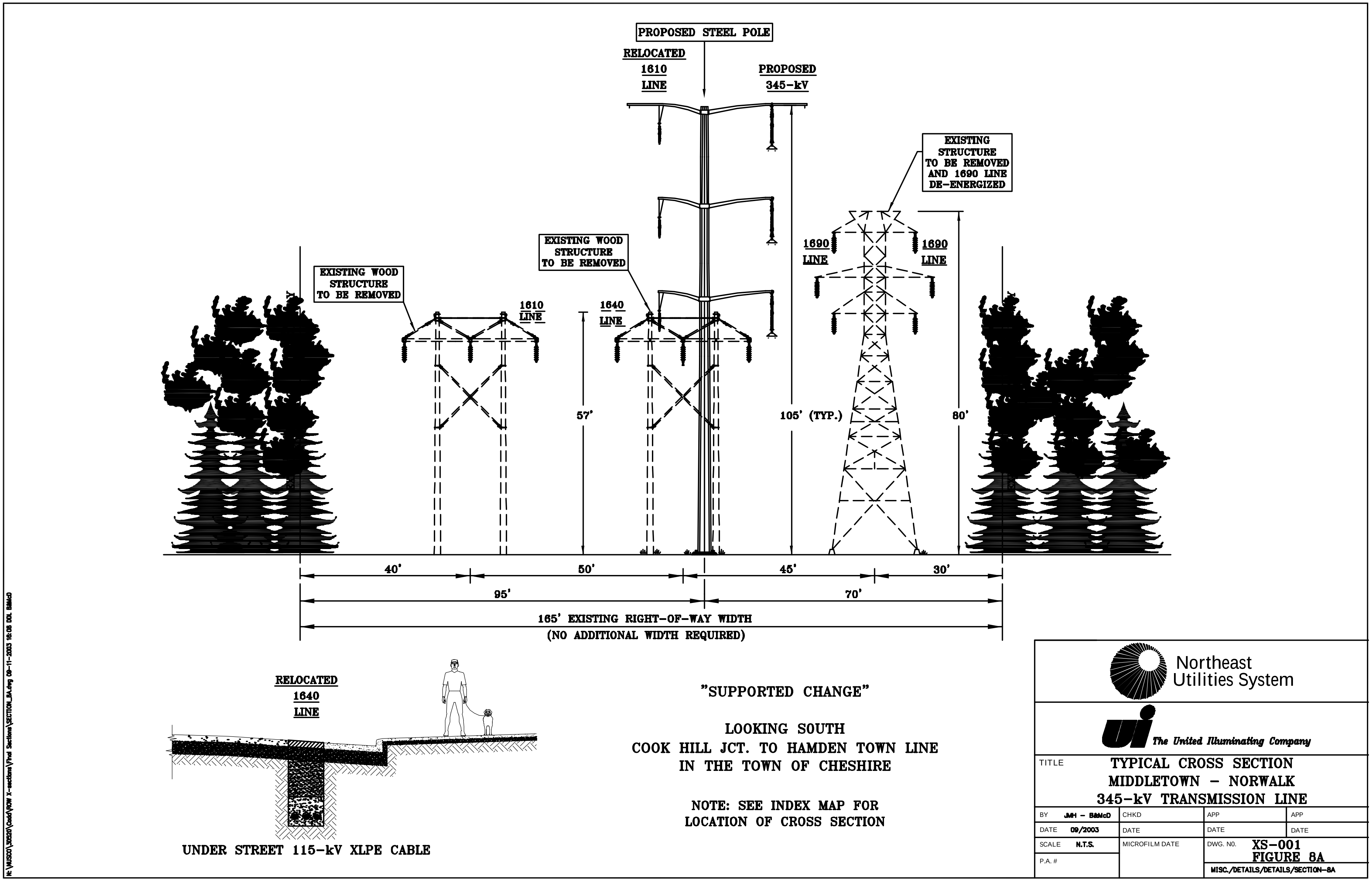
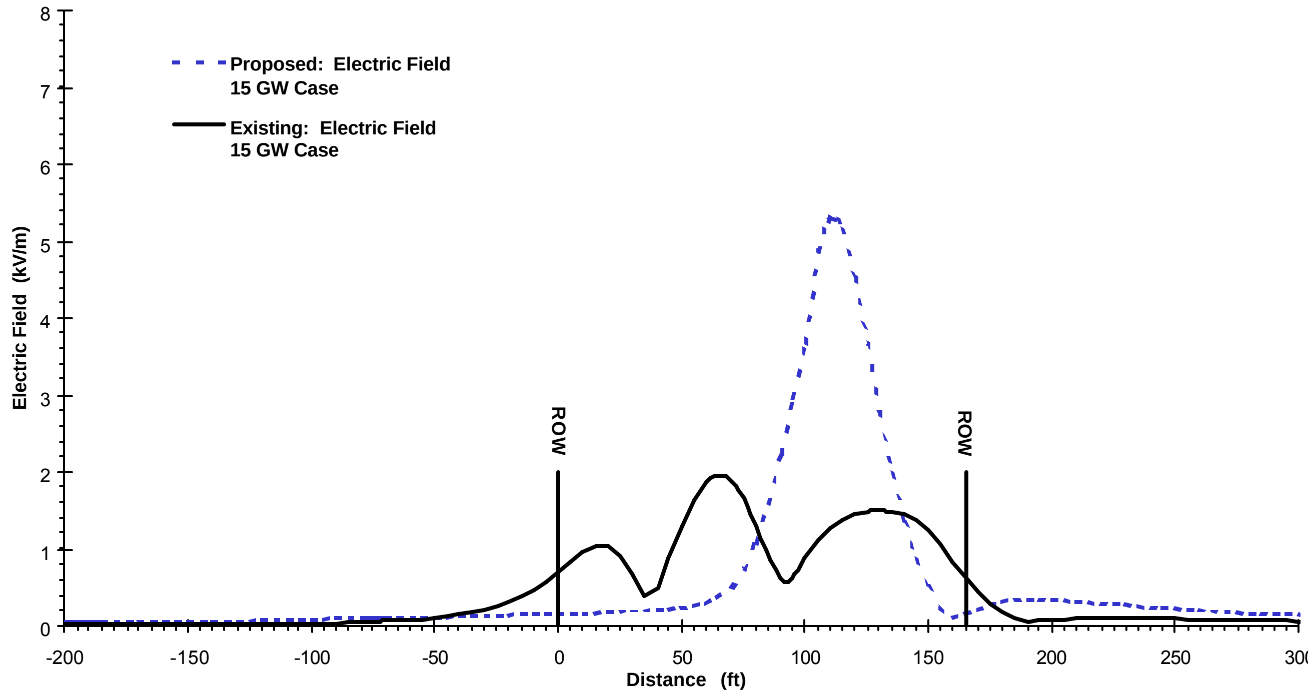


Figure 42. Cross section 8A - Cook Hill Junction to Hamden Town Line (Cheshire)
(Location of underground 115-kV line between 20 and 400 feet from 345-kV line)



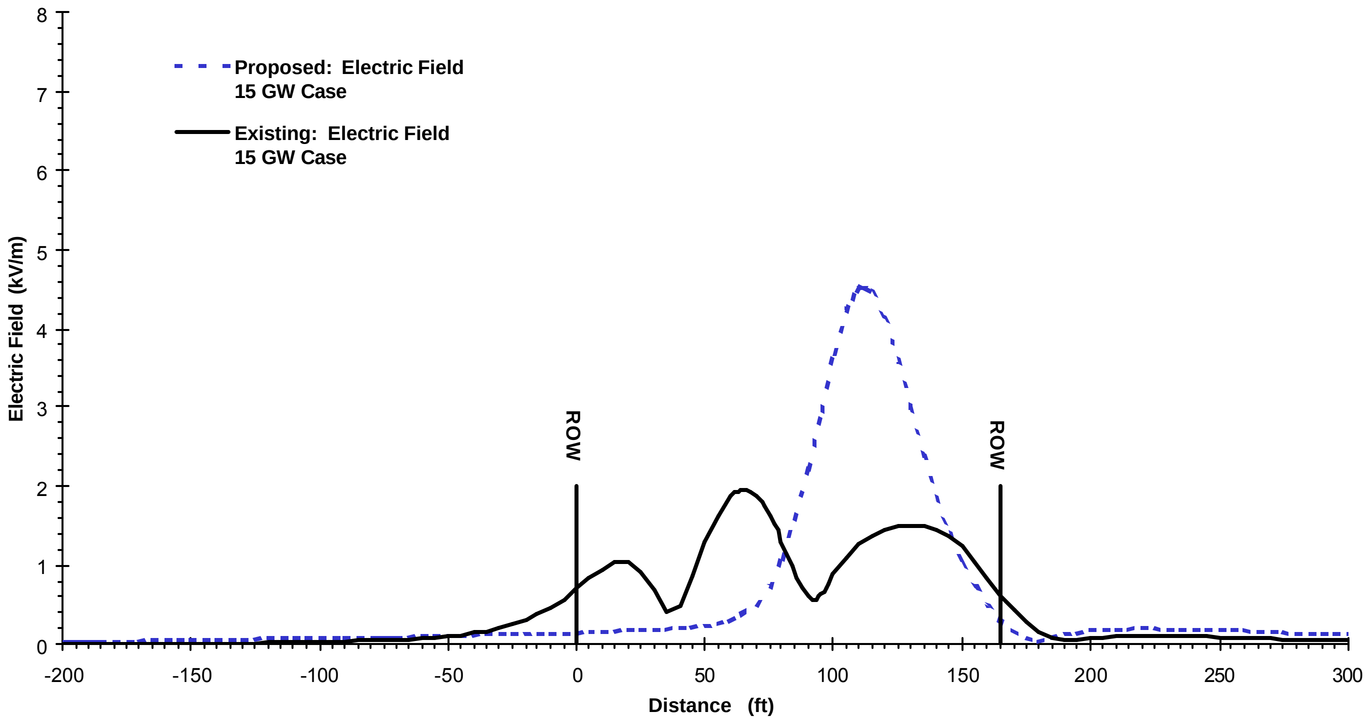
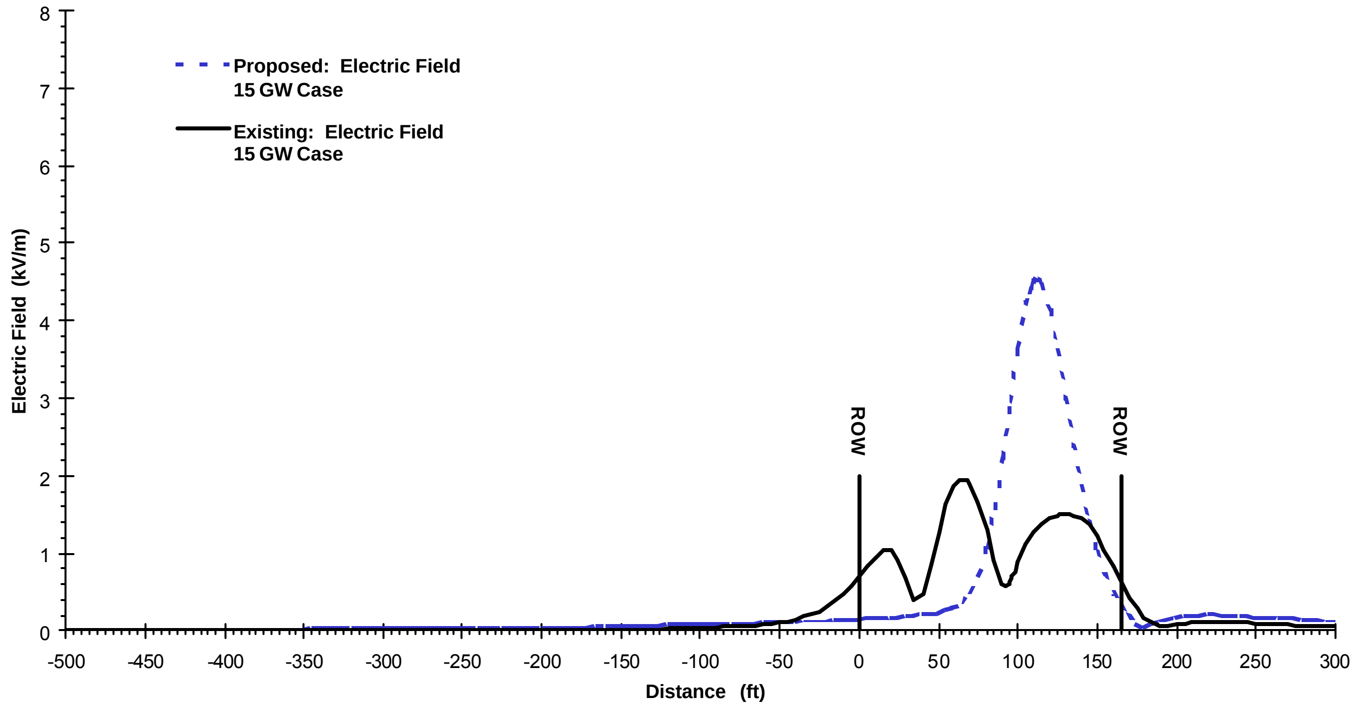


Figure 43. Electric and magnetic field profiles for overhead lines in cross section 8A (with underground transmission line at -20 feet)



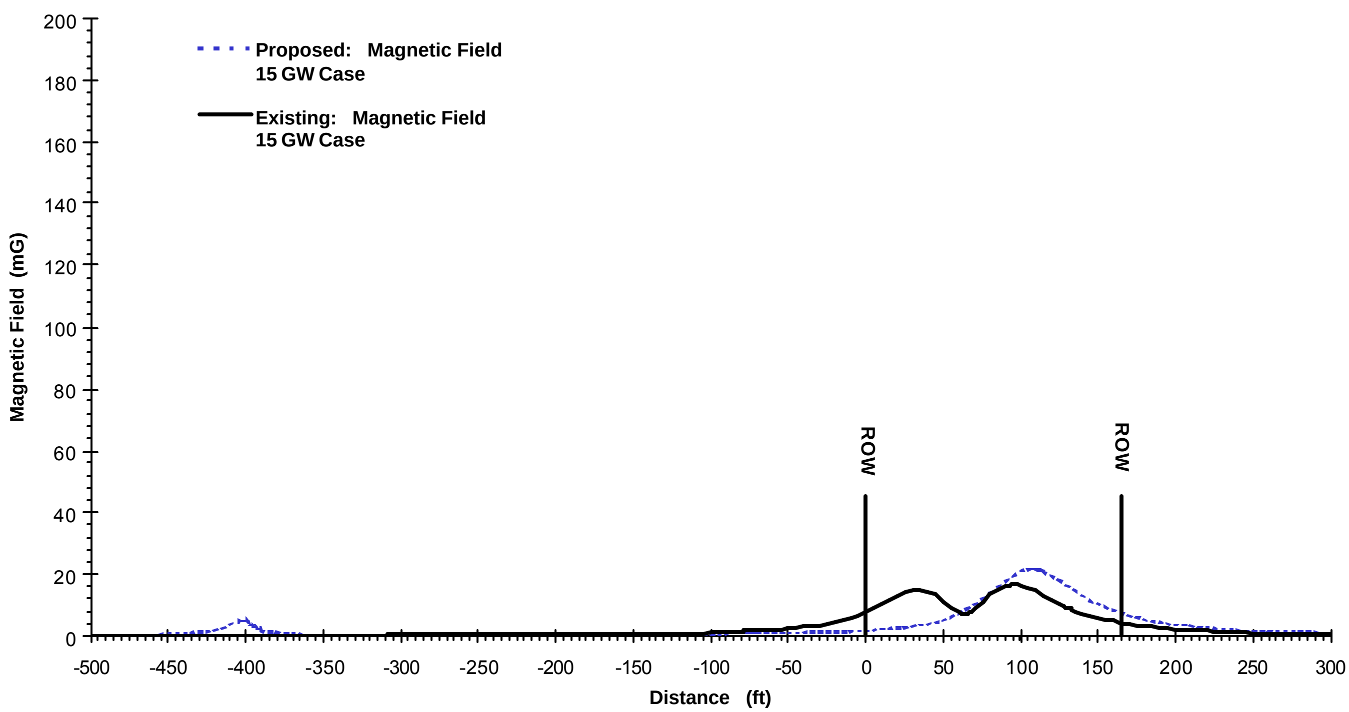


Figure 44. Electric and magnetic field profiles for overhead lines in cross section 8A (with underground transmission line at -400 feet)

Cross Sections 9 and 9A

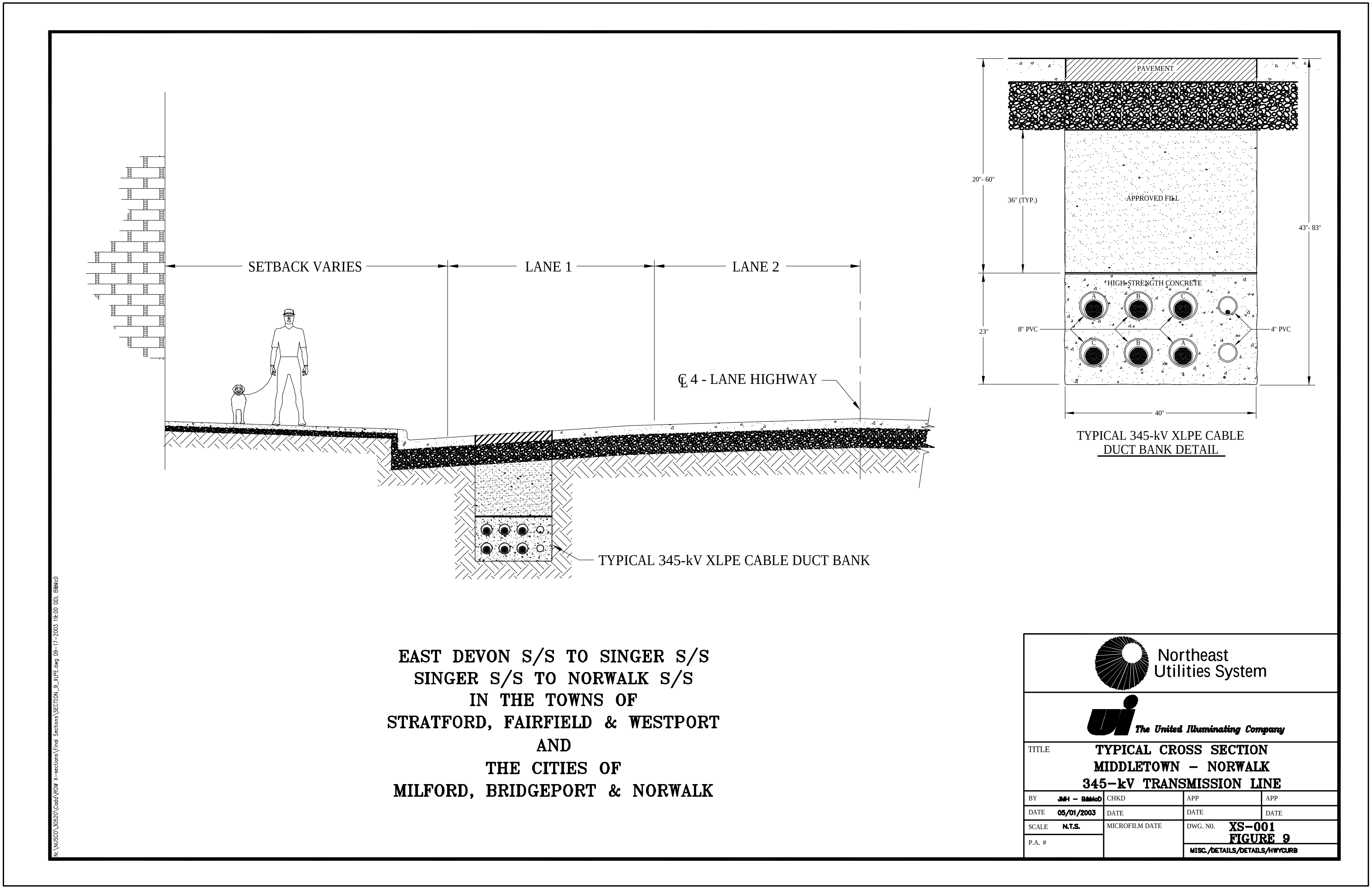


Figure 45. Cross section 9 - underground HPFF transmission line from East Devon to Singer to Norwalk Substations
Cross section 9A - underground XLPE transmission line from Singer to Hawthorne Substations in Alternative A (Stratford, Fairfield, Westport, Milford, Bridgeport, Norwalk) (No electric field above ground.)

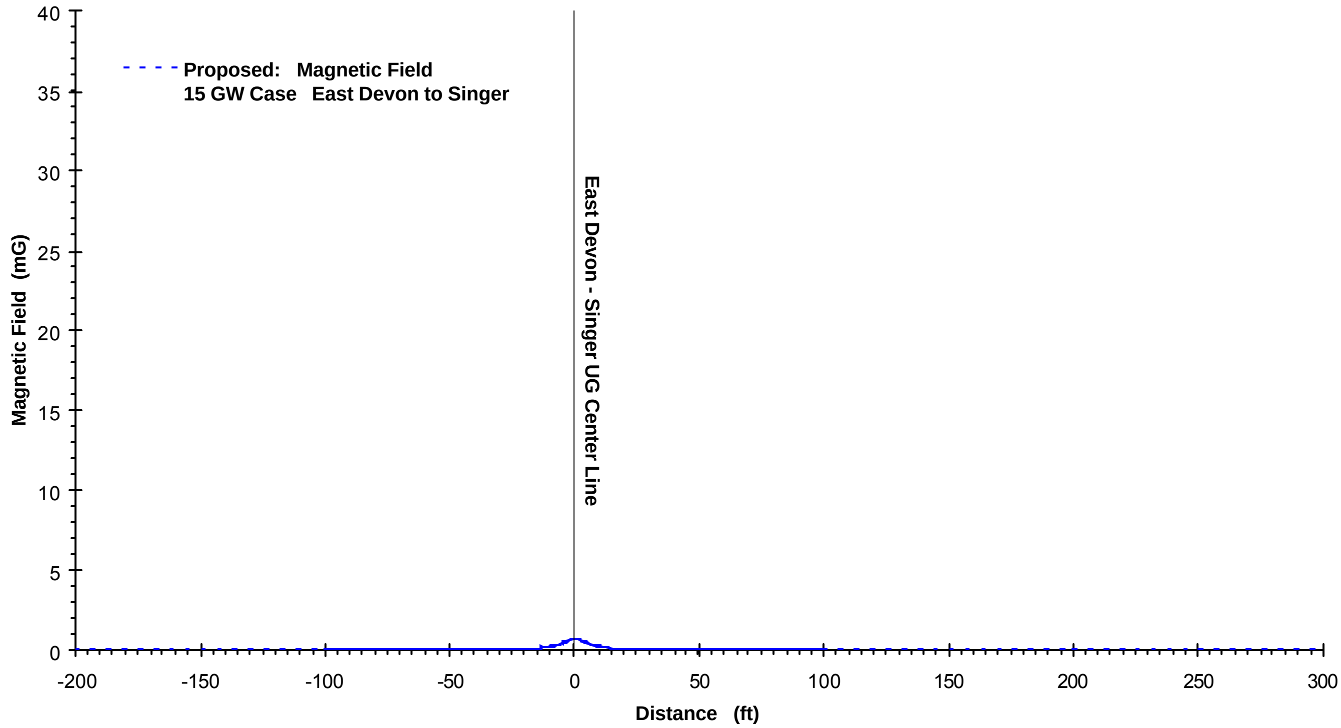


Figure 46. Magnetic field profile for cross section 9 from East Devon Substation to Singer Substation

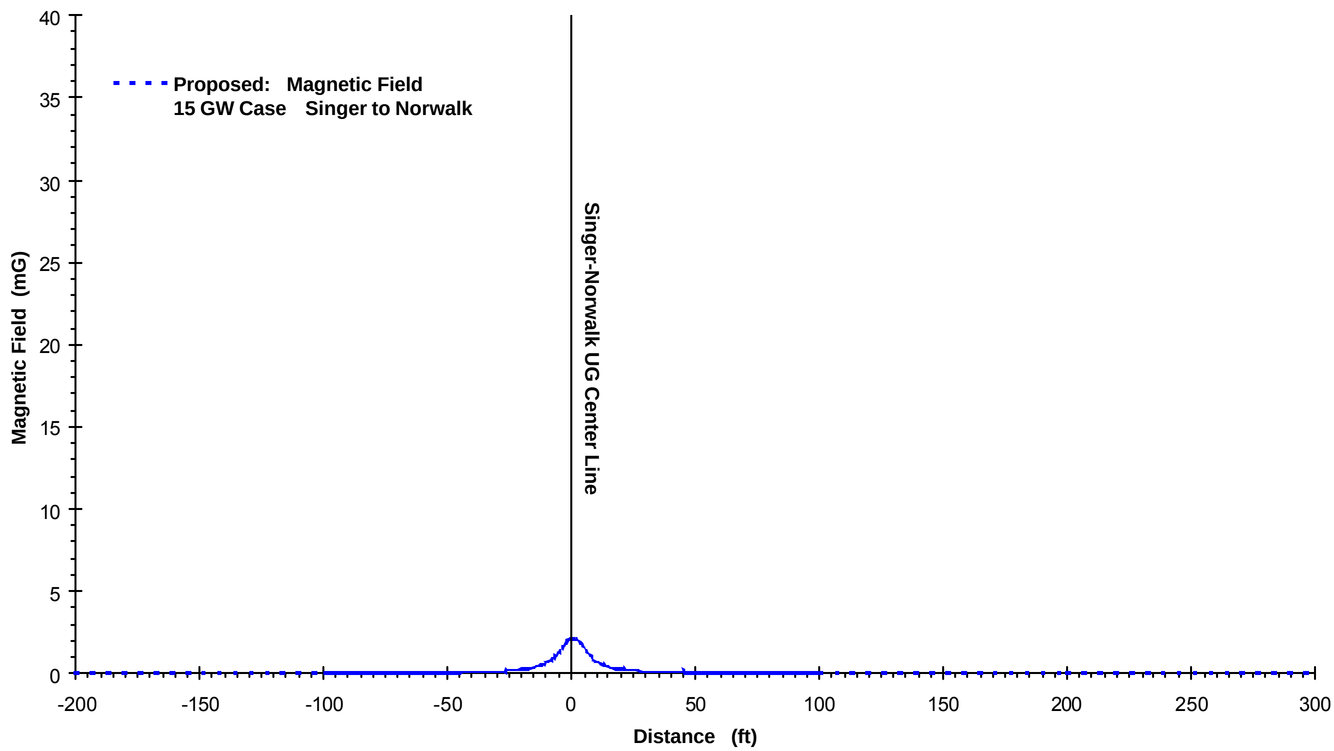


Figure 47. Magnetic field profile for cross section 9 from Singer Substation to Norwalk Substation

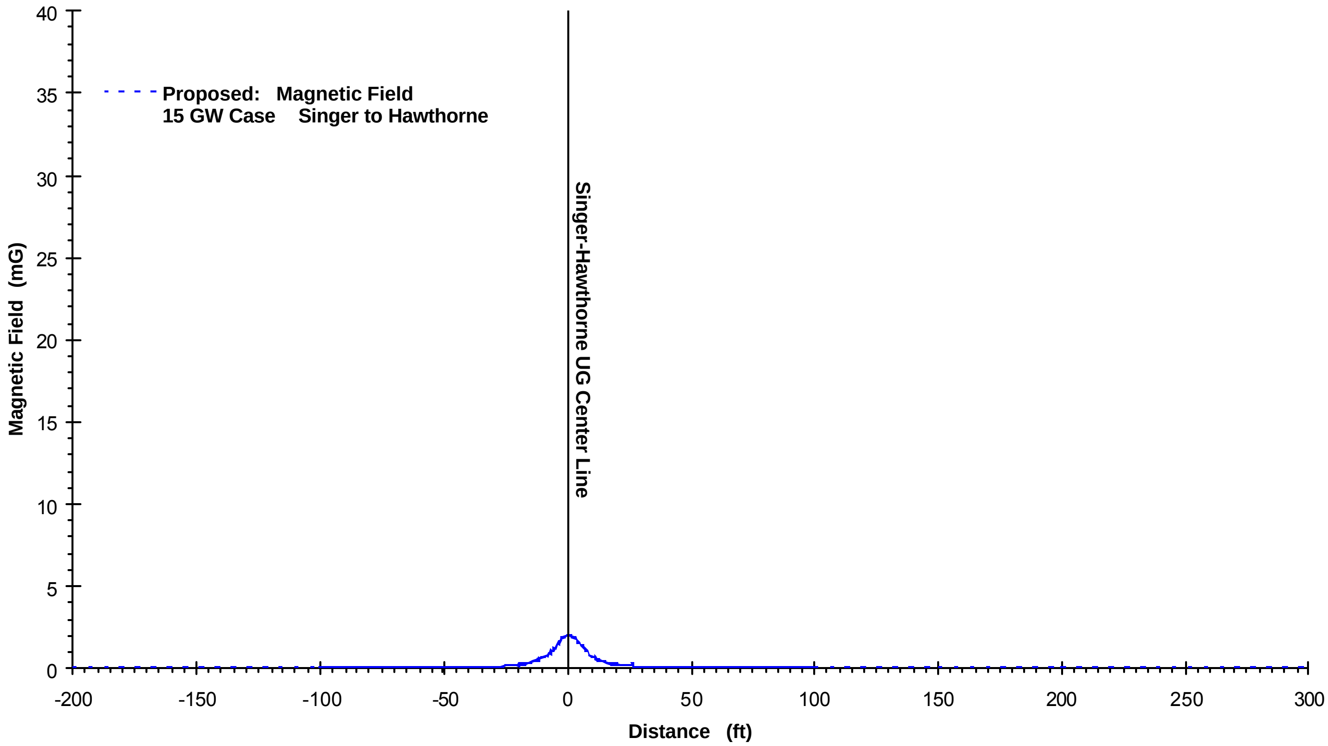


Figure 48. Magnetic field profile for cross section 9A from Singer Substation to Hawthorne Substation (Alternative A)

Cross Section 10

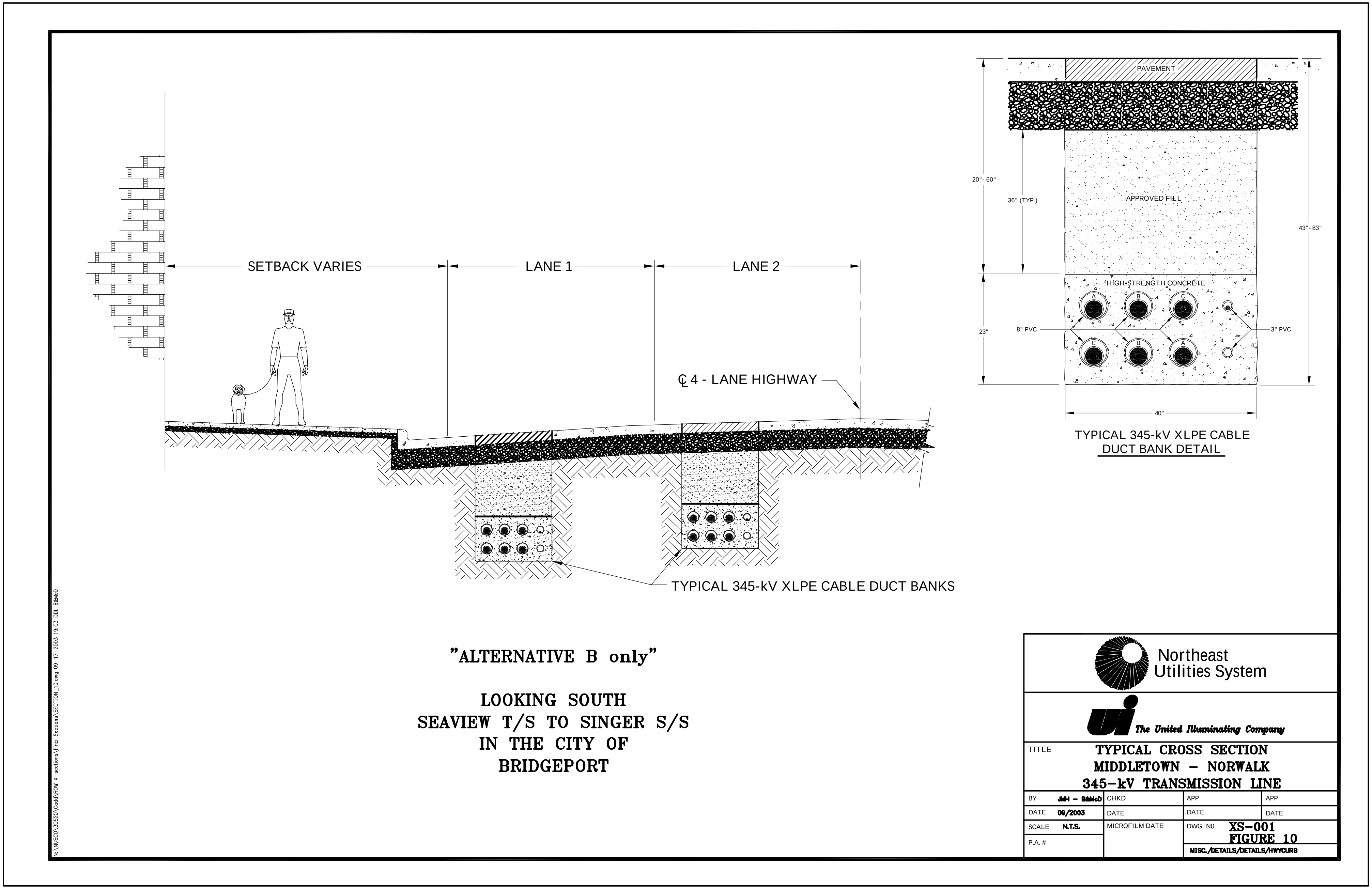


Figure 49. Cross section 10 - Underground from Seaview Transfer Station to Singer Substation (Bridgeport)
(No electric field above ground)

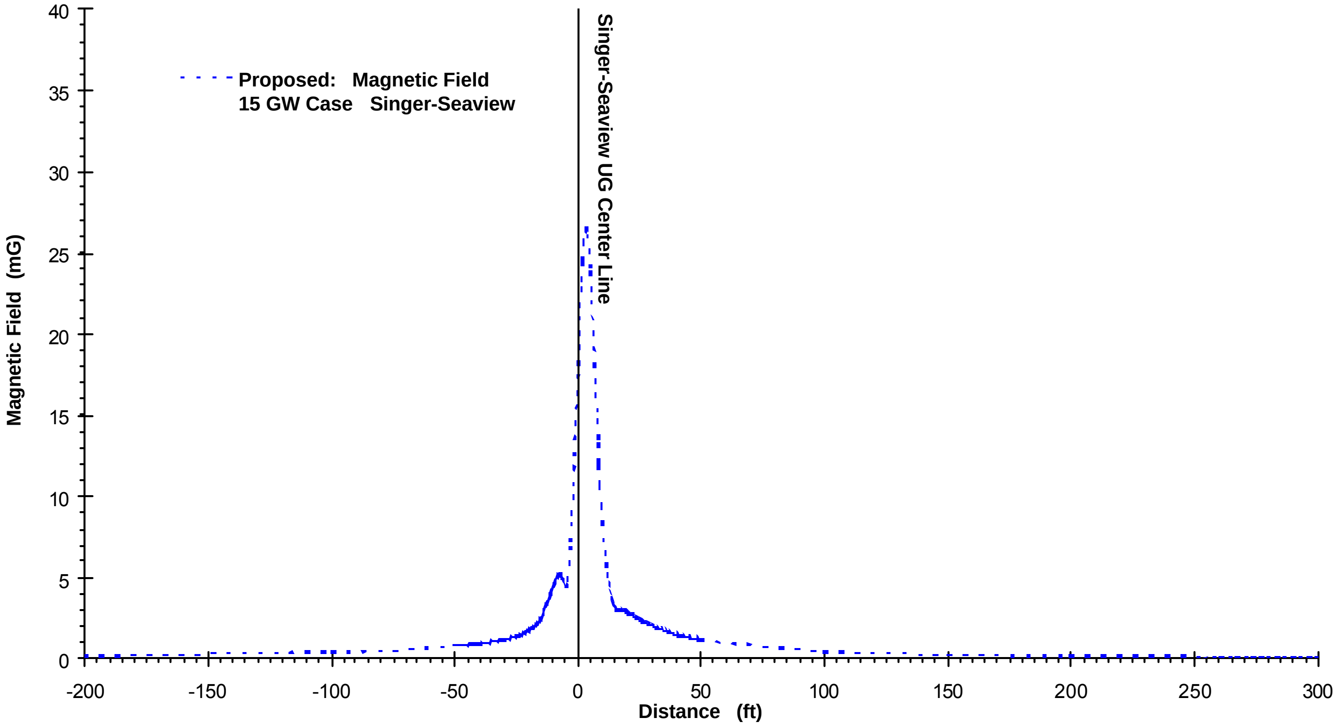


Figure 50. Magnetic field profile for cross section 10 from Singer Substation to Seaview Transition Station and return (Alternative B)

Cross Section 11

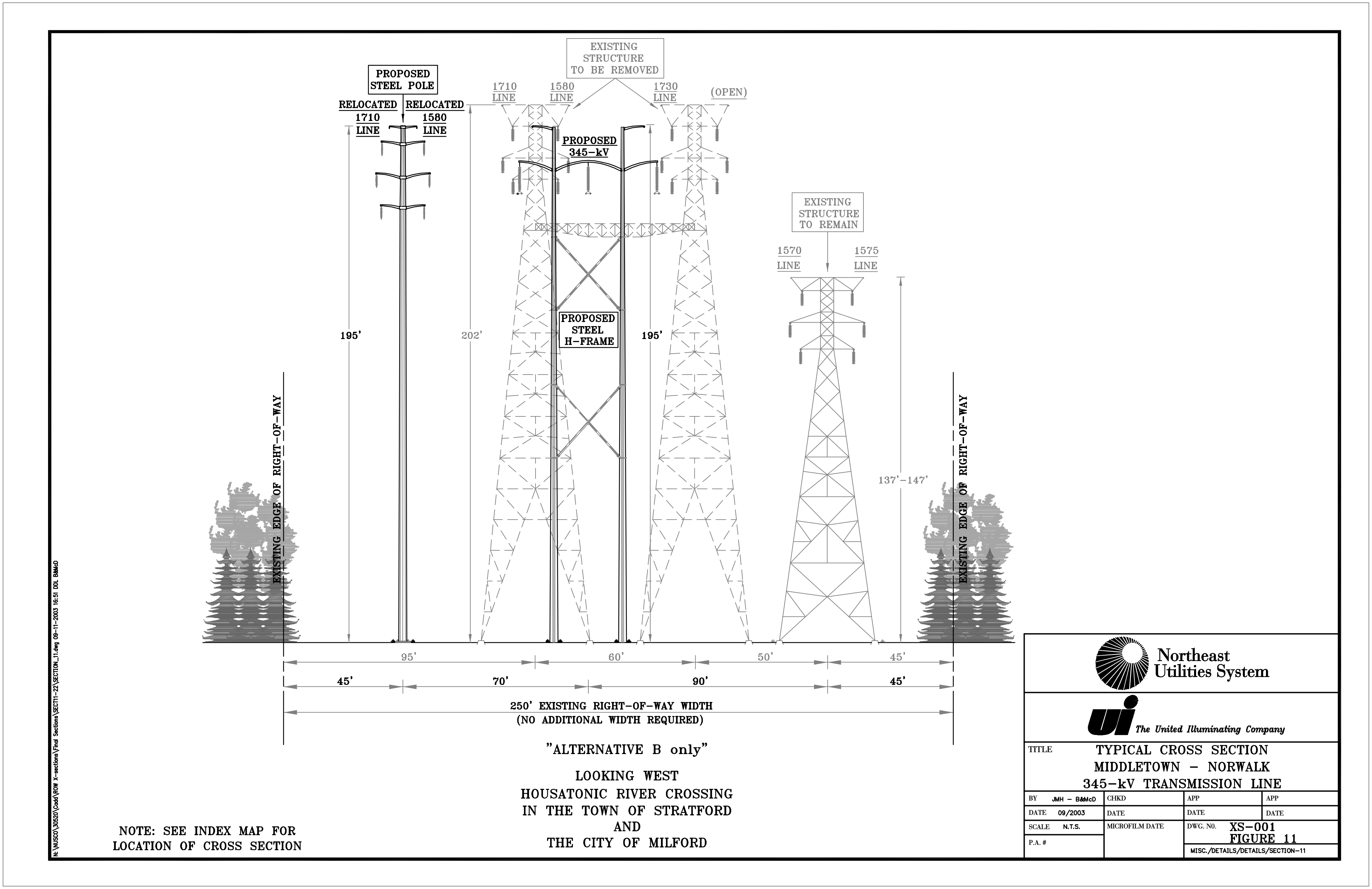
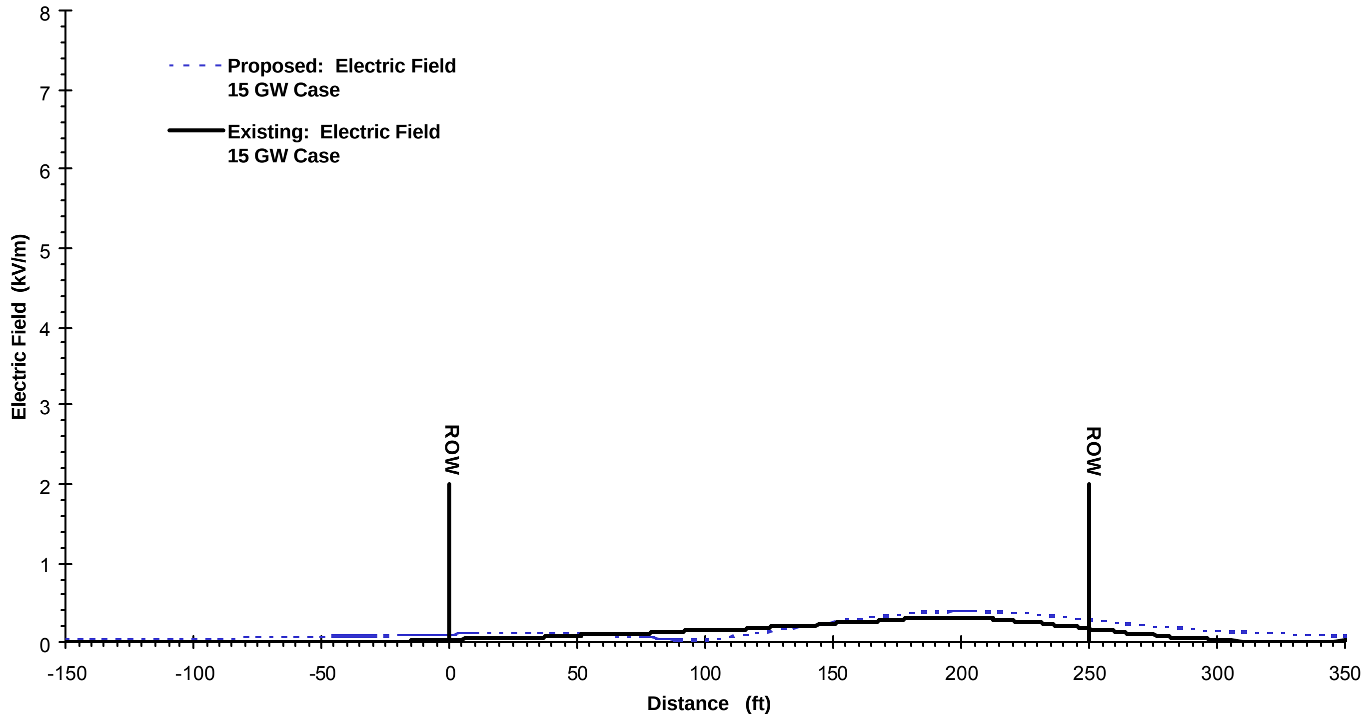


Figure 51. Cross section 11 - Housatonic River Crossing (Stratford, Milford)



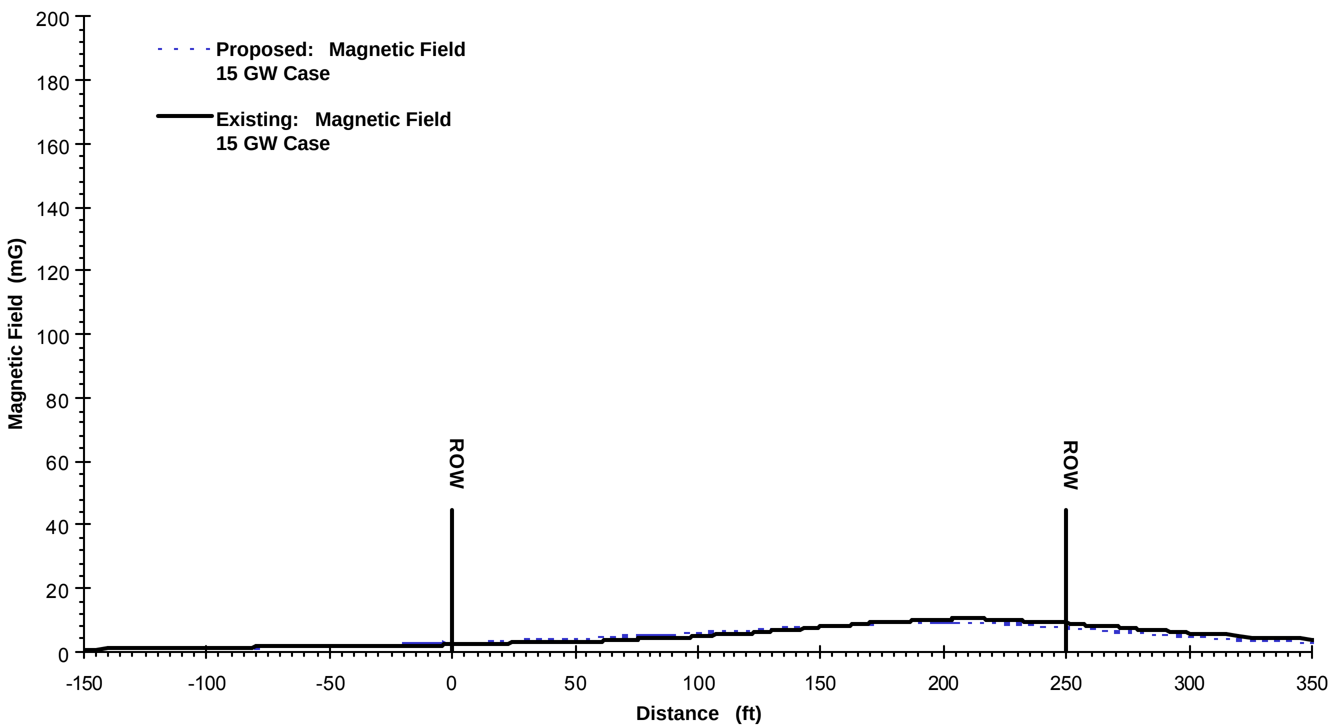


Figure 52. Electric and magnetic field profiles for cross section 11 (Alternative B)

Cross Section 12

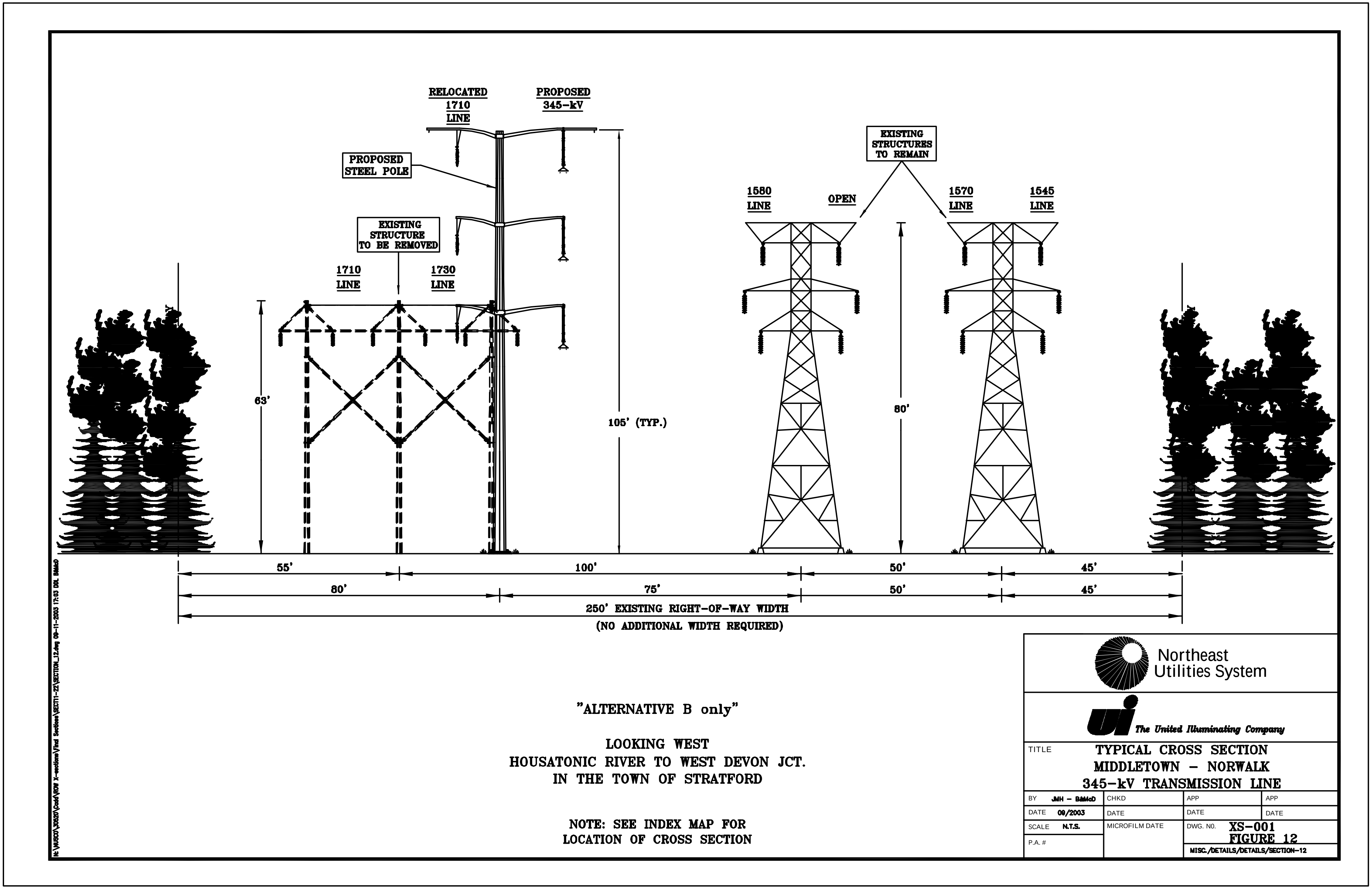
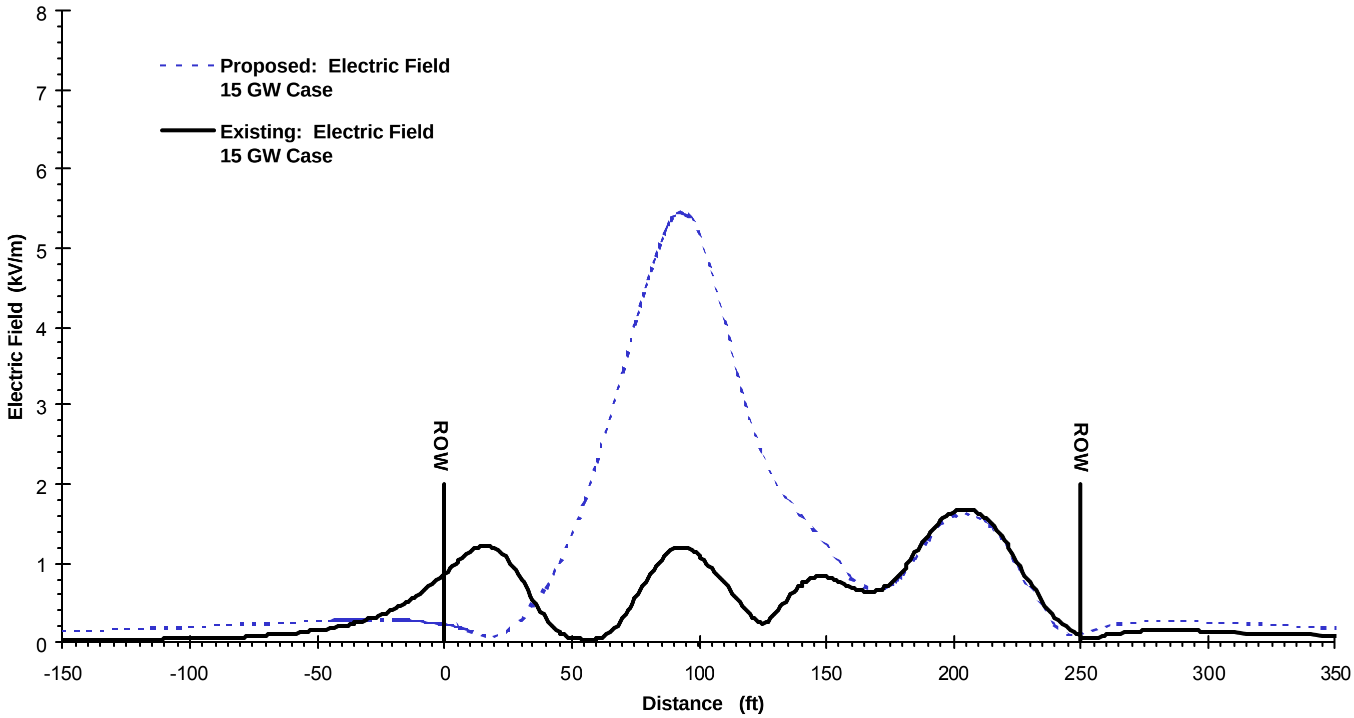


Figure 53. Cross section 12 - Housatonic River to West Devon Junction (Stratford)



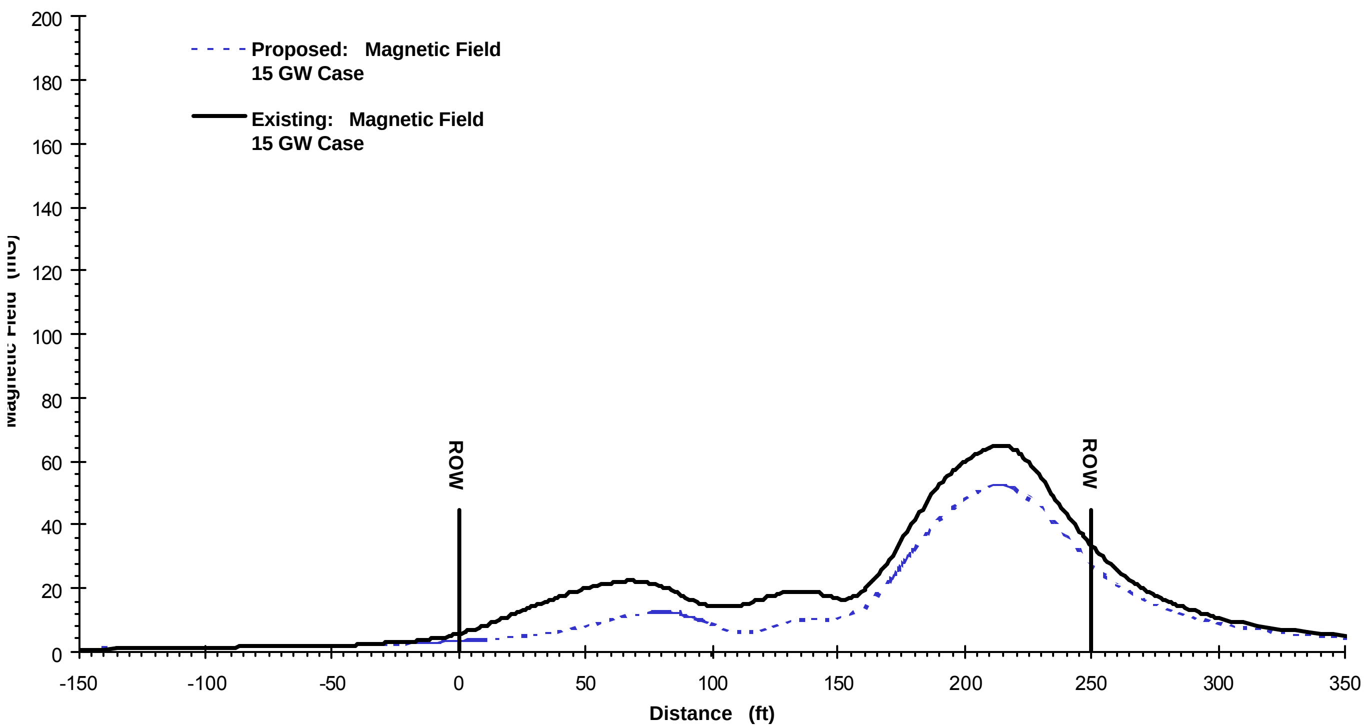


Figure 54. Electric and magnetic field profiles for cross section 12 (Alternative B)

NY10132.000 C0T0 1003 WB24

Cross Section 13

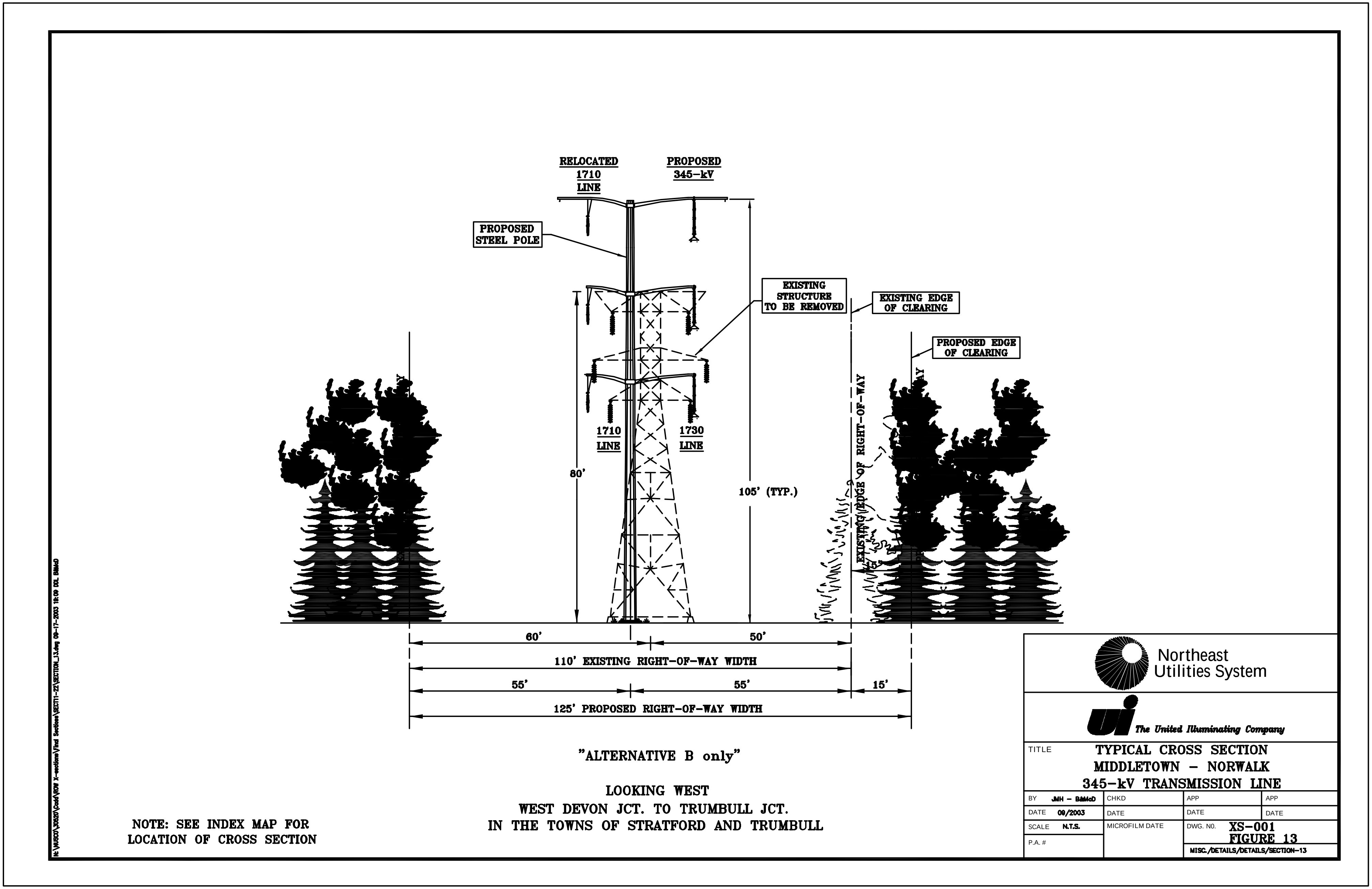
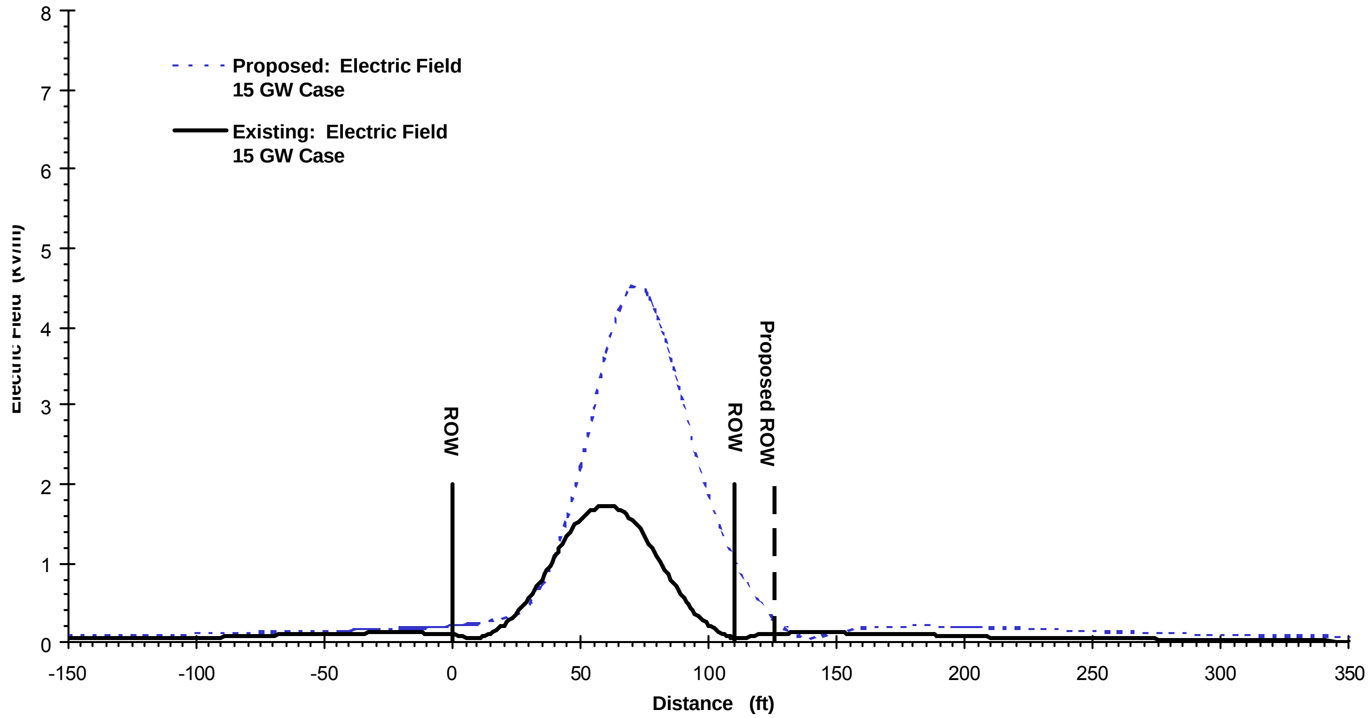


Figure 55. Cross section 13 - West Devon Junction to Trumbull Junction (Stratford, Trumbull)



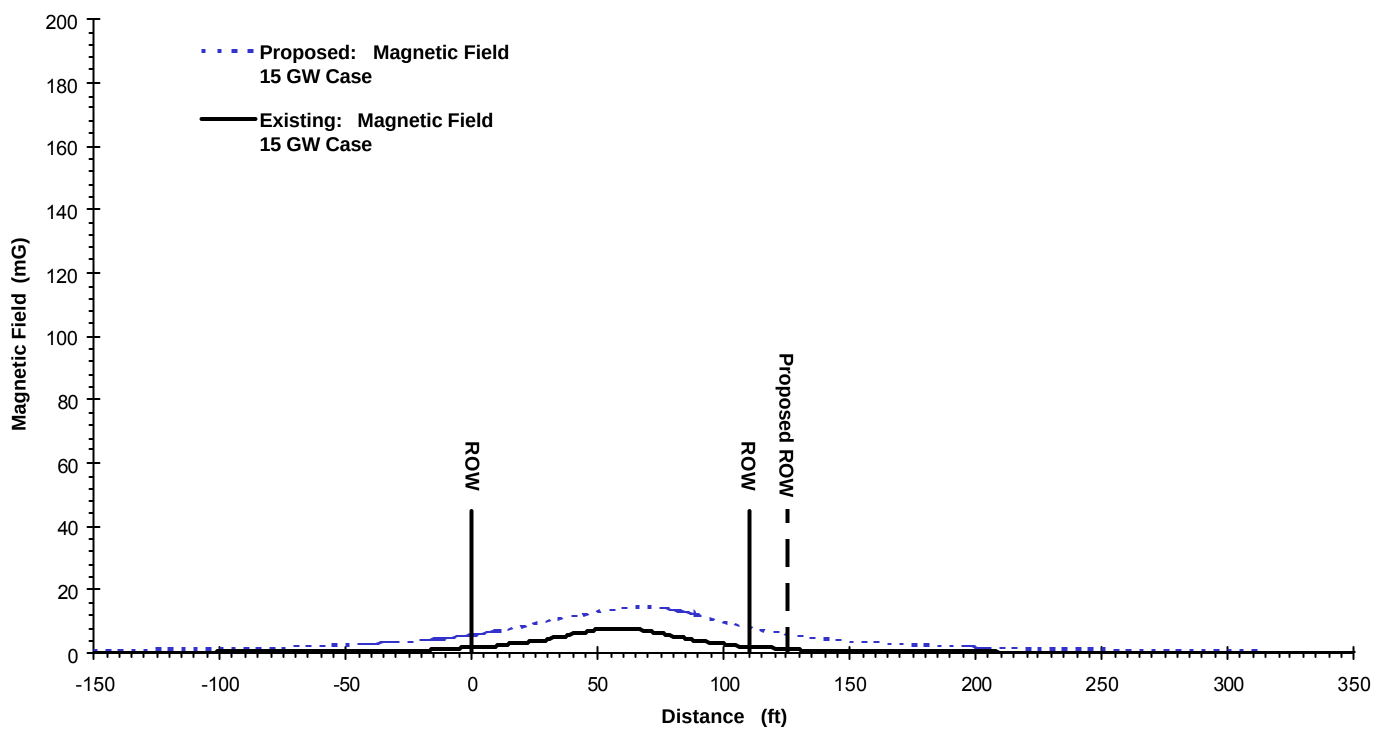


Figure 56. Electric and magnetic field profiles for cross section 13 (Alternative B)

Cross Section 14

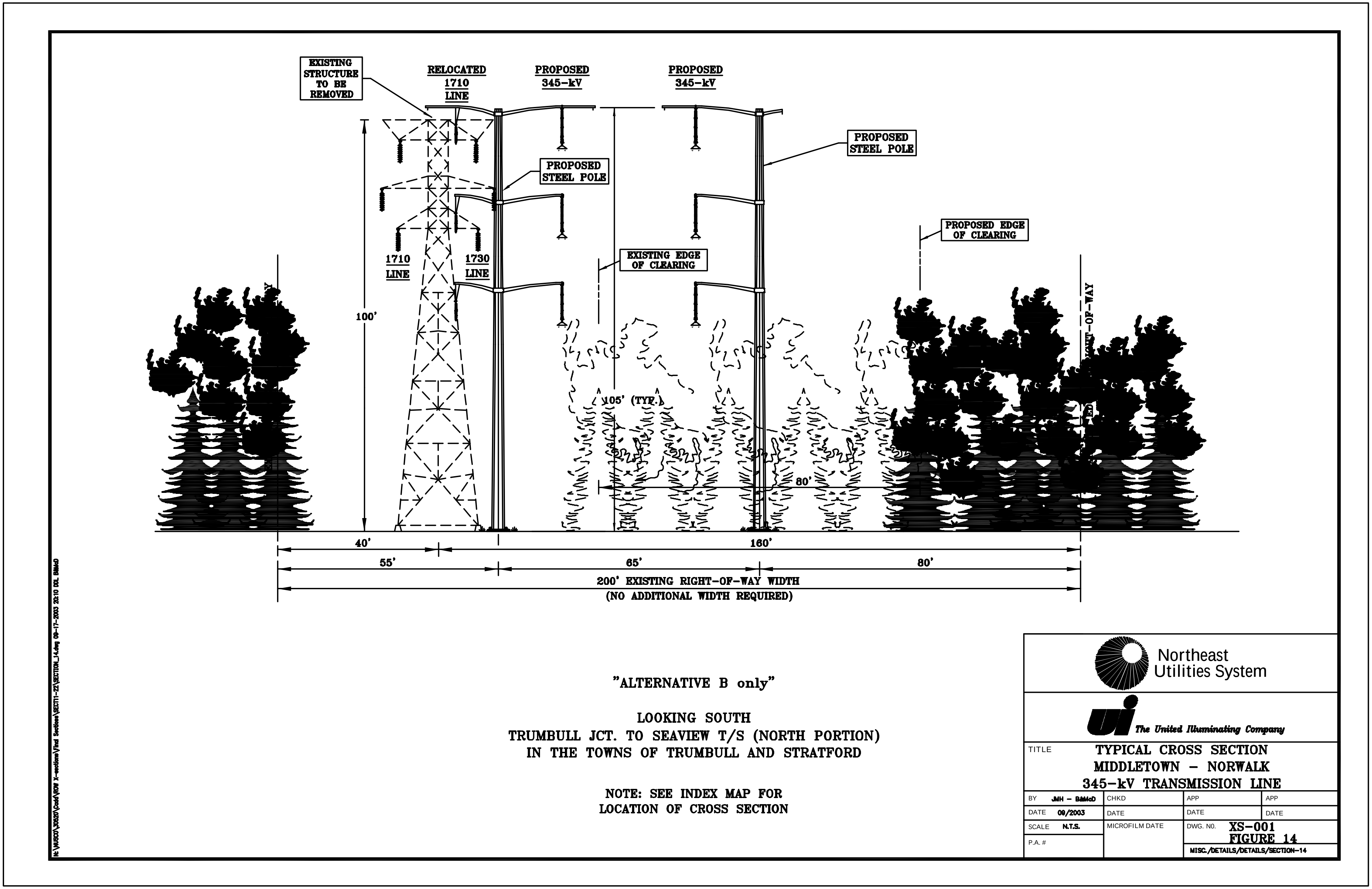


Figure 57. Cross section 14 - Trumbull Junction to Seaview Transfer Station (Stratford, Trumbull)

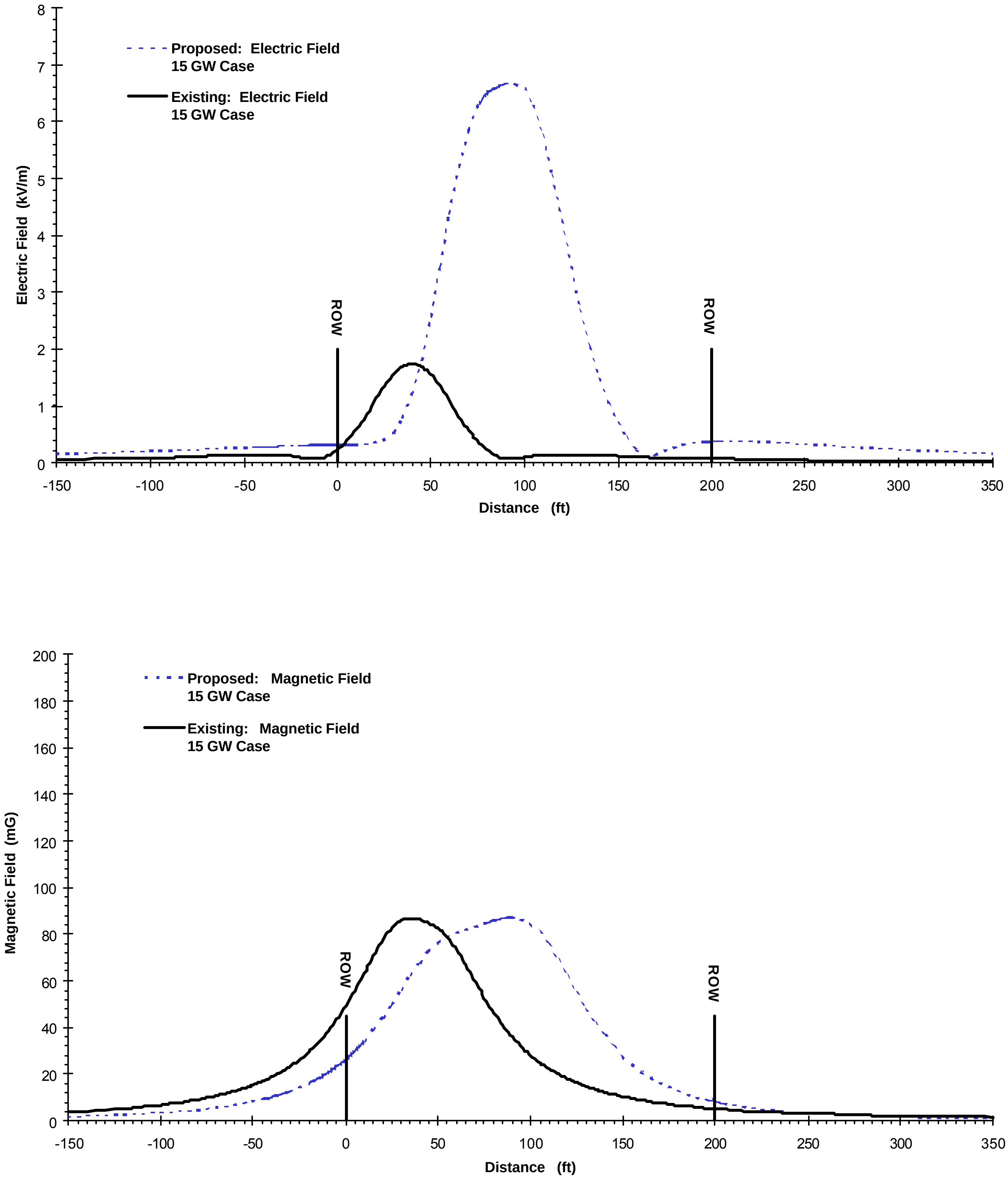


Figure 58. Electric and magnetic field profiles for cross section 14 (Alternative B)

NY10132.000 C0T0 1003 WB24

Cross Section 15

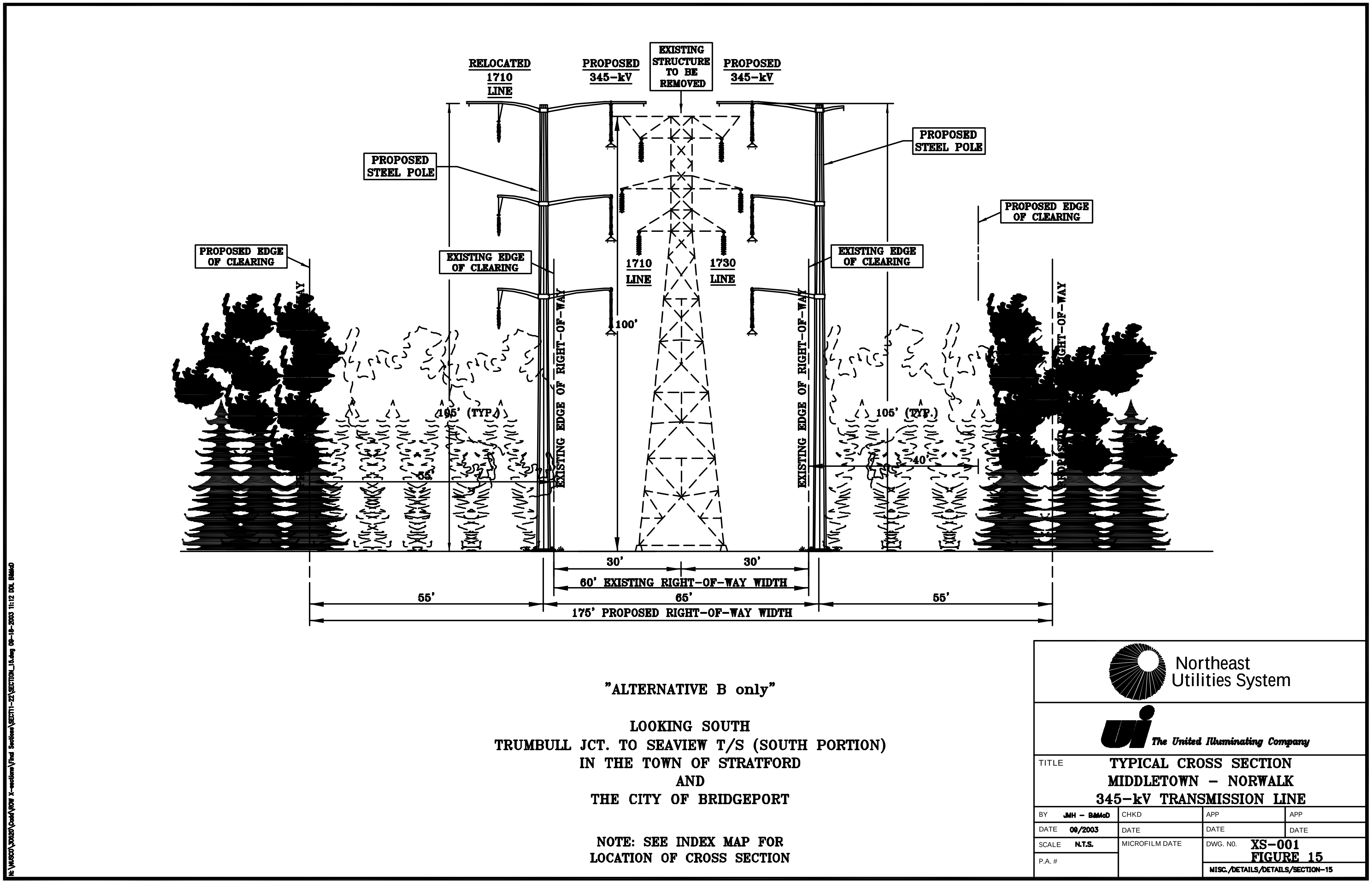
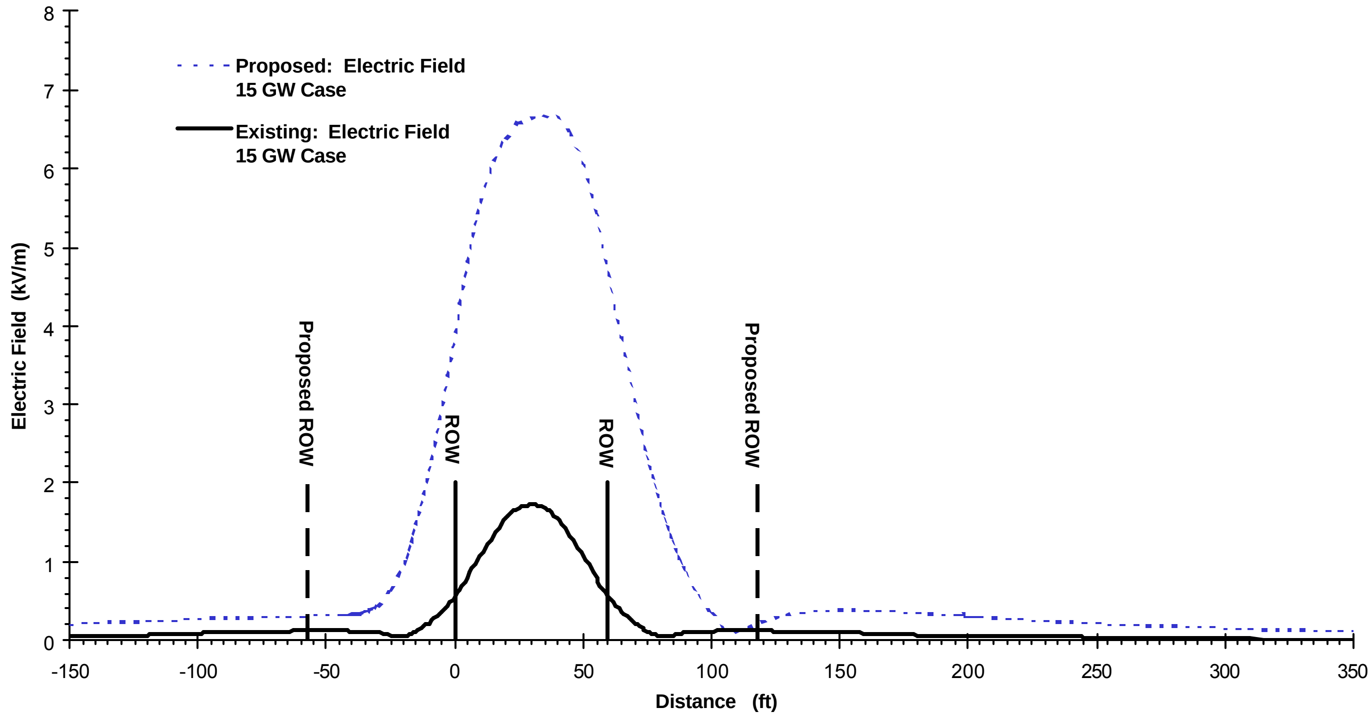


Figure 59. Cross section 15 - Trumbull Junction to Seaview Transfer Station (Stratford, Bridgeport)



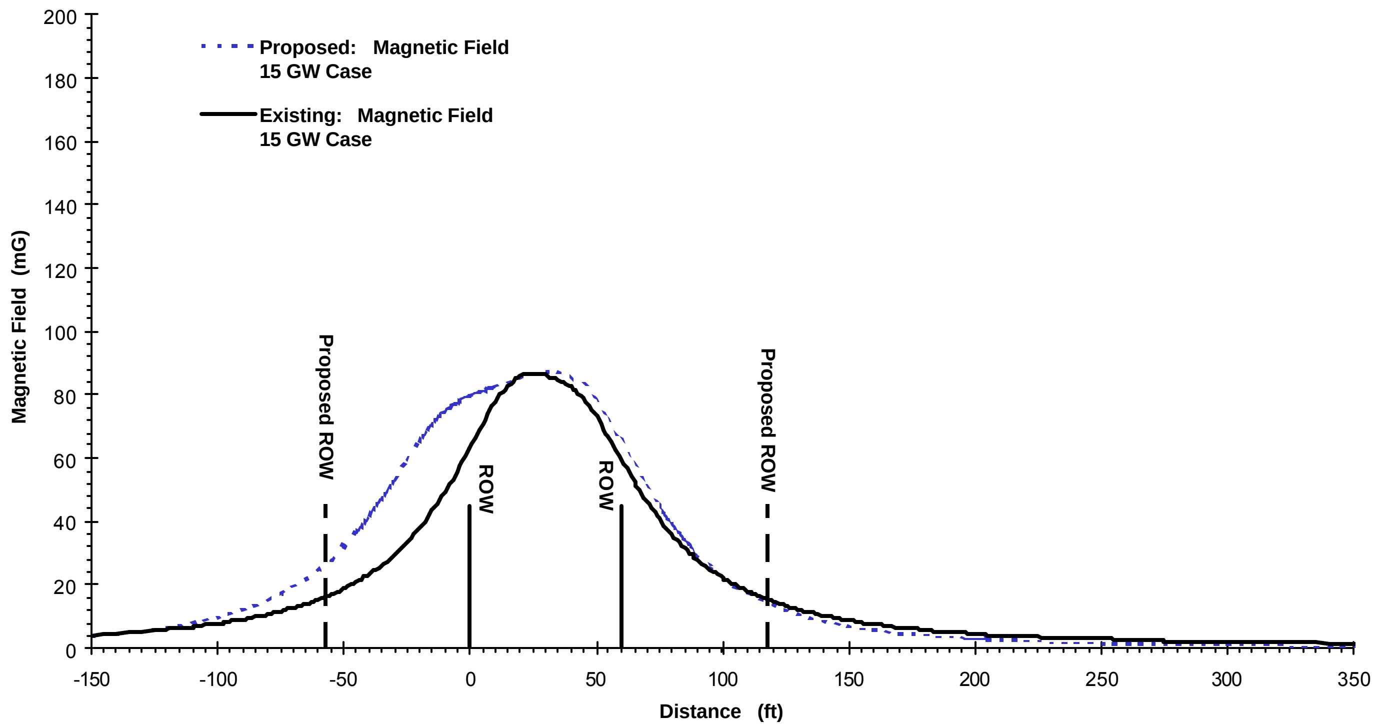


Figure 60. Electric and magnetic field profiles for cross section 15 (Alternative B)

NY10132.000 C0T0 1003 WB24

Cross Section 16

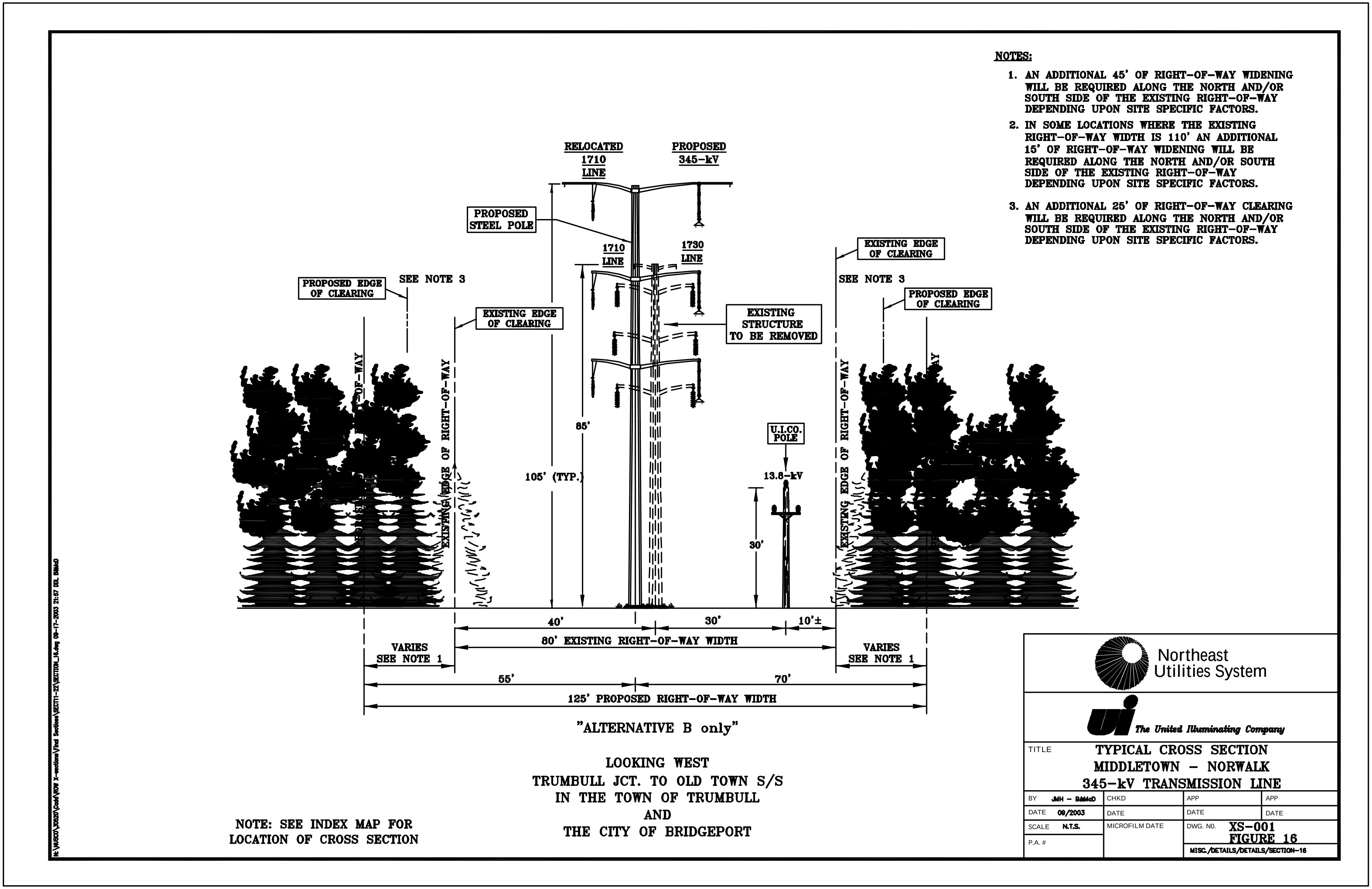
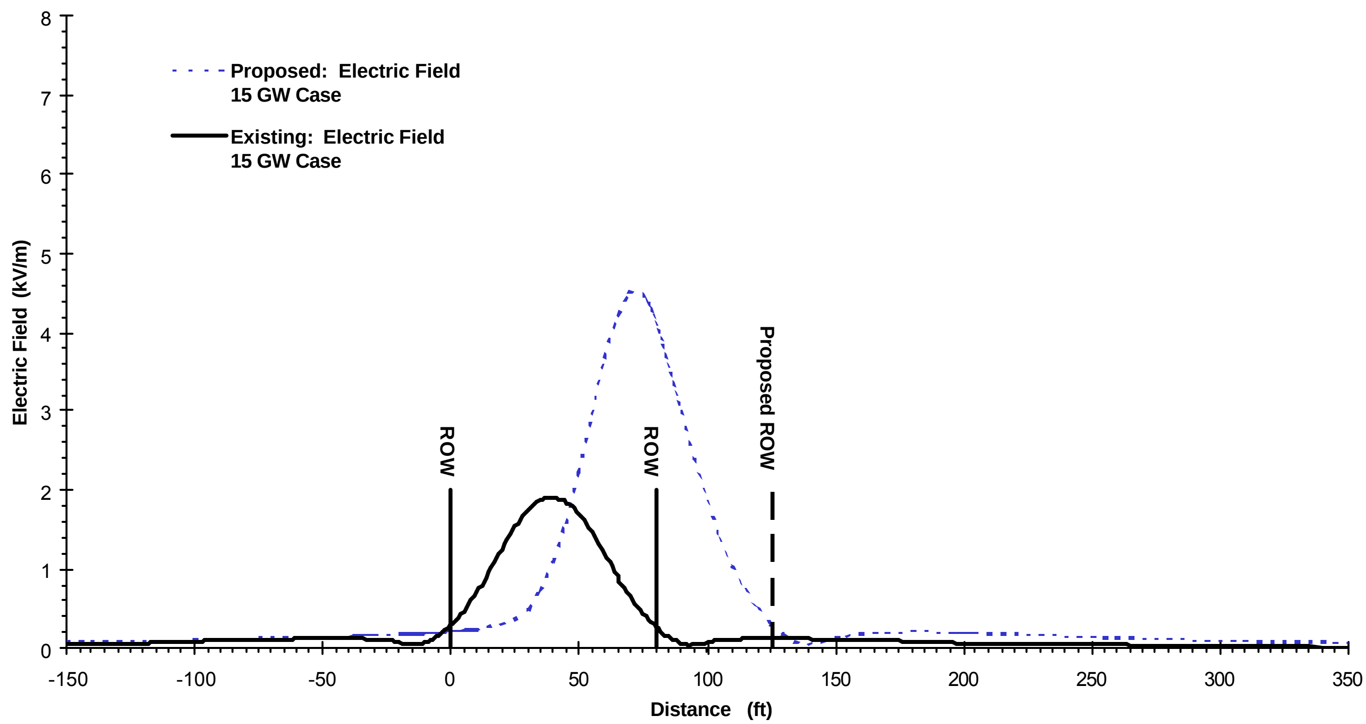


Figure 61. Cross section 16 - Trumbull Junction to Old Town Substation (Trumbull, Bridgeport)
(Alignment of proposed structure on ROW may vary slightly along route)



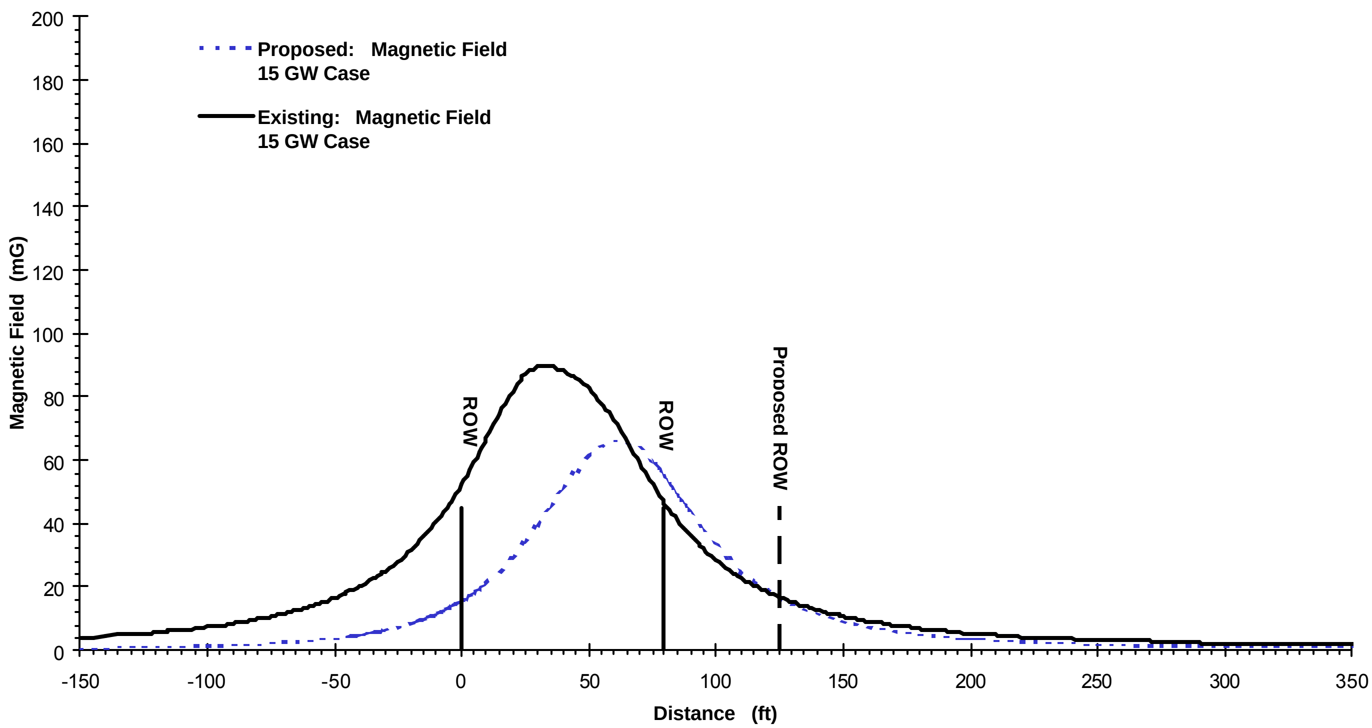


Figure 62. Electric and magnetic field profiles for cross section 16 for typical alignment of proposed structure (Alternative B)

NY10132.000 C0T0 1003 WB24

Cross Section 17

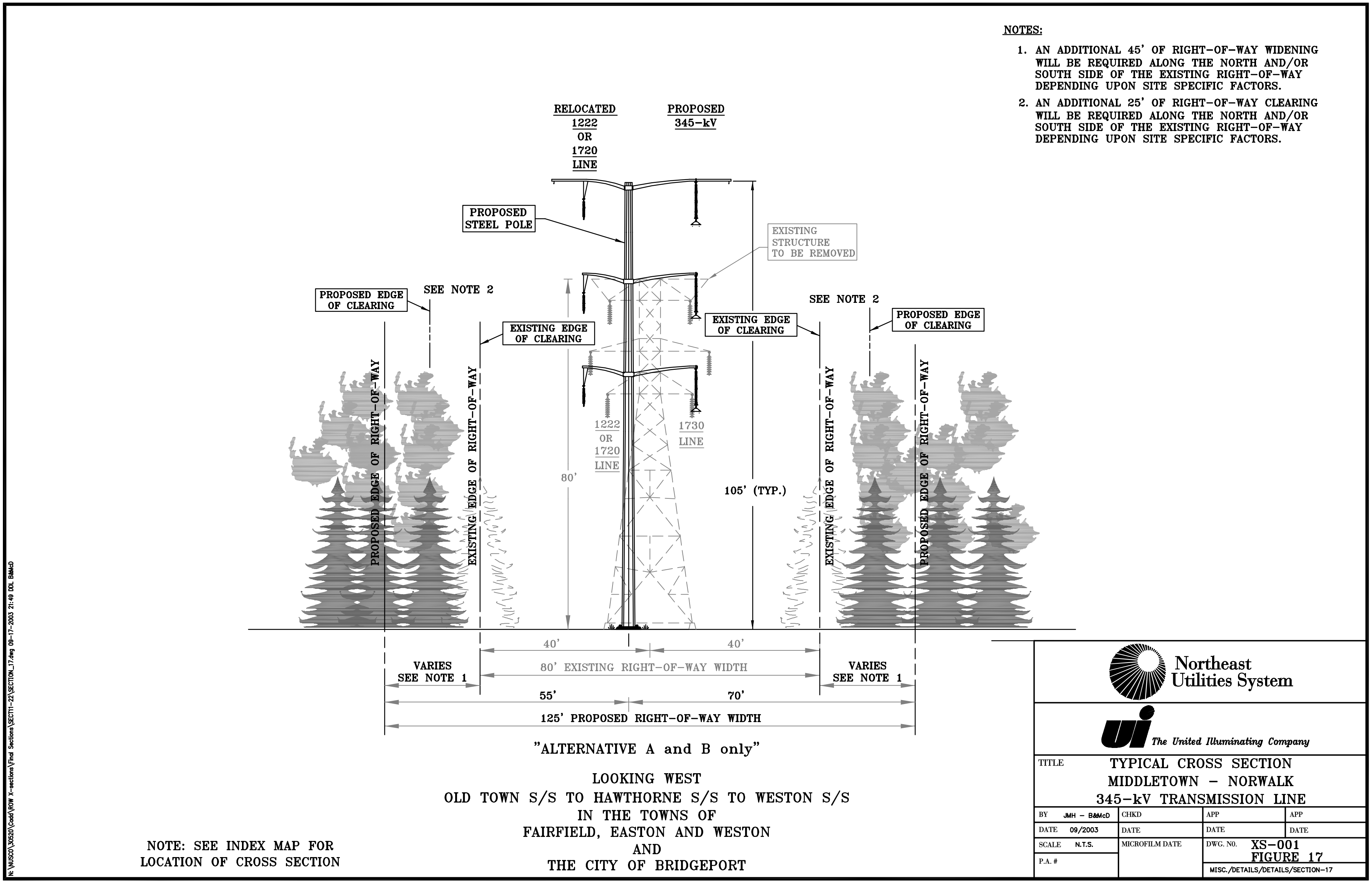
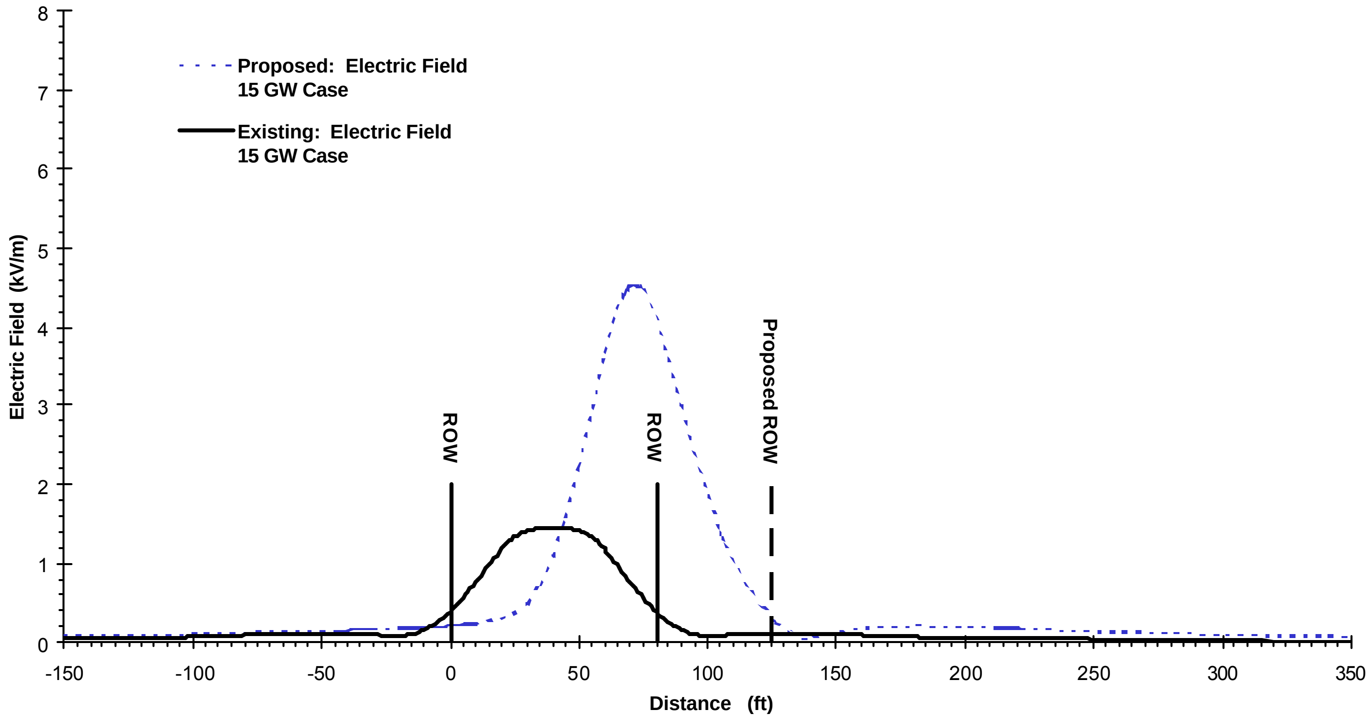


Figure 63. Cross section 17 - Old Town to Hawthorne to Weston Substations (Fairfield, Easton, Weston, Bridgeport)



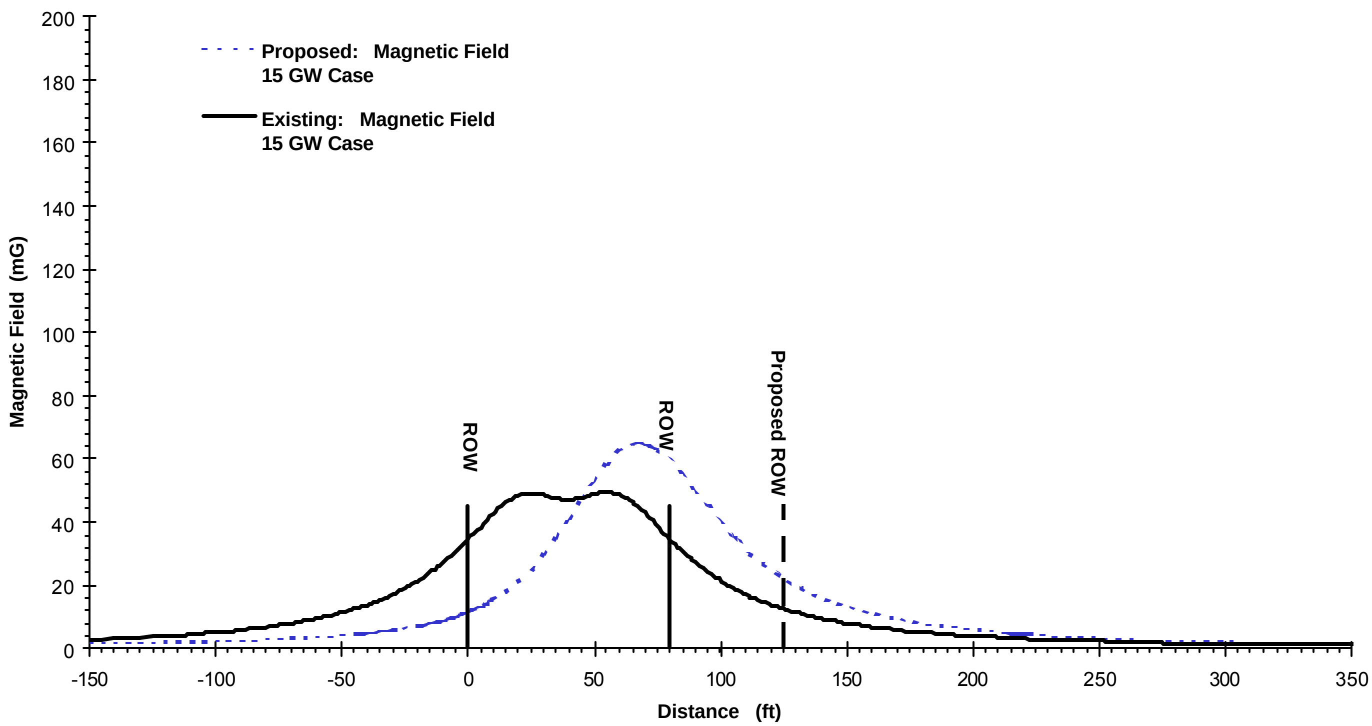


Figure 64. Electric and magnetic field profiles for cross section 17 (Alternatives A and B)

Cross Section 18

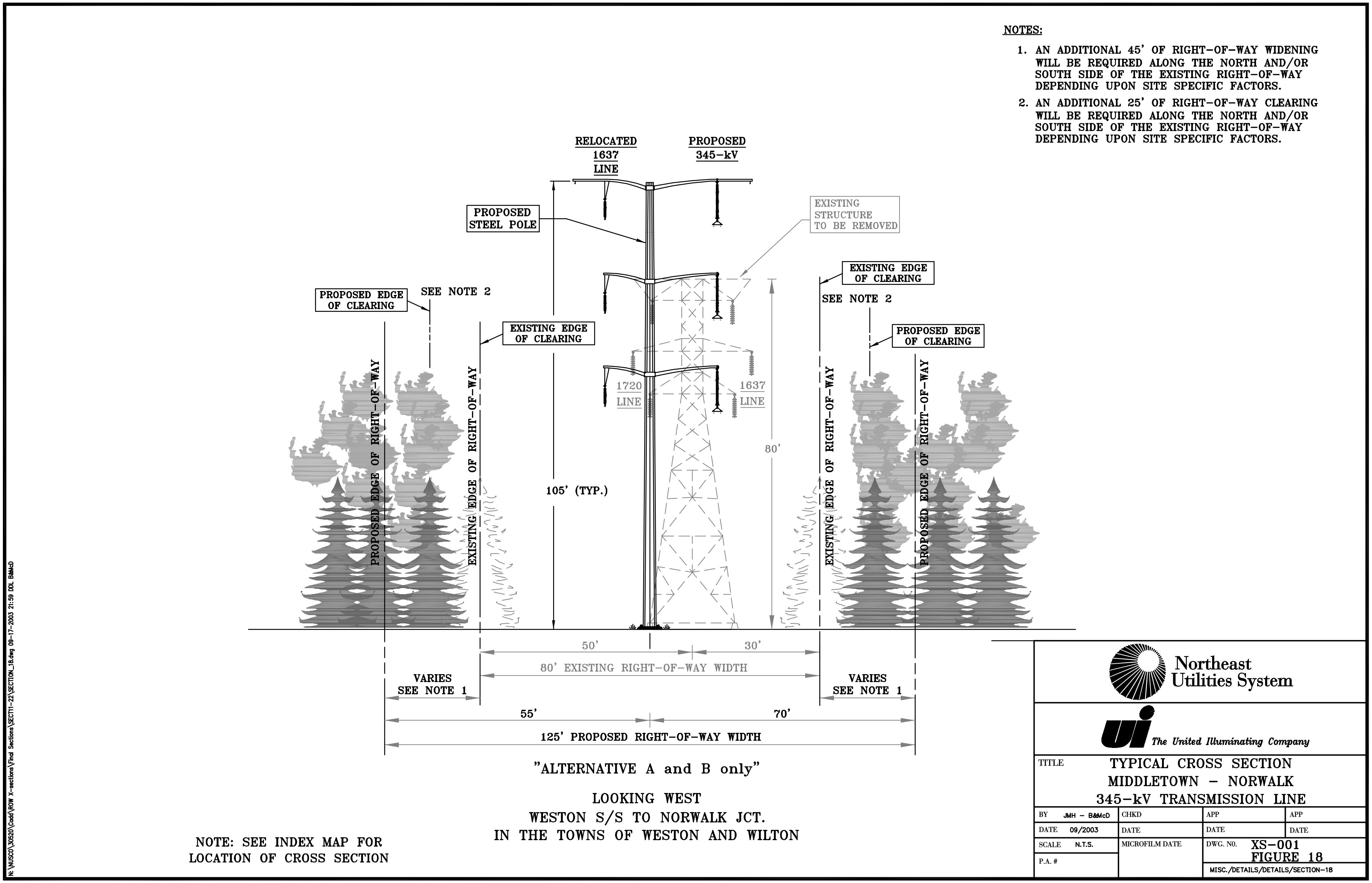


Figure 65. Cross section 18 - Weston Substation to Norwalk Junction (Weston, Wilton)

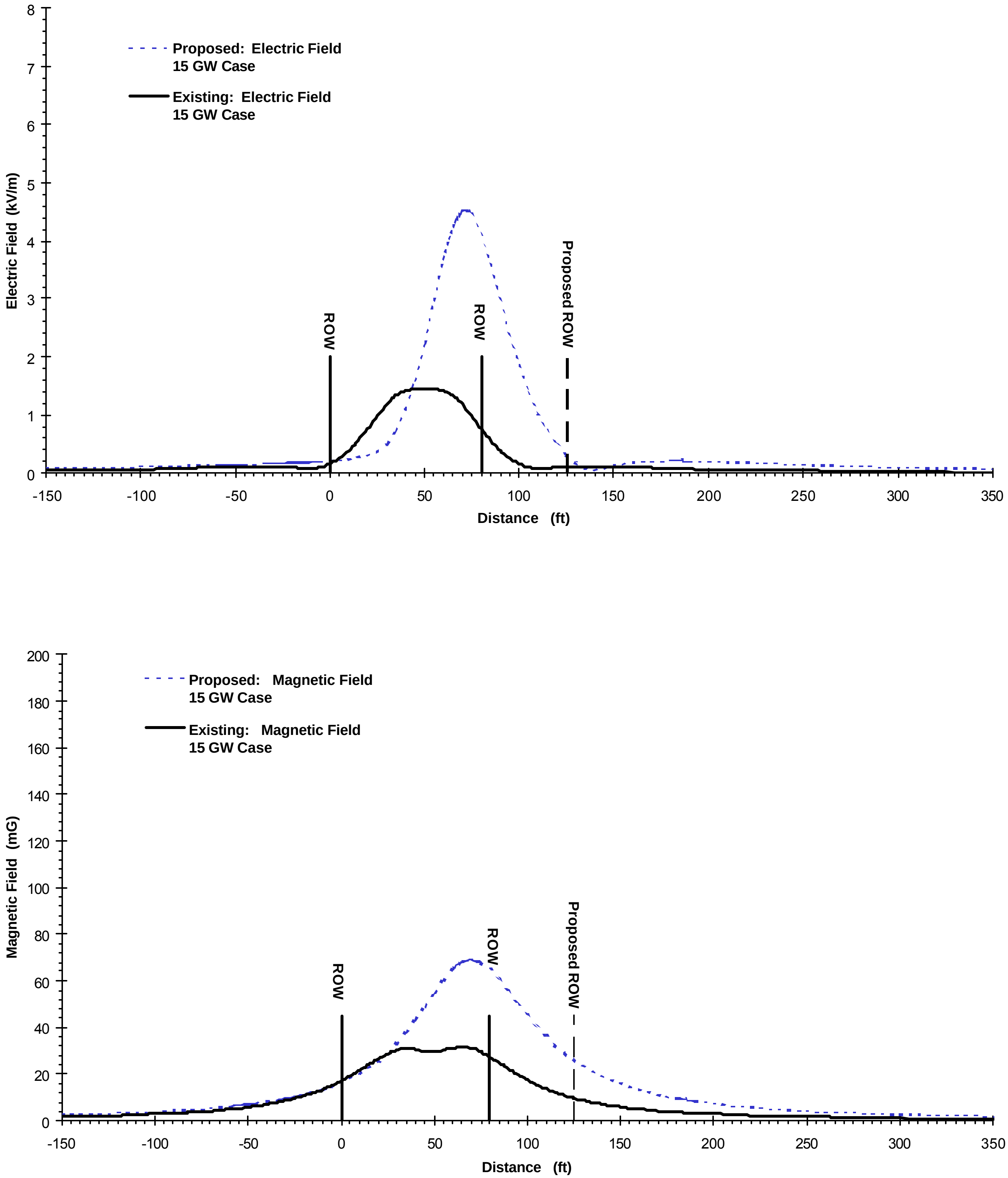


Figure 66. Electric and magnetic field profiles for cross section 18 (Alternatives A and B)

Cross Section 19

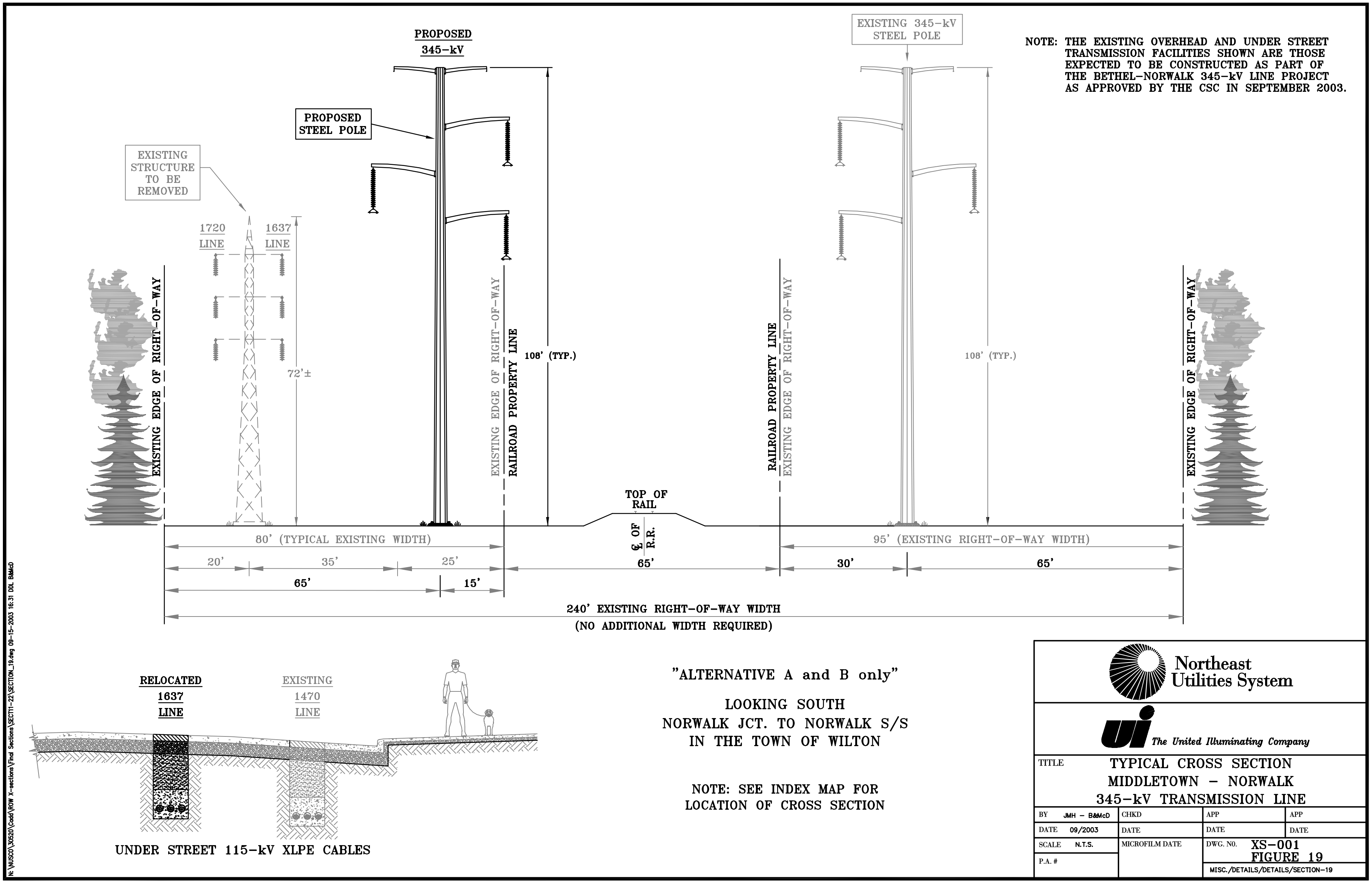


Figure 67. Cross section 19 - Norwalk Junction to Norwalk Substation (Wilton)
(Underground lines shown are 800 feet or more off the ROW and do not effect the magnetic field levels at the ROW edge. The 345-kV line labeled as "existing," represents the not-yet-built Bethel-Norwalk line.)

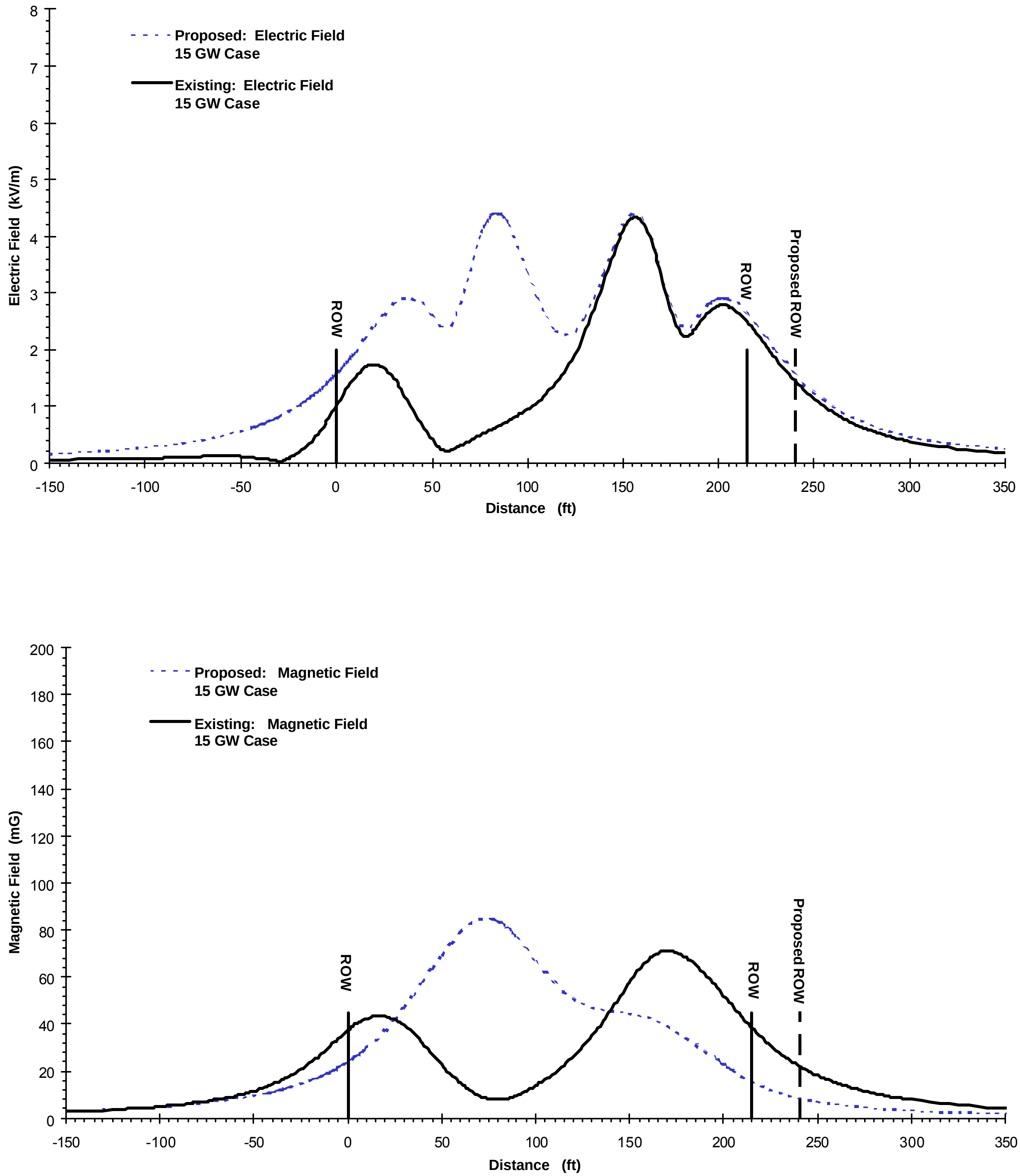


Figure 68. Electric and magnetic field profiles for cross section 19 (Alternatives A and B)

Cross Section 20

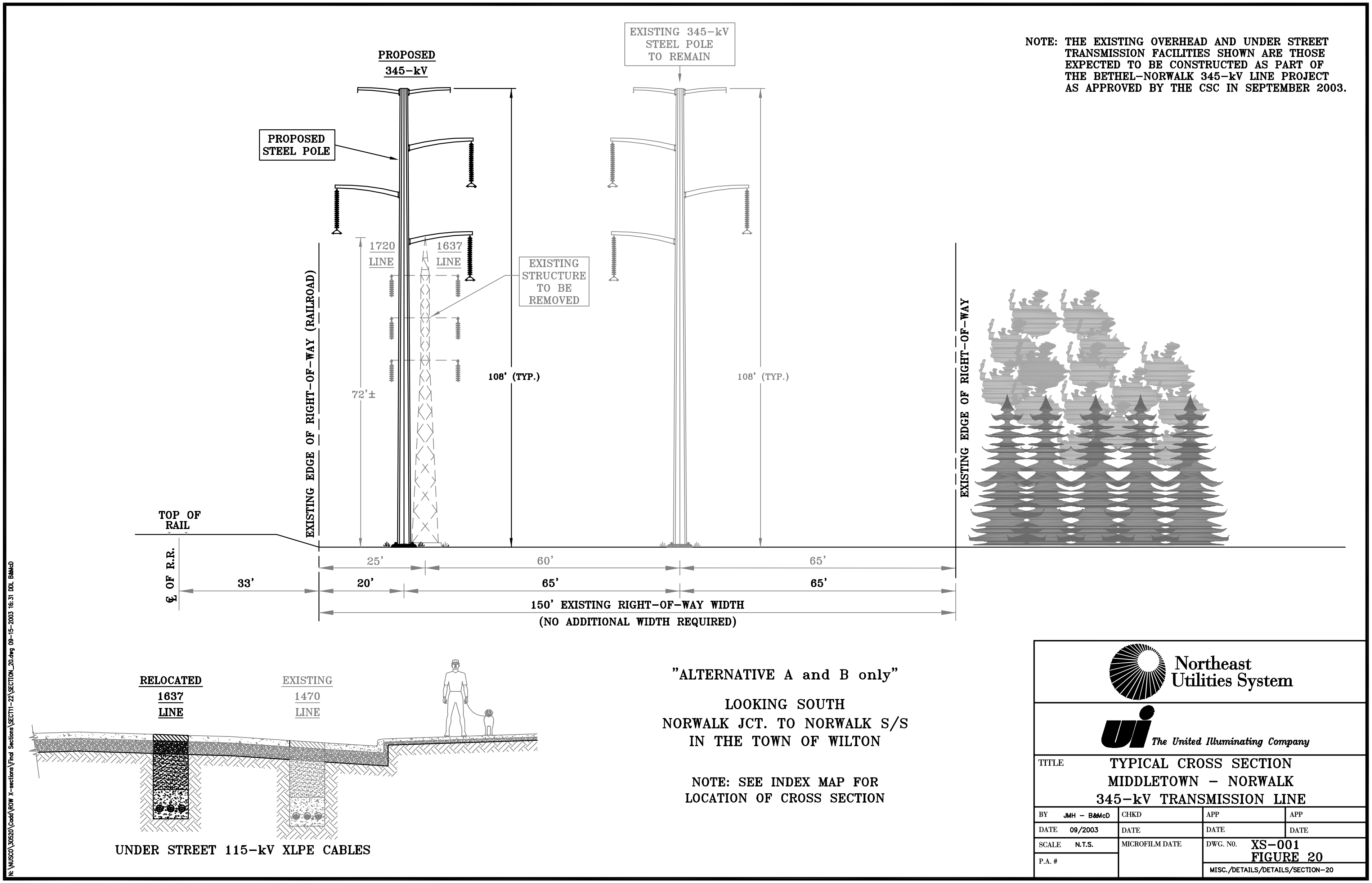
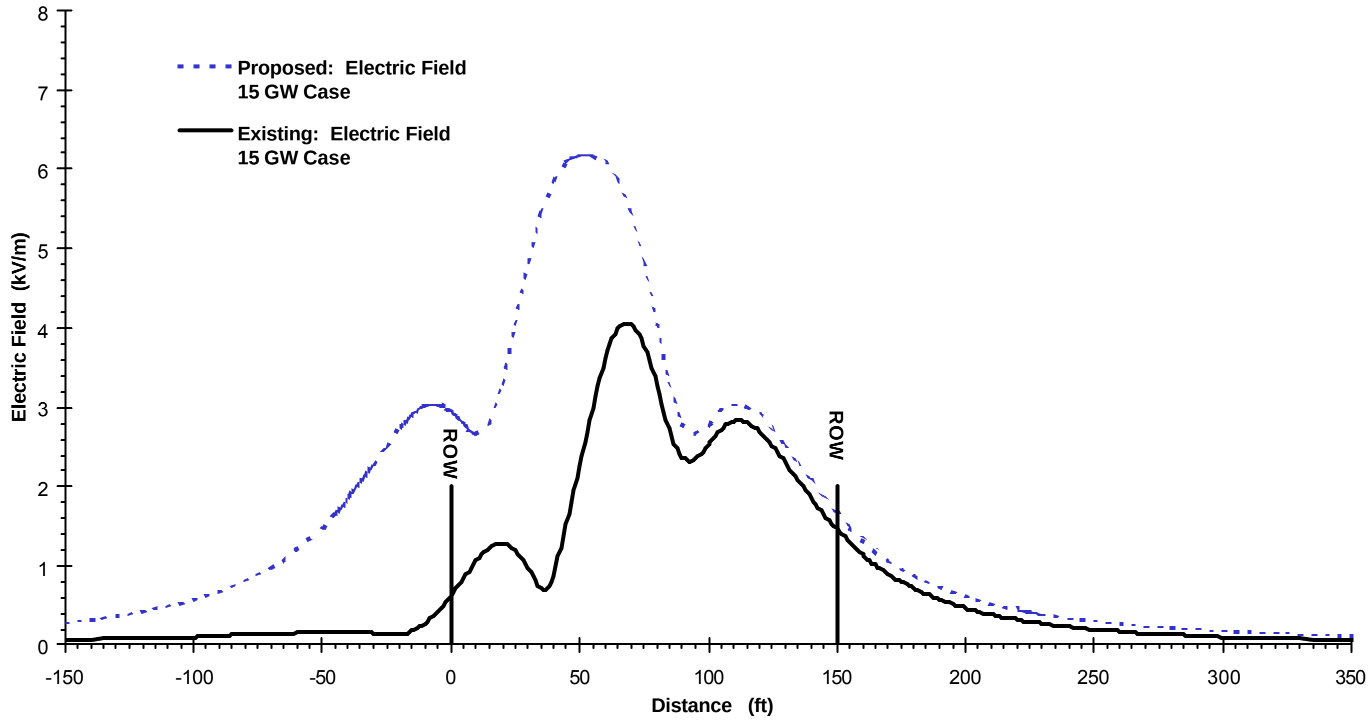


Figure 69. Cross section 20 - Norwalk Junction to Norwalk Substation (Wilton)
(Underground lines shown are 800 feet or more off the ROW and do not effect the magnetic field levels at the ROW edge. The 345-kV line labeled as "existing," represents the not-yet-built Bethel-Norwalk line.)



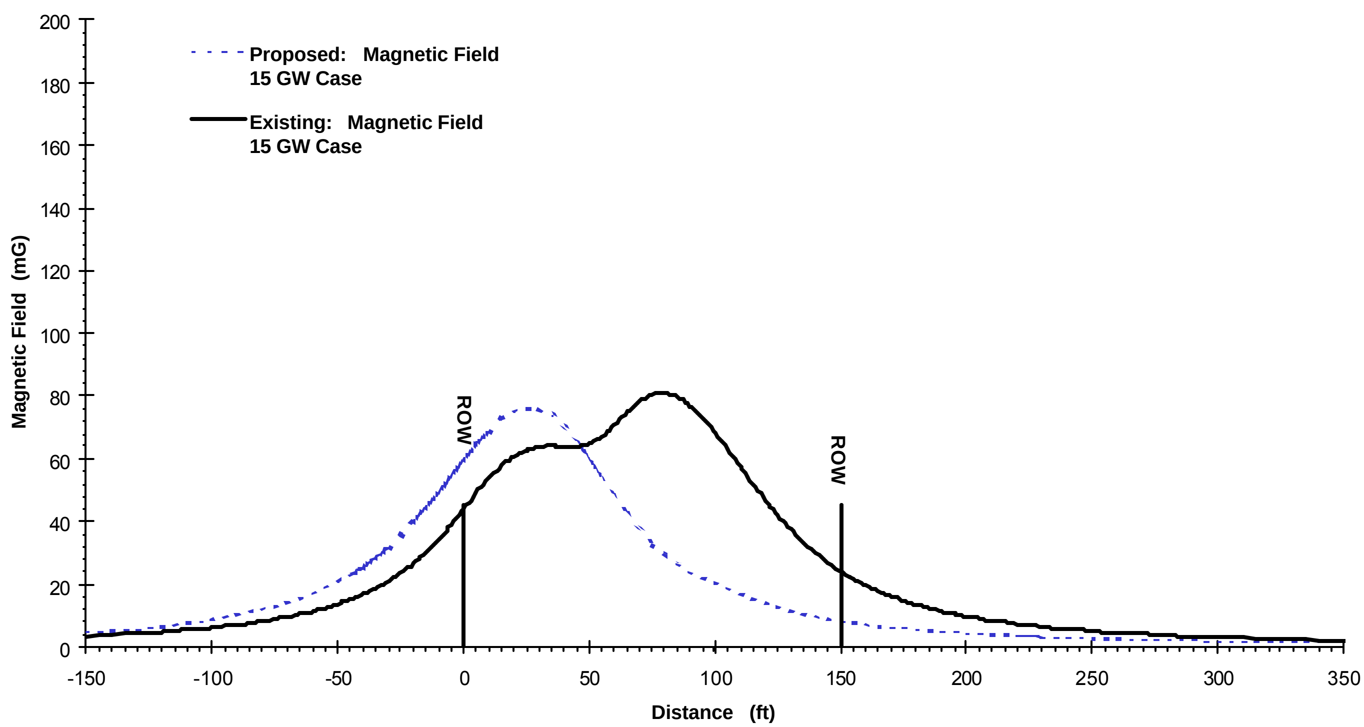


Figure 70. Electric and magnetic field profiles for cross section 20 (Alternatives A and B)

Cross Section 21

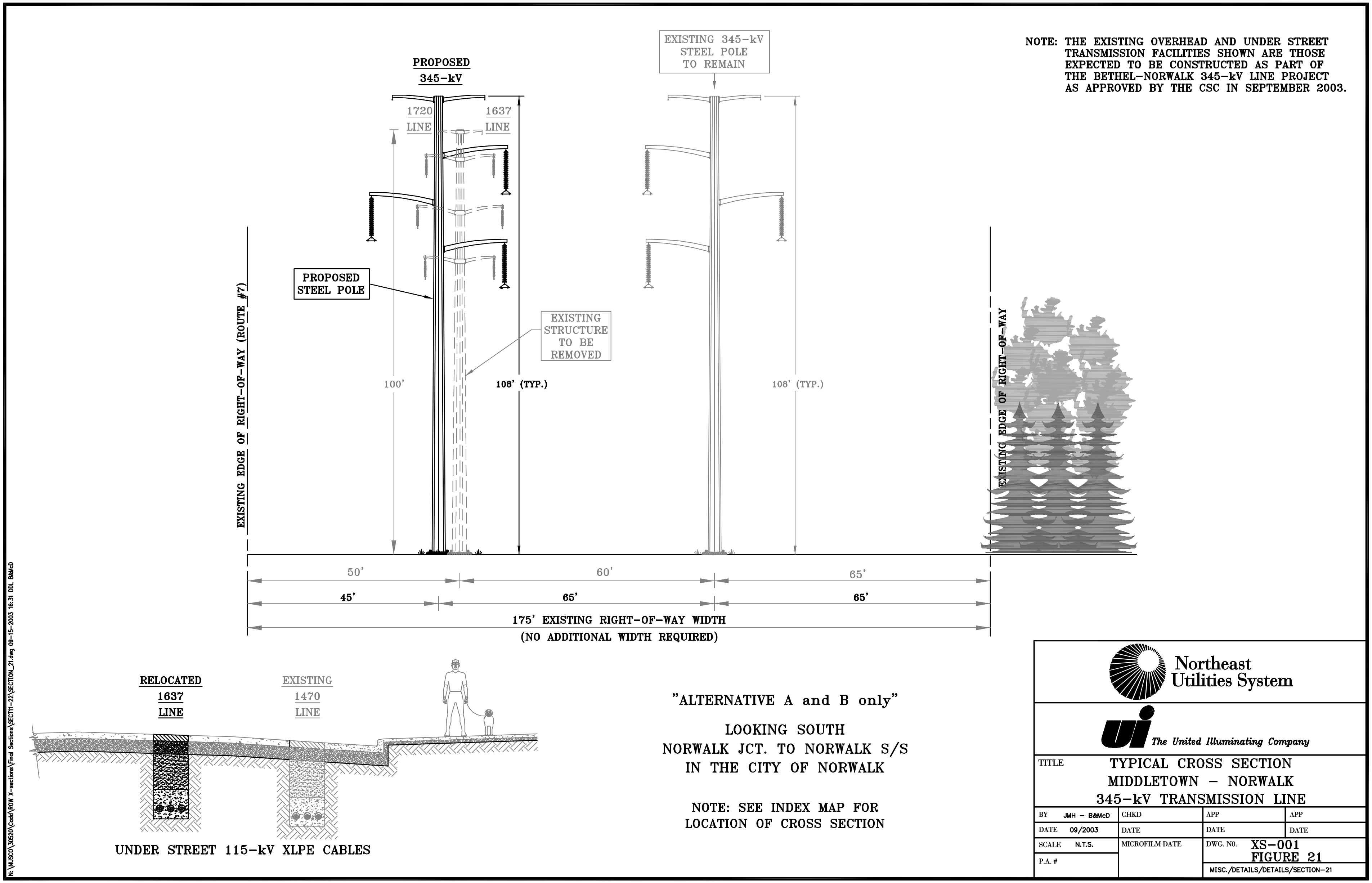


Figure 71. Cross section 21 - Norwalk Junction to Norwalk Substation (Norwalk)
(Underground lines shown are 800 feet or more off the ROW and do not effect the magnetic field levels at the ROW edge. The 345-kV line labeled as “existing,” represents the not-yet-built Bethel-Norwalk line.)

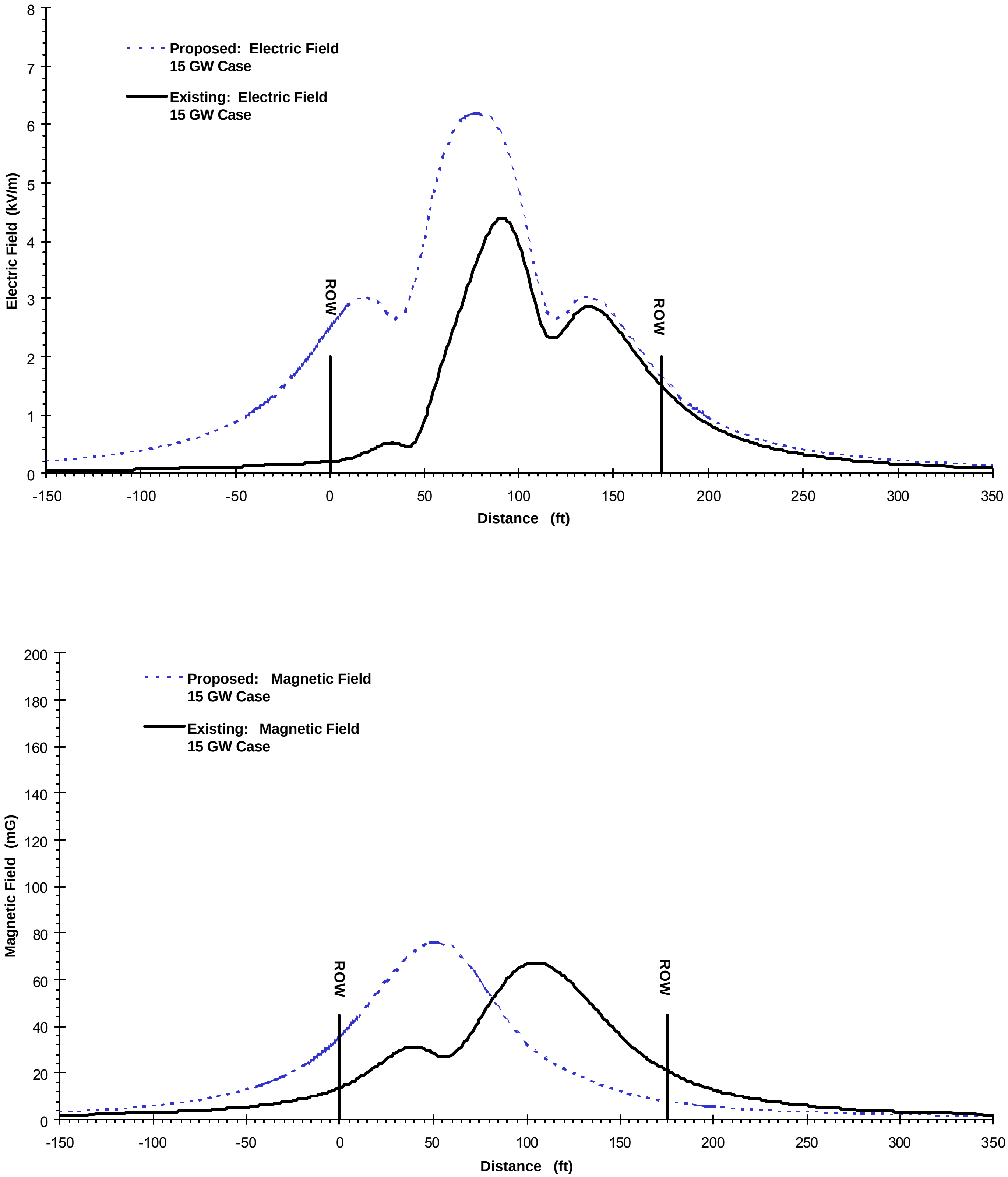


Figure 72. Electric and magnetic field profiles for cross section 21 (Alternatives A and B)

NY10132.000 C0T0 1003 WB24

Cross Section 22

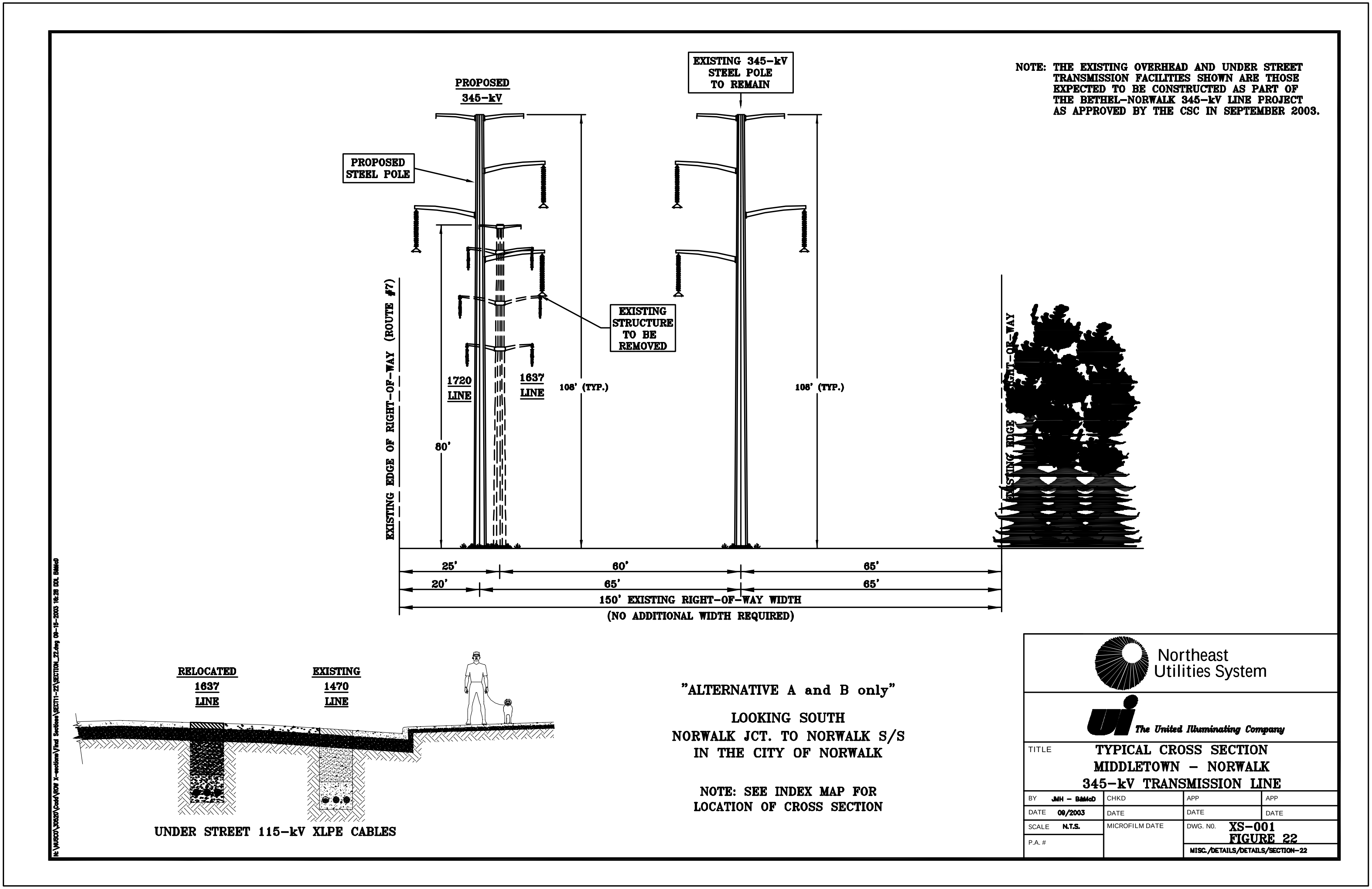
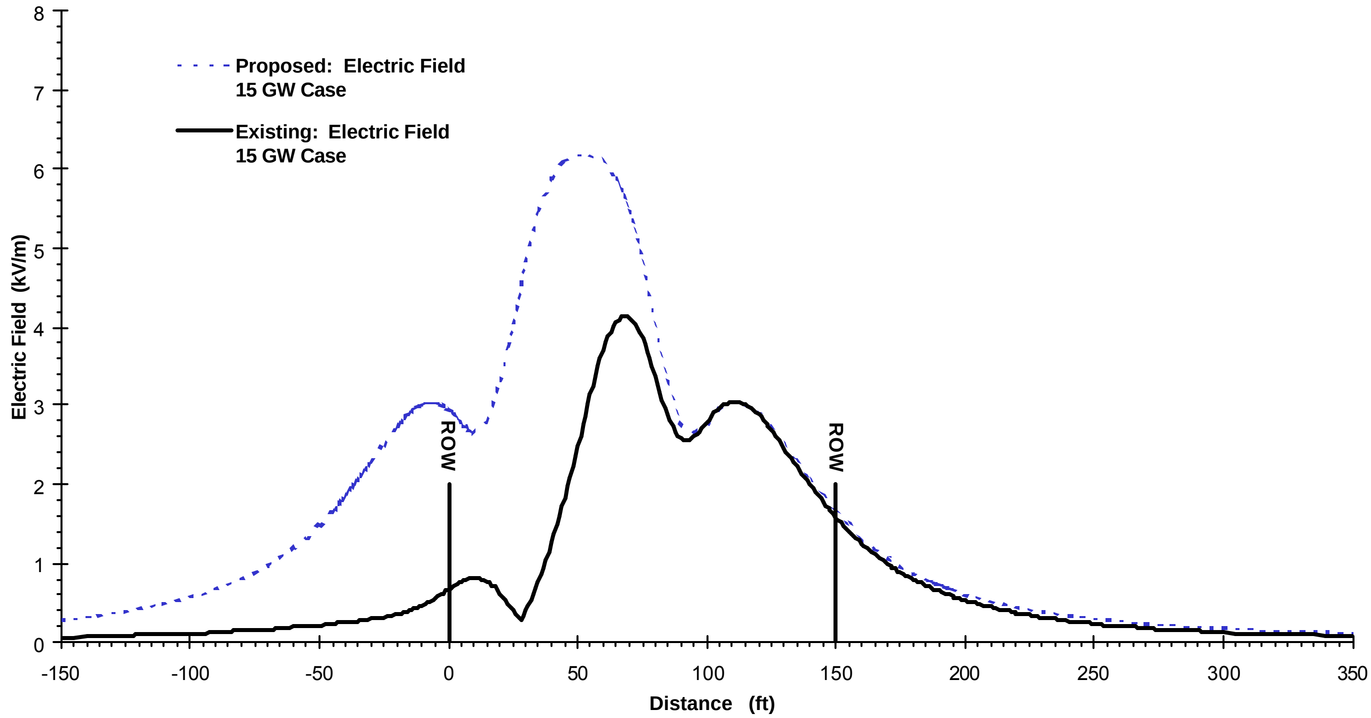


Figure 73. Cross section 22 - Norwalk Junction to Norwalk Substation (Norwalk)
(Underground lines shown are 800 feet or more off the ROW and do not effect the magnetic field levels at the ROW edge. The 345-kV line labeled as "existing," represents the not-yet-built Bethel-Norwalk line.)



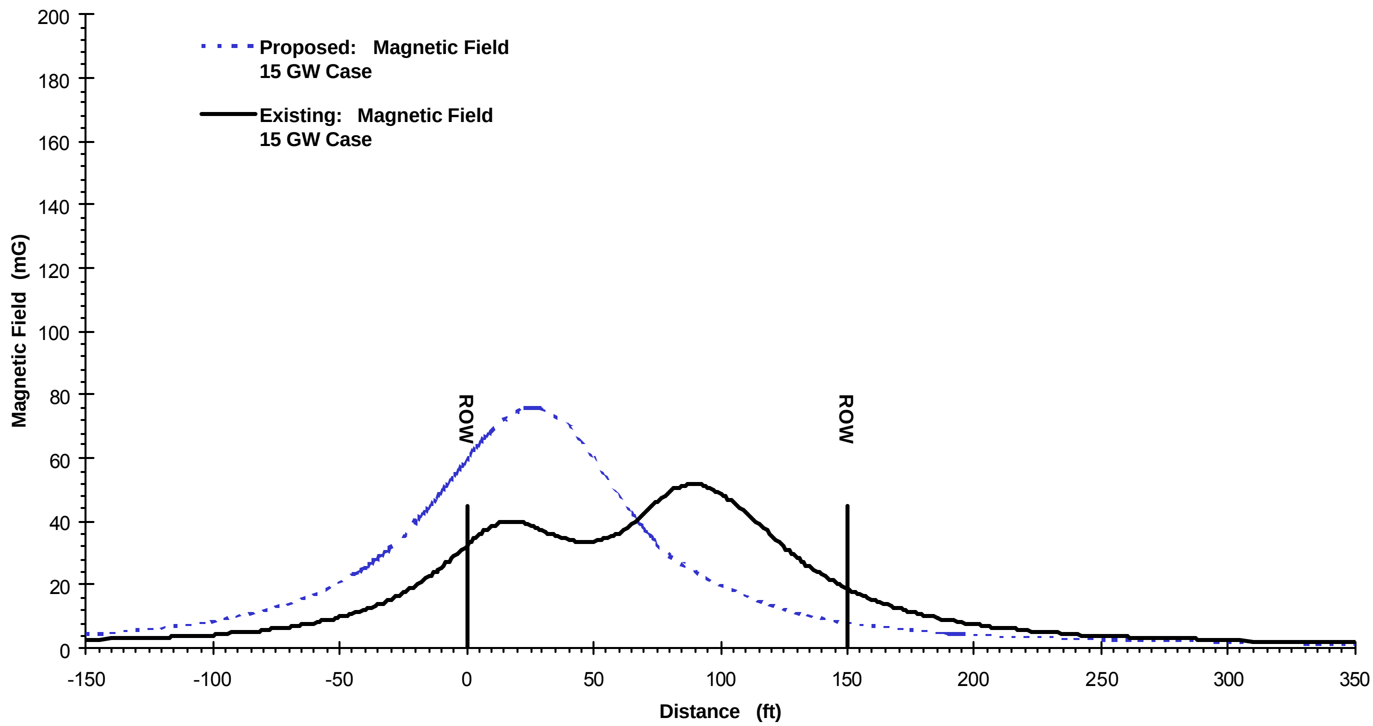


Figure 74. Electric and magnetic field profiles for cross section 22 (Alternatives A and B)

3 EMF Research

Although electric energy is a beneficial and indispensable component of our society, questions have been raised over the past forty years as to whether exposure to EMF may in some way be adverse. Scientific research to assess whether exposure to electric and magnetic fields at power frequencies can affect human health has been conducted over the past 30 years. Public interest has focused mainly, although not entirely, on the question of cancer and long-term exposures to magnetic fields. This interest arose from studies of human populations in their natural environment (epidemiologic studies of children, adults, in communities, and workers in jobs presumed to include EMF exposures). This research has been supplemented by studies of cells, tissues, and of laboratory animals exposed to EMF. These different approaches – epidemiologic and laboratory studies – are used to evaluate the potential long-term human health effects of any environmental exposure, including EMF.

Epidemiologic studies are valuable because they are conducted in human populations, but they also have limitations because they are not experimental. For example, researchers cannot control the amount of individual exposure to EMF, how exposure occurred over time, the contribution of many different field sources, or individual traits, such as diet and other exposures as can be controlled in laboratory studies. Nonetheless, the search for better methods to assess human exposure has progressed and thereby we have more accurate information on possible links to health than in the past.

Over the past few years, several groups have reviewed and evaluated reported research findings regarding potential health effects of residential electric and magnetic fields. A broad range of possible biological and health effects have been studied to assess whether elevated exposure to EMF presents a health risk to populations. The following review has been prepared to update the Connecticut Siting Council (CSC) on the status of recent scientific research regarding the potential for health effects of exposure to EMF, and will focus on research published after 1998, highlighting literature published in the last few years.

3.1 Epidemiology Studies of Cancer

The question of a link between power lines and childhood cancer is based on the results of earlier studies beginning in 1979. The assumption is that the relevant exposure associated with power lines is the magnetic field, rather than the electric field. This assumption rests on the fact that walls and vegetation shield the interior of homes from electric fields, where people spend the vast majority of their time; magnetic fields are not shielded. The magnetic field in the vicinity of a power line is the result of a flow of current. Higher currents result in higher levels of magnetic fields. The majority of epidemiology studies have largely focused on magnetic rather than electric fields, although there is a small body of literature that has evaluated the latter.

Epidemiologic studies report results in the form of statistical associations. The term "statistical association" is used to describe the tendency of two things to be linked or to vary in the same way, such as higher level of exposure and increased occurrence of disease. However, statistical associations are not automatically an indication of cause and effect relationship, because the interpretation of numerical information depends on the context, including (for example) the nature of what is being studied, the source of the data, how the data were collected, and the size of the study. In addition, both epidemiology data in humans and laboratory data in animals or cells are used to assess the possibility of human health effects.

3.1.1 Studies of Children

The goal of EMF health epidemiology studies has been to estimate the average or typical exposure of an individual during the year, not the fluctuating level at any single spot, whether it is in the playground, a school, or a place in the home. Opportunities for encountering magnetic fields in excess of a few mG or even 10 mG for brief periods (seconds, minutes, a few hours) abound in our environment but *these field values, whether measured or estimated by calculation, are not the same as estimates of long-term exposures to magnetic fields.*

The estimate of a person's long-term exposure reflects both the **level of fields in the environment,** and the **duration** of time one spends in areas with fields of that level. Thus, a calculated or measured magnetic field greater than a particular value, say 4 mG, in a playground or even a small area of a residence would not necessarily indicate that a person at these locations would have an average or time-weighted exposure greater than 4 mG. This distinction should be kept in mind when reviewing measured or calculated values in Section 2 or in the Appendix of this report. These values cannot be directly compared with the exposure estimates discussed in this section because they do not reflect how a field value at a single location contributes to a person's overall average annual exposure.

3.1.1.1 Studies of Magnetic Field Exposures

Prior to 1998, epidemiologic studies of cancer reported that children who developed leukemia were more likely to live near power lines that were presumed to produce higher magnetic fields than other power lines. The term "power line" refers to both transmission lines and neighborhood distribution lines. In most of these studies, the power lines the children lived near were more often distribution lines. The exposure to EMF was based on an indirect, and therefore imprecise, method for estimating magnetic field exposure from power lines called the "wiring code." (Wiring codes are a surrogate for magnetic field exposure, based on the number of wires, their diameter or 'thickness' and their distance from the residence, and are not based on actual magnetic field levels.) Subsequent studies have included important improvements to obtain more reliable results for resolving the differences in results among studies. These improvements include more extensive EMF measurements in the homes, measurements taken by a personal exposure monitor, a larger study population, or a shorter interval between the time the disease was diagnosed and the time exposure was assessed. Major recent studies are summarized below:

- A study conducted in Ontario, Canada compared the estimated magnetic field exposure of 201 children who had cancer to that of a similar group of children without cancer (Green et al, 1999a). No increased risk estimates were found for exposure assessed as average magnetic fields in the bedroom or the interior, or any of the three methods of estimating exposure from wiring. An even smaller group of 88 children with leukemia and their controls wore personal monitors to measure magnetic fields (Green et al, 1999b). Associations with magnetic fields were reported in some of the analyses, but most of the risk estimates had a broad margin or error, and major methodological problems in the study preclude any clear interpretation of the findings.

- A study from British Columbia, Canada included 462 children who had been diagnosed with leukemia and an equal number of children without leukemia for comparison (McBride et al, 1999). Magnetic field exposure was assessed for each of the children in several ways; regardless of the method used to estimate magnetic field exposure, the magnetic field exposure of children who had leukemia was not greater than the children in the comparison group.

- In December 1999, the United Kingdom Childhood Cancer Study (UKCCS) investigators reported the results of a well-designed study of EMF and childhood cancer (UKCCS, 1999). Exposure was assessed by magnetic field measurements in the home (bedroom and family room) and school, and summarized for each individual by averaging these over time. The children who had cancer of the central nervous system, other cancers, or total malignant disease had no different exposure to magnetic fields than that experienced by controls (children who had no disease). Those who had acute lymphocytic leukemia (ALL) also had exposures similar to the controls for the three lower exposure levels (less than 4 mG). However, slightly more cases than controls were found in the highest exposure category where fields were categorized as greater than 4 mG. These results indicated a weak association with magnetic fields above 4 mG that was likely due to chance.

- The UKCCS investigators had only obtained magnetic field measurements on a portion of the cases in their study. To obtain additional information, they used a method to assess exposure to magnetic fields without entering homes (UKCCS, 2000) and were able to analyze 50% more subjects (a total of 3380 all cancer cases and 3390 controls). For all these children they measured distances to power lines and substations. This information was used to calculate the magnetic field from these external field sources, based on power line characteristics related to production of magnetic fields. The results of the second UKCCS study showed no association with leukemia for magnetic fields calculated to be 4 mG or greater at the residence, in contrast to the weak association reported for measured fields 4 mG or greater in the first report (UKCCS, 1999).

- A study from Germany included 502 children with leukemia and 1,289 control children (Schuz et al, 2001). EMF in Europe changes direction and intensity 50 times, or cycles, per second (50 Hz). Measurements of magnetic field intensity (50 Hz) were taken for 24 hours in the child's bedroom. The results were calculated for daytime or nighttime levels in the bedroom, rather than the child's overall 24-hour exposure. They reported a positive association between mean nighttime magnetic field levels and leukemia for the highest exposed group (4 mG or higher; 9 cases). However, magnetic field levels measured in the bedroom represent a mixture of sources from household appliances, powerlines, etc., and cannot link magnetic field levels directly to any specific source; the authors note, "…fewer than one-third of all stronger magnetic fields were caused by high-voltage powerlines…" Several aspects of the study detract from the validity of the results. The estimate included a broad margin of error because only a small number of the cases were exposed at the higher levels, and many eligible cases and controls did not participate, which means that the responders may not represent the population and results could be biased. Another concern is that magnetic field measurements were taken in 1997, a long time after the relevant exposure period for cases that were diagnosed in 1990-1994.

Recently, researchers reanalyzed the data from previous epidemiology studies of magnetic fields and childhood leukemia that met specified criteria (Ahlbom et al, 2000; Greenland et al, 2000). In each of these analyses, the researchers pooled the data on individuals from each of the studies, creating a study with a much larger number of subjects and therefore greater statistical power than any single study. In addition, pooling the individual data is preferable to other types of meta-analyses in which the results from several studies are combined, using the grouped data reported in the published studies. These meta-analyses focused on studies that assessed exposure to magnetic fields using 24-hour measurements or calculations based on the characteristics of the power lines and current load. Both Greenland et al and Ahlbom et al used exposures less than 1 mG as a reference category, which is roughly the average level reported in a survey of American homes (Zaffenella, 1993). Ahlbom et al combined nine studies, and Greenland et al used 12 studies of magnetic fields, eight of which were the same as used by Ahlbom. Both studies included ALL as well as other forms of leukemia. The Greenland et al study did not include results from the recent, very large study from the United Kingdom (UKCCS, 1999, 2000). The statistical results of these analyses can be summarized as follows:

- The pooled analyses provided no indication that wire codes are more strongly associated with leukemia than measured magnetic fields.
- Pooling these data corroborates an absence of an association between childhood leukemia and magnetic fields for exposures below 3 mG.
- Pooling these data results in a statistical association with leukemia for exposures greater than 3-4 mG.

Average magnetic fields above 3 mG in residences are estimated to be rather rare, about 3 % in the US. The authors are appropriately cautious in the interpretation of their analyses and they clearly identify the limitations in their evaluation of the original studies. One limitation is that there are too few cases at higher environmental levels to adequately characterize a relationship between magnetic fields and leukemia. Another limitation is the uncertainty related to pooling estimates of exposure obtained by different methods from studies of diverse design without evidence that all of the estimates are comparable. The authors also expressed concern about the possibility of systematic error in the selection of control populations. Greenland et al (2000) comments, "In light of the above problems, the inconclusiveness of the results seems inescapable; resolution will have to await considerably more data on high electric and magnetic-field exposures, childhood leukemia, and possible bias sources."

It is important to note that the information from these pooled analyses is not new because, for many years, epidemiologic studies and reviews have suggested an association between magnetic fields and childhood leukemia. What is new is that an association of magnetic fields with childhood leukemia is *not* present for exposures below about 3 to 4 mG. Previous reviews based on fewer studies had suggested an association at levels as low as 2 mG.

Wartenberg (2001) published a different type of meta-analysis of data from epidemiologic studies of childhood leukemia studies. He used 19 studies overall, including the UKCCS (1999) study which included over 1,000 cases of childhood leukemia, after excluding seven studies that had insufficient data on individuals or deficiencies in the exposure assessment data. This meta-analysis did not have the advantage of obtaining and pooling the data on all of the individuals in the studies, unlike those published before it (Ahlbom et al, 2000; Greenland et al, 2000). Rather than individual data each of the individual studies, Wartenberg used an approach based on the results from several published studies, which were reported as grouped data. No statistically consistent results of the meta-analysis were found. He reported a weak association for a) "proximity to electrical facilities" based on wire codes or distance, and b) magnetic-field level over 2 mG, based on either calculations from wiring and loading characteristics (if available) or on spot magnetic-field measurements.

There are several limitations of the Wartenberg meta-analysis. The author concludes that the analysis supports an association, however, few statistically significant odds ratios were found. In the discussion section of the paper, Wartenberg states, "limitations due to design, confounding, and other biases may suggest alternative interpretations" (p. 100). The results of this meta-analysis are not directly comparable to previous ones regarding fields of 3 or 4 mG because the analysis was not based on individual data, and because the exposure cut-points used for grouping data for the analysis differed from the previous analyses (2 mG vs. 3 or 4 mG). Scientifically, because of the heterogeneity of the studies included in the analyses, meta-analyses remain a controversial tool for summarizing these study findings.

3.1.1.2 Studies of Electric Field Exposures

Assessing electric field exposures is more difficult than magnetic field exposures because electric fields are easily blocked by objects. A few epidemiology studies of children, however, have focused on exposures to electric fields from transmission lines and electrical appliances.

Childhood cancer was not found to be associated with electric fields whether exposure was estimated with spot measurements (Savitz, 1988; London, 1991), mean measurements (Coghill et al, 1996; Dockerty et al, 1998), or personal monitoring (McBride et al, 1999; Green et al, 1999a). The UKCCS recently re-evaluated a subset of subjects from their study in 2000 in which magnetic and electric field exposures were measured simultaneously at the residence. Measurements with two readings for validity checks were recorded for 549 subjects (273 cases, 276 controls). No elevations in risk were found in any electric field exposure group for total leukemia, ALL, central nervous system cancers, other malignancies, or all malignancies.

IARC (2002) has evaluated the body of evidence of electric field exposures in children and conclude that there is "*inadequate evidence* in humans for the carcinogenicity of extremely low-frequency electric fields." They state:

> Numerous studies of the relationship between electrical appliance use and various childhood cancers have been published. In general, these studies provide no discernable pattern of increased risks associated with increased duration and frequency of use of appliances…. Studies of parental occupational exposure to ELF electric and magnetic fields in the preconceptional period or during gestation are methodologically weak and the results are not consistent (IARC, 2002; p. 333).

3.1.2 Studies of Adults

3.1.2.1 Studies of Residential Exposures

Studies of adults in their residences have generally not supported the idea that overall cancer, or any particular type of cancer, is increased by EMF exposure (e.g., Verkasalo et al, 1996). Several studies have reported associations for certain types of cancer, such as brain cancer or leukemia in adults but results have not been consistent across studies (Feychting and Ahlbom, 1994; Li et al, 1997). Contradictory results among studies that are considered of similar quality and strength argue against a conclusion that the association is cause and effect. Larger studies with more detailed and individual exposure assessments are weighed more heavily in the scientific assessment of risk, as seen in the following examples:

- A large study of 492 adult cases of brain cancer in California included measurements taken in the home, and at the front door, and considered the types of power line wiring (Wrensch et al, 1999). The authors report no evidence of increased risk with higher exposures, no association with type of power line, and no link with levels measured at the front door.

- A study of residential exposures to magnetic fields in Sweden found no association with breast cancer in the women who were studied, although an assessment of the younger women (pre-menopausal) provided some weak evidence for a link (Feychting et al, 1998). Subsequent studies provide important additional evidence. A large, recent study of residential exposures of women on Long Island in New York reported no association between four indicators of magnetic field exposure and breast cancer. Electric blankets are assumed to be one of the strongest sources of EMF exposure in the home, yet four recent studies found no evidence for an increased risk of breast cancer in those who used electric blankets (Gammon et al, 1998; Zheng et al, 2000; Laden et al, 2000; Kabat et al, 2003). The Laden et al (2000) study is the largest; in a cohort of over 120,000 female nurses, data was obtained on known risk factors for breast cancer as well as electric blanket use. Women who developed breast cancer reported no difference from other women in total use of electric blankets, use in recent years, or use many years in the past.

3.1.2.2 Studies of Occupational Exposures

The exploration of occupational exposures of EMF and adult cancers began with a report of increased leukemia in "electrical workers" (Milham, 1982). Milham developed a list of occupations that he presumed would include high exposure to "electromagnetic fields." The occupations categorized as "electrical workers" were used in numerous subsequent studies, despite the absence of any systematic measurements of electric or magnetic fields for any job descriptions. Based on associations reported in studies of "electrical workers," EMF was equated with power frequency exposure, i.e., 50-60 Hz, in both scientific publications and media reports. No systematic measurements for these jobs were available for many years. These studies reported statistical associations between electrical workers and leukemia or brain cancer, but not with all cancers combined or more common cancer types. Better exposure assessment was needed to understand these results.

Exposure assessment was improved by focusing on cohorts of workers in the electric utility industry, a workplace presumed to have relatively high exposure to power frequency fields compared to residential exposures. Estimates of exposures were developed from personal dosimeters worn by workers in various jobs in the industry. Industry records provided information on all of the jobs held by these workers while they were employed. Several researchers designed studies in which cumulative exposure was estimated from the measurements in the utility workplace environment (Sahl et al, 1993; Savitz and Loomis, 1995; Feychting et al, 1997; Johansen et al, 1998). The large populations and the ability to isolate workers with high levels of cumulative exposure were design factors that increased the ability to detect potential risk. However, these studies did not show stronger, more consistent associations with brain cancer or leukemia than previous studies. No increase in overall cancer was found in these workers.

The occupational studies published through 1998 are described in the IARC review (2002). Subsequently, a case-control study of men in eight Canadian provinces estimated their occupational exposure to magnetic fields and risks of different types of brain cancer. The study reported an association between one type of brain cancer and an estimate of occupational magnetic field exposure. However, no increased risk for any other type of brain cancer was found. The authors caution that the study had a small number of cases of each cancer type and that the magnetic field exposures were indirectly estimated (Villeneuve et al, 2002).

3.2 Laboratory Studies of Cancer

Studies in which laboratory animals receive high exposures provide an important basis for evaluating the safety of chemicals and medicine. Laboratory studies complement epidemiologic studies of people because while people are the species of interest, there are large variations in heredity, diet, and other health-related exposures. These variables can be better controlled or eliminated in studies of laboratory animals than in humans. The assessment of EMF and health, as for any other exposure, includes chronic, long-term studies in animals (*in vivo* studies), as well as studies of cancer-related changes in genes or other cellular processes observed in isolated cells and tissues in the laboratory (*in vitro* studies).

In several recent studies, rats and mice were exposed to magnetic fields for almost their entire lifetime. In these studies, neither overall cancer occurrence, nor the occurrence of specific types of cancer such as brain cancer, breast cancer or leukemia were different in the exposed animals from those of unexposed, control animals, even at the highest exposure levels.

Studies of tumor formation, or of tumor promotion in animals have not shown that magnetic fields promote the growth of cancer in general, or breast or brain cancer in particular (e.g., Anderson et al, 1999; DiGiovanni et al, 1999; Boorman et al, 1999a; Mandeville et al, 2000), although there have been suggestive findings from one other laboratory. In a study of a different design, researchers used an animal model for progression of leukemia that involves transplanting leukemia cells into young rats prior to exposure (Morris et al, 1999; Anderson et al, 2001). In these studies, both at the same laboratory, continuous or intermittent exposure to magnetic fields did not alter or increase the speed at which the leukemia cells developed and produced disease symptoms. The combined animal bioassay results do not provide evidence that magnetic fields cause, enhance, or promote the development of leukemia and lymphoma, or mammary cancer (e.g., Boorman et al, 1999a,b; McCormick et al, 1999; Boorman et al, 2000 a,b; Anderson et al, 2001).

Although the results of the RAPID Program were described in some detail in the NIEHS reports (NIEHS, 1998), many of the studies had not been published in the peer-reviewed literature. The RAPID research program included studies of four biological effects, each of which had been observed in only one laboratory. These effects are as follows: effects on gene expression, increased intracellular calcium in a human cell line, proliferation of cell colonies on agar, and increased activity of the enzyme ornithine decarboylase (ODC). Some scientists have suggested that these biological responses are signs of possible adverse health effects of EMF. It is standard scientific procedure to attempt to replicate results in other laboratories, because artifacts and investigator error can occur in scientific investigations. Replications, often using more experiments or more rigorous protocols, help to ensure objectivity and validity. Attempts at replication can substantiate and strengthen an observation, or they may discover the underlying reason for the observed response.

Studies in the RAPID program reported no consistent biological effects of EMF exposure on (1) gene expression, (2) intracellular calcium concentration, (3) growth of cell colonies on agar, or (4) ODC activity (Sisken and DeRemer, 2000; Boorman et al, 2000b). Loberg et al (2000) and Balcer-Kubiczek et al (2000) studied the expression of hundreds of cancer-related genes in human mammary or leukemia cell lines. They found no increase in gene expression with increased intensity of magnetic fields. To test the experimental procedure, they used X-rays and treatments known to affect the genes. These are known as positive controls and, as expected, caused gene expression in exposed cells.

3.3 Summary of Research on Cancer

The results of the latest epidemiologic studies of childhood cancer do not provide sufficient or convincing evidence to support the hypothesis that exposure to electric or magnetic fields or power lines near the home are a cause of leukemia or other cancers in children. The larger or more reliable residential and occupational studies do not support the idea that fields in the residence or workplace contribute to the risk of cancer in adults. Although they provide evidence most relevant to humans, the results of epidemiologic studies may include uncertainties because they are observational rather than experimental. For this reason, laboratory studies can provide important complementary information. The larger animal studies that exposed animals for EMF for their entire lifespan show no increases in cancer or other adverse health effects in exposed animals.

3.4 Research Related to Reproduction

Several epidemiology studies have examined effects on pregnancy, including miscarriages[3] in relation to exposures to magnetic fields. Previous large epidemiology studies reported no association with birth weight or fetal growth retardation after exposure to sources of relatively strong magnetic fields, such as electric blankets, or sources of typically weaker magnetic fields such as power lines (Bracken et al, 1995; Belanger et al, 1998; Lee et al, 2000).

- Belanger et al (1998) assessed the magnetic field exposure of 2967 women during their pregnancy in two different ways. Exposure to magnetic fields from electric bed-heating (electric blankets and water beds), sources of relatively strong magnetic fields was estimated from the women's responses in an interview. In general, electric bed heating results in higher magnetic field exposures than those from residential fields. Wiring codes were assessed for each woman to estimate the contribution of transmission and distribution lines within 150 feet of the house to exposure in the residence. No evidence was found for an association between miscarriage and exposure to magnetic fields from living in a residence with "high wire code," or from using electric blankets or a waterbed around the time of conception or during pregnancy (at time of interview). There was no indication of an increased risk with daily exposure, or longer hours, or using the electric bed at the high setting.
- The data collected in a large, prospective, epidemiology study by Belanger et al (1998) had been analyzed previously for other endpoints. The results of this analysis also showed no evidence of reduced birth weight in the infants, or slower fetal growth after exposure to sources of relatively strong magnetic fields, such as electric blankets, or sources of typically weaker magnetic fields such as power lines (Bracken et al, 1995).
- Another study also focused on exposures from electric bed heating (electric blankets, heated waterbeds and mattress pads) (Lee et al, 2000). The researchers assessed the women's exposure prior to birth and included information to control for potential confounding factors. This study had a large number of cases and high participation rates. Miscarriage rates were lower among users of electric bed heating.

Two recent studies of EMF and miscarriage reported a positive association between miscarriage and exposure to high, or instantaneous, peak magnetic fields (Li et al, 2002; Lee et al, 2002). However, no reliable associations were found with higher average magnetic field levels during the day, the typical way of assessing exposure. In these studies, women wore magnetic-field monitors for a 24-hour period to assess exposure. Magnetic field levels similar to the peak

[3] The medical term for miscarriage is spontaneous abortion.

levels are routinely found near electric devices such as hairdryers, photocopy machines, electric tools, shavers, in or near electric trains, and under some types of power lines. Neither study found that miscarriage was associated with wiring codes or average magnetic fields. There are several possible issues to be considered in assessing whether these statistical associations with the maximum, or peak, exposure during the day might be causal. First, the studies include possible biases. For example, each of the studies had a low response rate, which means that the study groups may not be comparable because those who participate may differ from those who decline (selection bias). Second, these studies found no reliable association with higher daily average exposure, that is, the average of the measurements recorded throughout the day. Third, despite years of research, there is no biological basis to indicate that EMF increases the risk of miscarriage (Savitz, 2002).

Large studies of laboratory animals exposed to pure 60-Hz magnetic fields have shown no increase in birth defects, no multigenerational effects, and no changes that would indicate an increase in miscarriage or loss of fertility (e.g., Ryan et al, 1999; Ryan et al, 2000; Ohnishi et al, 2002). Exposed and unexposed litters were the same in the amount of fetal loss and the number and type of birth defects, indicating no reproductive effect of magnetic fields.

In summary, the recent evidence from laboratory studies provides no indication that exposure to power-frequency EMF has an adverse effect on reproduction, pregnancy, or growth and development of the embryo. The epidemiology evidence from recent studies suggests that miscarriage may be linked to high peak field levels, not averages. However, the lack of biological support and the presence of possible sources of bias counter the idea that the statistical association is causal.

3.5 Research Related to Neurobiological Effects and Neurological Diseases

Studies of mental health and behavior reflect the functioning of neurobiological systems. Epidemiologic studies have examined the relationship between EMF and diseases of the central nervous system, and between EMF and mental health. One hypothesis that has been proposed to explain how EMF might affect health suggests that exposure to electric or magnetic fields decreases the body's production of the hormone melatonin. Because melatonin is related to the body's daily rhythms, depression and effects on mood and the nervous system have been hypothesized. On this basis, scientists studied occupational magnetic field exposure in relation to suicide (e.g., van Wijngaarden et al, 2000). The NIEHS reviewed data through 1998 and concluded that there was inadequate evidence for linking occupational or residential EMF exposure to suicide or depression. In addition, studies in humans and animals, including those published after the NIEHS report, have not supported the conjecture that EMF exposure suppresses melatonin secretion in men or women (e.g., Löscher et al, 1998; Davis et al, 2002).

Research has also addressed neurodegenerative diseases such as amyotrophic lateral sclerosis (ALS), Parkinson's Disease and Alzheimer's Disease without any consistent evidence of a link between exposure to EMF and these diseases independent of other risk factors (NRPB, 2001a, Feychting et al., 2003, Hakansson, et al, 2003).

3.6 Research Regarding Exposure to Appliances

Electric and magnetic fields associated with appliances within the home are discussed in Section 2.1 above. As with all other sources of EMF, the intensity of the fields is higher closer to the appliance than further away (Figure 1). Therefore, exposure to fields from these sources depends on the pattern of use. For example, electric blankets have been considered a likely source of higher exposure because they are used near the body for relatively long periods of time.

Few studies have evaluated appliances as sources of overall exposure to EMF. Mezei et al. (2001) used interviews and personal monitors to assess 24-hour magnetic field exposure from appliance use. Subjects who used computers accumulated an average of 16% of their total daily magnetic field exposures during computer use, but use of other appliances contributed less that 5% of the user's total exposure (e.g., electric stove 4.6 %; electric shaver 0.5%). In this study group (162 adults), 13% of the total exposure was from the nine appliances studied. Time-weighted exposures to fields above 5 mG were highest for use of computers, electric stoves, and microwave ovens and lowest for electric shavers.

Epidemiologic studies of several different adult cancer types have considered exposure to fields from electric blankets or other appliances, and results did not support a link with leukemia (Preston-Martin et al, 1988), endometrial cancer (McElroy et al., 2002), testicular cancer (Verreault et al, 1990) or prostate cancer (Zhu et al., 1999). Several studies of breast cancer and electric blankets have not found evidence of an association (see Section 3.1). Dlugosz et al. (1992) did not detect an increase in two types of congenital defects in children born to women who used electric bed heating. Studies of exposures to magnetic fields from appliances and reproductive endpoints, including fetal growth, low birth weight, and miscarriage, are discussed in Section 3.4 above.

Several epidemiology studies have examined statistical associations between reported exposure to appliances and childhood brain cancer, or leukemia. The largest of these studies of childhood leukemia reported associations with electric blankets, television, and hair dryers (Hatch et al, 1998). However, these associations do not support cause and effect because they showed no evidence of dose–response, that is, they were not stronger for more frequent or longer time of use. These investigators from the National Cancer Institute stated that "a causal relationship between magnetic fields from the appliances and acute lymphoblastic leukemia is unlikely…" Preston-Martin et al. (1996) reported that use of appliances was reported more frequently for children who had brain cancer compared to other children, however, the increase appeared to be due to chance. All of these studies are case-control studies, which can be biased because people who are ill are more likely to recall or overemphasize exposures than healthy individuals. Studies that assessed magnetic field exposure using personal monitors that measured all sources, including appliances and power lines, have not found that children with cancer had increased exposure. IARC (2002) wrote that these studies provide no discernable pattern of increased risks for childhood cancers associated with increased duration and frequency of use of appliances (see Section 3.1.1).

3.7 Power Line Electric Fields and Airborne Particles

Researchers from a university in England have suggested that the AC electric fields from power lines might affect health indirectly, by interacting with the electrical charges on certain airborne particles in the air. They hypothesize that more particles will be deposited on the skin by a strong electric field, or in the lung by charges on particles (Henshaw et al, 1996; Fews et al, 1999 a,b; Fews et al, 2002). If this interaction did occur, i.e., the airborne particles were charged to increase deposition on skin and in lungs to a sufficient degree, then they further hypothesize that increased exposure to various airborne particles might contribute to disease. These hypotheses remain highly speculative. Other scientists have found their assumptions unconvincing, and recognize data gaps in the steps of the hypotheses. IARC has stated that the "relevance of these suggestions to health has not been established" (IARC, 2002). Similar conclusions have been reached in other evaluations of this hypothesis (NRPB, 2001b; HCN, 2001). However, questions about effects of these charged particles have been raised in the media.

In their laboratory, Henshaw and colleagues have developed models to test the physical assumptions that are the first step of their hypotheses, that electric fields can change the movement of particulates in the air. For example, they measured the deposition of radon daughter[4] particles on metal plates, in the presence of electric fields at intensities found under or near to power lines. Under these conditions, deposition of products on surfaces was slightly increased, which implies that the deposition might also occur on other surfaces, such as the skin. What they have not tested is the most speculative part of the hypothesis, that such changes in the deposition rate of particles lead to an important increase in human exposure under real world conditions, and also that the increased skin exposure would be sufficient to impact human health, in this case increase skin cancer. Given the small change anticipated, the effect of wind to disperse particles, and the limited time that people spend outdoors directly under high-voltage power lines, the assumption of health effects is unsupported (Swanson and Jeffers, 2000).

Another hypothesis described by these researchers is that AC electric fields at the surface of power line conductors leads to increased charges on particles and thereby increase the likelihood that inhaled particles, including radon daughters, will be deposited on surfaces inside the lung or airways, even at considerable distances from the line. Air contains particles of various sizes, including aerosols[5] from emissions from cars and trucks, manufacturing, and natural sources such as radon from soil, rock, and building materials. If, as hypothesized, charges on the aerosol particles increased the deposition in the lungs when inhaled over long periods of time, this could in theory lead to increases in respiratory disease as well as possibly other diseases.

Although some aspects of these hypotheses have a physical basis, other aspects of the hypothesis are highly speculative, and the conclusion that power lines could substantially affect human exposure to airborne particles or lead to adverse health effects is unwarranted (Swanson and Jeffers, 2000). These speculations are not supported by the epidemiologic research, which does not provide evidence for an effect of power lines on lung cancer. In addition, radon has been linked to lung cancer, but not to leukemia (IARC, 2001).

---

[4] Radon daughters refer to the radioactive decay products of radon (^{222}Rn).

[5] An aerosol is a relatively stable suspension of solid particles or liquid droplets in a gaseous medium.

The National Radiological Protection Board (NRPB) of Great Britain considered the hypotheses and data published by Fews et al regarding aerosol deposition by electric fields (1999a) and exposure to corona ions from power lines (1999b). The report concluded:

> The physical principles for enhanced aerosol deposition in large electric fields are well understood. However, it has not been demonstrated that any such enhanced deposition will increase human exposure in a way that will result in adverse health effects to the general public (NRPB, 2001b p. 23).

3.8 Reviews of EMF Research by Scientific Panels

Numerous organizations responsible for health decisions, including national and international organizations, have convened groups of scientists to review the body of EMF research. These expert groups, including the National Institute of Environmental Health Sciences (NIEHS), the International Agency for Research on Cancer (IARC), the National Radiological Protection Board of Great Britain (NRPB), and the Health Council of the Netherlands (HCN) have included many of scientists with diverse skills that reflect the different research approaches required to answer questions about health. The most recent review is from the IARC, published in 2002. In addition, three reviews from the California Department of Health Sciences (CDHS) have reviewed the literature.

3.8.1 International Agency for Research in Cancer (IARC)

The International Agency for Research on Cancer sponsored a review of EMF and health research by a Working Group of scientific experts from 10 countries. The Working Group concluded that the epidemiologic studies do not provide support for an association between childhood leukemia and residential magnetic fields at intensities less than 4 mG. Overall, EMF were evaluated as “possibly carcinogenic to humans” (Group 2B), based on the statistical association of higher-level residential magnetic fields and increased risk for childhood leukemia. IARC reviewers also evaluated the animal data and concluded that it was “inadequate” to support a risk for cancer. Coffee is also classified as Group 2B. Their summary states that the EMF data does not merit the category “carcinogenic to humans” or the category “probably carcinogenic to humans,” nor did they find that “the agent is probably not carcinogenic to humans.” Many hypotheses have been suggested to explain possible carcinogenic effects of electric or magnetic fields; however, no scientific explanation for carcinogenicity of EMF fields has been established (IARC, 2002).

3.8.2 Neutra et al.

In response to a request from the California Public Utilities Commission, three scientists at the CDHS reviewed and evaluated the scientific research regarding EMF and health. Two epidemiologists and a physicist from the department’s EMF Program, fewer than any review group, were assigned to this task. The scientists completed their fourth and final draft in June 2002 (Neutra et al., 2002). This review has gotten considerable attention and therefore is described below.

The scientists used two different approaches to conduct their evaluation. One was characterized as following the IARC approach, described above, in which reviewers summarize the "quality of evidence." However, unlike IARC, which weighs both epidemiology and experimental data, the scientists gave little weight to the experimental data. The other approach was a set of guidelines developed by the reviewers, which calls for each scientist to express a degree of confidence that the disease may be caused by high EMF exposures. For example, a scientist who was certain, or thought it highly probable, that observed statistical associations indicated causality would present their judgment as "virtually certain that they [EMF] increase the risk to some degree."

The scientists evaluated data regarding approximately a dozen health conditions and concluded that the epidemiologic data provided little support for an association of EMF with nine of the conditions. For the rest, they expressed the belief "that EMFs can cause some degree of increased risk of childhood leukemia, adult brain cancer, Lou Gehrig's disease, and miscarriage." Their median 'confidence ratings' for these conditions, however, were not high enough to indicate any strong certainty or "high probability" that EMF was a cause of these conditions. As noted previously, they state, "there is a chance that EMFs have no effect at all" (Neutra et al., 2001). For all other health effects, including breast cancer, heart disease, Alzheimer's Disease, depression, increased risk of suicide, and adult leukemia, the CDHS reviewers do not believe that there is evidence that exposures to EMF increases the risk of developing any of these illnesses. They agree that EMF is not a universal carcinogen (Neutra et al., 2002).

3.8.3 Conclusions of Other National and International Organizations

The conclusions from several other national and international organizations including the National Institute of Environmental Health Sciences, the National Radiological Protection Board of Great Britain (NRPB), and the Health Council of the Netherlands (HCN) are listed in Table 7. The conclusions from the report prepared by the NRPB's Advisory Group on Non-Ionising Radiation on Extremely Low Frequency (ELF) electromagnetic fields and the risk of cancer are consistent with previous reviews as are those from the Health Council of the Netherlands (HCN, 2001).

Scientists from the IARC, the NIEHS, the NRPB, and the HCN agree that there is little evidence suggesting that EMF is associated with adverse health effects, including most forms of adult and childhood cancer, heart disease, Alzheimer's disease, depression, and reproductive effects. All organizations believe that there is some evidence that EMF at high exposures is linked to childhood leukemia, agree that the laboratory data does not support a link between EMF and any adverse health effect, including leukemia, and have not concluded that EMF is, in fact, the cause of any disease. None of these organizations have recommended exposure limits or required measures to reduce exposures.

Table 6. Conclusions of international agencies and scientific groups

Agency or Scientific Group	Conclusions
National Institute of Environmental Health Sciences (NIEHS, 1998; NIEHS, 1999)	"The scientific evidence suggesting that ELF-EMF exposures pose any health risk is weak. The strongest evidence for health effects comes from associations observed in human populations with two forms of cancer: childhood leukemia and chronic lymphocytic leukemia in occupationally exposed adults . . . In contrast, the mechanistic studies and animal toxicology literature fail to demonstrate any consistent pattern . . . No indication of increased leukemias in experimental animals has been observed . . . The lack of consistent, positive findings in animal or mechanistic studies weakens the belief that this association is actually due to ELF-EMF, but it cannot completely discount the epidemiological findings . . . The NIEHS does not believe that other cancers or other non-cancer health outcomes provide sufficient evidence of a risk to currently warrant concern."
International Agency for Research on Cancer (IARC, 2002)	"Studies in experimental animals have not shown a consistent carcinogenic or co-carcinogenic effects of exposures to ELF [extremely low frequency] magnetic fields, and no scientific explanation has been established for the observed association of increased childhood leukaemia risk with increasing residential ELF magnetic field exposure." IARC categorized EMF as a "possible carcinogen" for exposures at high levels, based on the meta-analysis of studies of statistical links with childhood leukemia at levels above 3-4 mG.
National Radiological Protection Board of Great Britain (NRPB, 2001b)	"Laboratory experiments have provided no good evidence that extremely low frequency [ELF] electromagnetic fields are capable of producing cancer, nor do human epidemiological studies suggests that they cause cancer in general. There is, however, some epidemiological evidence that prolonged exposure to higher levels of power frequency magnetic fields is associated with a small risk of leukemia in children. In practice, such levels of exposure are seldom encountered by the general public in the UK [or in the US]."
Health Council of the Netherlands (HCN, 2001)	"Because the association is only weak and without a reasonable biological explanation, it is not unlikely that it [an association between ELF exposure and childhood leukemia] could also be explained by chance… The committee therefore sees no reason to modify its earlier conclusion that the association is not likely to be indicative of a causal relationship."

4 Overall Project EMF Assessment

The proposed project will affect ambient levels of electric and magnetic fields, with the greatest effect within the boundaries of the Middletown-Norwalk right-of-way. Outside the boundaries of the right-of-way and substations, the effect of the project on EMF levels will be limited. At distances greater than approximately 100 feet from edges of the proposed right-of-way, the differences between the levels of fields produced by existing and future line configurations become smaller for this and other route sections under consideration. This results from the overall design and the location of the proposed facilities, the proposal to expand the right-of-way in some sections, and the placement of the 345-kV line underground between the East Devon and Norwalk Substations.

Despite the addition of a 345-kV overhead transmission line to existing rights-of-way, the electric field will be lower along one or both right-of-way edges for five of the eight sections of the primary overhead route because of consolidation with existing transmission lines (Cross Sections 1-8, Table 4). The changes in electric field level (increase or decrease) at the edge of right-of-way would be less than 0.8 kV/m except for one side of one route section. No change in the electric field will occur on sections where the line would be placed underground on the proposed route (Section 9), Alternative A (Section 9A) or Alternative B (Section 10).

Similarly, the magnetic field will be lower along one or both right-of-way edges for five of eight overhead sections of the primary route (Cross Sections 1-8, Table 5). The contribution of the HPFF underground line to magnetic fields on streets above would be less than 3 mG. At a distance of 20 feet, the magnetic field would diminish to 0.2 mG or less. A 345-kV XLPE underground line has been considered for sections of Alternative Routes A and B. The magnetic field over this XLPE line is about 30 mG and diminishes to less than 3 mG within 20 feet.

The "supported changes" to the proposed route arising from the public consultation process involve the relocation of a 115-kV overhead line to an underground 115-kV XLPE line. This may lower the electric field, particularly for Cross Section 8 – Alternative A. The effects of the "supported changes" in magnetic field levels produce small decreases for Cross Section 8 and a small increase/decrease on opposite right-of-way edges of Section 7B relative to the proposed route.

On the Alternative A route (Cross Sections 9A and 17-22) and Alternative B route (Cross Sections 10-22), the addition of a 345-kV overhead line would have a minimal effect on the electric field at the edge of the ROW and beyond for most cross sections. However, along the East/South edge of Sections 20-22, closest to Norwalk on Alternative A and B routes, the electric field will increase by just over 2 kV/m. The magnetic fields from existing overhead lines tend to be higher on the proposed overhead route than on the alternative routes but the addition of the 345-kV line reduces the magnetic field on one or both sides of the right-of-way on 11 of 12 Alternative cross sections. The addition of the proposed line will reduce the magnetic field more than 10 mG and sometimes more than 20 or 30 mG at the edge of some sections.

Caveat: The measurements or calculations to estimate typical magnetic fields present in areas adjacent to the line, reported in Section 2 above, *are not the same* as estimated long-term exposures to magnetic fields that are used in epidemiologic studies. These numbers cannot be directly compared, just as the grams of protein in one day's lunch do not represent the average daily level of protein in your diet over a year.

Both CL&P and UI follow the Connecticut Siting Council's "Electric and Magnetic Field Best Management Practices." As called for by these practices, this report contains a project-specific assessment of EMF including baseline, pre-construction measurements and modeling of EMF levels after construction. Additional measurements and calculations for categories of locations listed in the Application Guidelines are also provided. The Companies' design and location of the new facilities also minimizes potential EMF exposure as a recommended practice. Specific design features that have the effect of reducing field magnetic field exposure include; operating the proposed line at 345 kV to reduce current flow, the consolidation of circuits on towers where appropriate, selection of optimal phasing when adjacent to existing lines, and the undergrounding of lines where existing right-of-ways cannot be expanded without undesirable impacts on land use in densely populated urban areas.

An important component of the "Electric and Magnetic Field Best Management Practices" is the recognition of completed and ongoing research on EMF. The maximum field levels associated with the operation of existing and proposed facilities are well below limits for public exposure recommended by the International Committee on Electromagnetic Safety (ICES, 2002). The weight of the evidence in the review and research evaluation in Exponent's report does not support a conclusion that exposure to lower levels of EMF associated with the proposed project would have adverse effects on human health, compromise normal function, or cause cancer. This assessment is consistent with those of large, interdisciplinary scientific reviews performed for organizations in the U.S. and Europe. Thus, the approach proposed by the Connecticut Siting Council for responding to project-related changes in ambient EMF levels remains consistent with the state of knowledge about EMF and health.

5 References

Ahlbom, A, Day, N, Feychting, M, Roman, E, Skinner, J, Dockerty, J, Linet, M, McBride, M, Michealis, J, Olsen, JH, Tynes, T, Verkasalo, PK. 2000. A pooled analysis of magnetic fields and childhood leukemia. Br. J. Cancer. 83:692-698.

Anderson, LEW, Boorman, GA, Morris, JE, Sasser, LB, Mann, PC, Grumbein, SL, Hailey, JR, McNally, A, Sills, RC, Haseman, JK. 1999. Effect of 13-week magnetic field exposure on DMBA-initiated mammary gland carcinomas in female Sprague-Dawley rats. Carcinogenesis. 20:1615-1620.

Anderson, LEW, Morris, JE, Miller, DL, Rafferty, CN, Ebi, KL, Sasser, LB. 2001. Large granular lymphocytic (LGL) leukemia in rats exposed to intermittent 60 Hz magnetic fields. Bioelectromagnetics. 22:185-193.

Balcer-Kubiczek, EK, Harrison, GH, Davis, CC, Haas, ML, Koffman, BH. 2000. Expression analysis of human HL60 exposed to 60 Hz square or sine-wave magnetic fields. Radiat. Res. 153:670-678.

Belanger, K, Leaderer, B, Hellenbrand, K, Holford, TR, McSharry, J, Power, ME, Bracken, MB. 1998. Spontaneous abortion and exposure to electric blankets and heated water beds. Epidemiology. 9:36-42.

Bonneville Power Administration (BPA). 1991. Corona and Field Effects Computer Program.

Boorman, GA, McCormick, DL, Findlay, JC, Hailey, JR, Gauger, JR, Johnson, TR, Kovatch, RM, Sills, RC, Haseman, JK. 1999a. Chronic toxicity/oncogenicity evaluation of 60-Hz (power frequency) magnetic fields in F344/n rats. Toxicol. Pathol. 27:267-278.

Boorman, GA, Anderson, LE, Morris, JE, Sasser, LB, Mann, PC, Grumbein, SL, Hailey, JR, McNally, A, Sills, RC, Haseman, JK. 1999b. Effects of 26-week magnetic field exposure in a DMBA initiation-promotion mammary glands model in Sprague-Dawley rats. Carcinogenesis. 20:899-904.

Boorman, GA, McCormick, DJ, Ward, JM, Haseman, JK, Sills, RC. 2000a. Magnetic fields and mammary cancer in rodents: A critical review and evaluation of published literature. Radiat. Res. 153, Part 2:617-626.

Boorman, GA, Rafferty, CN, Ward, JM, Sills, RC. 2000b. Leukemia and lymphoma incidence in rodents exposed to low-frequency magnetic fields. Radiat. Res. 153, Part 2:627-636.

Bracken, MB, Belanger, K, Hellenbrand, K, Dlugosz, L, Holford, TR, McSharry, JE, Addesso, K, Leaderer, B. 1995. Exposure to electromagnetic fields during pregnancy with emphasis on electrically heated beds: association with birth weight and intrauterine growth retardation. Epidemiology. 6:263-270.

Coghill, RW, Steward, J, Philips, A. 1996. Extra low frequency electric and magnetic fields in the bedplace of children diagnosed with leukaemia: a case-control study. Eur. J. Cancer Prev. 5:153-158.

Connecticut Siting Council (CSC). 1993. Electric and magnetic field best management practices. February 11, 1993.

Connecticut Siting Council (CSC). 2003. Application guide: Application guides for terrestrial electric transmission line facilities. September 9, 2003.

Davis, S, Mirick, DK, Stevens, RG. 2002. Residential magnetic fields and the risk of breast cancer. Am. J. Epidemiol. 155:446-454.

DiGiovanni, J, Johnston, DA, Rupp, R, Sasser, LB, Anderson, LE, Morris, JE, Miller, DL, Kavet, R, Walborg, Jr. EF. 1999. Lack of effect of 60 Hz magnetic fields on biomarkers of tumor promotion in the skin of SENCAR mice. Carcinogenesis. 20:685-689.

Dlugosz, L, Vena, J, Byers, T, Sever, L, Bracken, M, Marshall, E. 1992. Congenital defects and electric bed heating in New York State: A register-based case-control study. Am. J. Epidemiol. 135:1000-1011.

Dockerty, JD, Elwood, JM, Skegg, DCG, Herbison, GP. 1998. Electromagnetic field exposures and childhood cancers in New Zealand. Cancer Causes Control. 9:299-309.

Electric Power Research Institute (EPRI). 1992. Underground Transmission Systems Reference Book. EPRI, Palo Alto, CA.

Electric Power Research Institute (EPRI). 1994. Handbook of Shielding Principles for Power System Magnetic Fields. EPRI Report TR-103630-V2.

Fews, AP, Henshaw, DL, Wilding, RL, Close, JJ, Keitch, PA. 1999a. Increased exposure to pollutant aerosols under high voltage power lines. Int. J. Radiat. Biol. 75:1505-1521.

Fews, AP, Henshaw, DL, Wilding, RL, Keitch, PA. 1999b. Corona ions from power lines and increased exposure to pollutant aerosols. Int. J. Radiat. Biol. 75:1523-1531.

Fews, AP, Wilding, RL, Keitch, PA, Holden, NK, Henshaw, DL. 2002. Modification of atmospheric DC fields by space charge from high-voltage power lines. Atmospheric Research. 63:271-289.

Feychting, M, Ahlbom, A. 1994. Magnetic fields, leukemia and central nervous system tumors in Swedish adults residing near high-voltage power lines. Epidemiology. 5:501-509.

Feychting, M, Forssen, U, Rutqvist, LE, Ahlbom, A. 1998. Magnetic fields and breast cancer in Swedish adults residing near high-voltage power lines. Epidemiology. 9:392-397.

Feychting, M, Forssen, U, Floderus, B. 1997. Occupational and residential magnetic field exposure and leukemia and central nervous system tumors. Epidemiology. 8:384-389.

Feychting, M, Jonsson, F, Pedersen, NL, Ahlbom, A. 2003. Occupational magnetic field exposure and neurodegenerative disease. Epidemiology. 14:413-419.

Gammon, MD, Schoenberg, JB, Britton, JA, Kelsey, JL, Stanford, JL, Malone, KE, Coates, RJ, Brogan, DJ, Potischman, N, Swanson, CA, Brinton, LA. 1998. Electric blanket use and breast cancer risk among younger women. Am. J. Epidemiol. 148:556-563.

Gauger, JR. 1985. Household appliance magnetic field survey. IEEE Trans Power App Syst. 104:2436-2444.

Green, LM, Miller, AB, Villeneuve, PJ, Agnew, DA, Greenberg, ML, Li, JH, Donnelly, KE. 1999a. A case control study of childhood leukemia in southern Ontario, Canada, and exposure to magnetic fields in residences. Int. J. Cancer. 82:161-170.

Green, LM, Miller, AB, Agnew, DA, Greenberg, ML, Li, JH, Villeneuve, PJ, Tibshirani, R. 1999b. Childhood leukemia and personal monitoring of residential exposures to electric and magnetic fields in Ontario, Canada. Cancer Causes Control. 10:233-243.

Greenland, S, Sheppard, AR, Kelsh, MA, Kaune, WT. 2000. A pooled analysis of magnetic fields, wire codes, and childhood leukemia. Epidemiology. 11:624-634.

Hakansson, N, Gustavsson, P, Johansen, C, Floderus, B. 2003. Neurodegenerative diseases in welders and other workers exposed to high levels of magnetic fields. Epidemiology. 14:420-426.

Hatch, EE, Linet, MS, Kleinerman, RA, Tarone, RE, Severson, RK, Hartsock, CT, Haines, C, Kaune, WT, Friedman, D, Robison, LL, Wacholder, S. 1998. Association between childhood acute lymphoblastic leukemia and use of electrical appliances during pregnancy and childhood. Epidemiology. 9:234-245.

Health Council of the Netherlands (HCN): ELF Electromagnetic Fields Committee. 2001. Electromagnetic fields: Annual Update 2001. The Hague: Health Council of the Netherlands. Publication No. 2001/14.

Henshaw, DL, Ross, AN, Fews, AP, Preece, AW. 1996. Enhanced deposition of radon daughter nuclei in the vicinity of power frequency electromagnetic fields. Int. J. Radiat. Biol. 69:25-38.

International Agency for Research on Cancer (IARC). 2001. IARC Monographs on the evaluation of carcinogenic risks to humans. Volume 78: Ionizing radiation, Part 2: Some internally deposited radionuclides. IARC Press, Lyon, France.

International Agency for Research on Cancer (IARC). 2002. IARC Monographs on the evaluation of carcinogenic risks to humans. Volume 80: Static and extremely low-frequency (ELF) electric and magnetic fields. IARC Press, Lyon, France.

International Committee on Electromagnetic Safety (ICES). 2002. Standard for Safety Levels with Respect to Human Exposure to Electromagnetic Fields, 0-3 kHz. The Institute of Electrical and Electronics Engineers, Inc., New York, NY.

Institute of Electrical and Electronics Engineers (IEEE). 1994a. IEEE recommended practice for instrumentation: specifications for magnetic flux density and electric field strength meters- 10 Hz to 3 kHz. IEEE Standard 1308-1994.

Institute of Electrical and Electronics Engineers (IEEE). 1994b. IEEE standard procedures for measurement of power frequency electric and magnetic fields from AC power lines. IEEE Standard 644-1994, Revision of IEEE Standard 644-1987.

Institute of Electrical and Electronics Engineers (IEEE). 2002. National Electrical Safety Code. IEEE Standard NESC C-2.

Johansen, C, Olsen, JH. 1998. Risk of cancer among Danish utility workers- a nationwide cohort study. Am. J. Epidemiol. 147:548-555.

Kabat, GC, O'Leary, ES, Schoenfeld, ER, Green, JM, Grimson, R, Henderson, K, Kaune, WT, Gammon, MD, Britton, JA, Teitelbaum, SL, Neugut, AI, Leske, MC. 2003. Electric blanket use and breast cancer on Long Island. Epidemiol. 14:514-520.

Laden, F, Neas, LM, Tolbert, PE, Holmes, MD, Hankinson, SE, Spiegelman, D, Speizer, FE, Hunter, DJ. 2000. Electric blanket use and breast cancer in the nurses' health study. Am. J. Epidemiol. 152:41-49.

Lee, GM, Neutra, RR, Swan, S, Yost, M, Hristova, L, Hiatt, RA. 2000. The use of electric bed heaters and the risk of clinically recognized spontaneous abortion. Epidemiology. 11:406-415.

Lee, GM, Neutra, RR, Hristova, L, Yost, M, Hiatt, RA. 2002. A nested case-control study of residential and personal magnetic field measures and miscarriages. Epidemiology. 13:21-31.

Li, CY, Thériault, G, Lin, RS. 1997. Residential exposure to 60-hertz magnetic fields and adult cancers in Taiwan. Epidemiology. 8:25-30.

Li, DK, Odouli, R, Wi, S, Janevic, T, Golditch, I, Bracken, TD, Senior, R, Rankin, R, Iriye R. 2002. A population-based prospective cohort study of personal exposure to magnetic fields during pregnancy and the risk of miscarriage. Epidemiology. 13:9-20.

Loberg, LI, Engdahl, WR, Gauger, JR, McCormick, DL. 2000. Cell variability and growth in a battery of human breast cancer cell lines exposed to 60 Hz magnetic fields. Radiat. Res. 153:725-728.

London, SJ, Thomas, DC, Bowman, JD, Sobel, E, Cheng, TC, Peters, JM. 1991. Exposure to residential electric and magnetic fields and risk of childhood leukemia. Am. J. Epidemiol. 134:923-937.

Löscher, W, Mevissen, M, Lerchl, A. 1998. Exposure of female rats to a 100-µT 50 Hz magnetic field does not induce consistent changes in nocturnal levels of melatonin. Radiat. Res. 150:557-567.

Mandeville, R, Franco, E, Sidrac-Ghali, S, Paris-Nadon, L, Rocheleau, N, Mercier, G, Desy, M, Dexaux, C, Gaboury, L. 2000. Evaluation of the potential promoting effects of 60-Hz magnetic fields on N-Ethyl-N-Nitrosourea induced neurogenic tumors in female F344 rats. Bioelectromagnetics. 21:84-93.

McBride, ML, Gallagher, RP, Theriault, G, Armstrong, BG, Tamaro, S, Spinelli, JJ, Deadman, JE, Fincham, S, Robson, D, Choi, W. 1999. Power-frequency electric and magnetic fields and risk of childhood leukemia in Canada. Am. J. Epidemiol. 149:831-842.

McCormick, DL, Boorman, GA, Findlay, JC, Hailey, JR, Johnson, TR, Gauger, JR, Pletcher, JM, Sill, RC, Haseman, JK. 1999. Chronic toxicity/oncogenicity evaluation of 60 Hz (power frequency) magnetic fields in B6C3F mice. Toxicol. Pathol. 27:279-285.

McElroy, JA, Newcomb, PA, Trentham-Dietz, A, Hampton, JM, Kanarek, MS, Remington, PL. 2002. Endometrial cancer incidence in relation to electric blanket use. Am. J. Epidemiol. 156:262-267.

McElroy, JA, Newcomb, PA, Remington, PL, Egan, KM, Titus-Ernstoff, L, Trentham-Dietz, A, Hampton, JM, Baron, JA, Stampfer, MJ, Willett, WC. 2001. Electric blanket or mattress cover use and breast cancer incidence in women 50-79 years of age. Epidemiology. 12:613-617.

Mezei, G, Kheifets, LI, Nelson, LM, Mills, KM, Iriye, R, Kelsey, JL. 2001. Household appliance use and residential exposure to 60-Hz magnetic fields. J. Expo. Anal. Environ. Epidemiol. 11:41-49.

Milham, S. 1982. Mortality from leukemia in workers exposed to electrical and magnetic fields. N. Engl. J. Med. 307: 249.

Morris, JE, Sasser, LB, Miller, DL, Dagle, GE, Rafferty, CN, Ebi, KL, Anderson, LE. 1999. Clinical progression of transplanted large granular lymphocytic leukemia in Fischer 344 rats exposed to 60 Hz magnetic fields. Bioelectromagnetics. 20:48-56.

National Institute of Environmental Health Sciences (NIEHS). 1998. Assessment of Health Effects from Exposure to Power-Line Frequency Electric and Magnetic Fields: Working Group Report. NIH Publication No. 98-3981. Research Triangle Park, NC: National Institute of Environmental Health Sciences of the U.S. National Institutes of Health.

National Institute of Environmental Health (NIEHS). 1999. Health Effects from Exposure to Power Line Frequency Electric and Magnetic Fields. NIH Publication No. 99-4493. Research Triangle Park, NC: National Institute of Environmental Health Sciences of the U.S. National Institutes of Health.

National Radiological Protection Board (NRPB). 2001a. ELF Electromagnetic Fields and Neurodegenerative Disease: Report of an Advisory Group on Non-Ionising Radiation. National Radiological Protection Board, Volume 12, No 4.

National Radiological Protection Board (NRPB). 2001b. ELF Electromagnetic Fields and the Risk of Cancer: Report of an Advisory Group on Non-Ionising Radiation. National Radiological Protection Board, Volume 12, No 1.

Neutra, RR, Delpizzo, V, Lee, GM. 2001. An evaluation of the possible risks from electric and magnetic fields (EMFs) from power lines, internal wiring, electrical occupations and appliances. Draft 3. California Department of Health Services (CDHS). California EMF Program, Oakland, CA.

Neutra, RR, Delpizzo, V, Lee GM. 2002. An evaluation of the possible risks from electric and magnetic fields (EMFs) from power lines, internal wiring, electrical occupations and appliances. Final Report. California Department of Health Services (CDHS). California EMF Program, Oakland, CA.

Ohnishi, Y, Mizuno, F, Sato, T, Yasui, M, Kikuchi, T, Ogawa, MJ. 2002. Effects of power frequency alternating magnetic fields on reproduction and pre-natal development of mice. Toxicol Sci. 27:131-138.

Preston-Martin, S, Navidi, W, Thomas, D, Lee, P, Bowman, J, Pogoda, J. 1996. Los Angeles study of residential magnetic fields and childhood brain tumors. Am. J. Epidemiol. 143:105-119.

Preston-Martin, S, Peters, JM, Yu, MC, Garabrant, DH, Bowman, JD. 1988. Myelogenous leukemia and electric blanket use. Bioelectromagnetics. 9:207-213.

Ryan, BM, Polen, M, Gauger, JR, Mallett, E, Kerns, MB, Bryan, TL, McCormick, DL. 2000. Evaluation of the developmental toxicity of 60 Hz magnetic fields and harmonic frequencies in Sprague-Dawley rats. Radiat. Res. 153:637-641.

Ryan, BM, Symanski, RR, Pomeranz, LE, Johnson, TR, Gauger, JR, McCormick, DL. 1999. Multi-generation reproduction toxicity assessment of 60-Hz magnetic fields using a continuous breeding protocol in rats. Teratology. 59:156-162.

Sahl, JD, Kelsh, MA, Greenland, S. 1993. Cohort and nested case-control studies of hematopoietic cancers and brain cancer among electric utility workers. Epidemiology. 4:104-114.

Savitz, DA, Wachtel, H, Barnes, FA, John, EM, Tvrdik, JG. 1988. Case-control study of childhood cancer and exposure to 60-Hz magnetic fields. Am. J. Epidemiol. 128:21-38.

Savitz, DA, Pearce, NE, Poole, C. 1989. Methodological issues in the Epidemiology of electromagnetic fields and cancer. Epidemiol. Rev. 11:59-78.

Savitz, DA, and Loomis, DP. 1995. Magnetic field exposure in relation to leukemia and brain cancer mortality among electric utility workers. Am. J. Epidemiol. 141:123-134.

Savitz, DA. 2002. Magnetic fields and miscarriage. Epidemiology. 13:1-4.

Schoenfeld, ER, O'Leary, ES, Henderson, K, Grimson, R; Kabat, GC; Ahnn, S, Kaune, WT; Gammon, MD, EBCLIS Group. 2003. Epidemiol. 158:47-58.

Schuz, J, Grigat, JP, Brinkmann, K, Michaelis, J. 2001. Childhood acute leukemia and residential 16.7 Hz magnetic fields in Germany. Br. J. Cancer. 84: 697-699.

Sisken, JE, and DeRemer D. 2000. Power-frequency electromagnetic fields and the capacitative calcium entry system in sv40-transformed Swiss 3T3 cells. Radiat. Res. 153:699-705.

Swanson, J, Jeffers, DE. 2000. Comments on the paper "Increased exposure to pollutant aerosols under high voltage power lines." Int. J. Radiat. Biol. 76:1685-1691.

United Kingdom Childhood Cancer Study Investigators. 1999. Exposure to power frequency magnetic fields and the risk of childhood cancer. The Lancet. 353:1925-1931.

United Kingdom Childhood Cancer Study Investigators. 2000. Childhood cancer and residential proximity to power lines. Br. J. Cancer. 83:1573-1580.

United Kingdom Childhood Cancer Study. 2000. Objectives, materials and methods. British Journal of Cancer, 82: 1073-1102.

van Wijngaarden, E, Savitz, DA, Kleckner, RC, Cai, J, Loomis, D. 2000. Exposure to electromagnetic fields and suicide among electric utility workers: a nested case-control study. Occup. Environ. Med. 57:258-263.

Verkasalo, PK, Pukkala, E, Kaprio, J, Heikkila, KV, Koskenvuo, M. 1996. Magnetic fields of high voltage power lines and risk of cancer in Finnish adults: nationwide cohort study. Br. Med. J. 313:1047-1051.

Verreault, R, Weiss, NS, Hollenbach, KA, Strader, CH, Daling, JR. 1990. Use of electric blankets and risk of testicular cancer. Am. J. Epidemiol. 131:759-762.

Villeneuve, PJ, Agnew, DA, Johnson, KC, Mao, Y. 2002. Brain cancer and occupational exposure to magnetic fields among men: results from a Canadian population-based case-control study. Inter. J. Epidemiol. 31:210-217.

Wartenberg, D. 2001a. Residential EMF exposure and childhood leukemia: Meta-analysis and population attributable risk. Bioelectromagnetics Supplements. 5:S86-S104.

Wartenberg, D. 2001b. The potential impact of bias in studies of residential exposure to magnetic fields and childhood leukemia. Bioelectromagnetics Supplements. 5:S32-S47.

Wrensch, M, Yost, M, Miike, R, Lee, G; Touchstone, J. 1999. Adult glioma in relation to residential power frequency electromagnetic field exposures in the San Francisco Bay Area. Epidemiology. 10:523-527.

Zaffanella, LE. 1993. Survey of Residential Magnetic Field Sources. Volume I. Electric Power Research Institute, EPRI TR-102759-V1, Project 3335-02, Final Report, September.

Zheng, TZ, Holford, TR, Mayne, ST, Owens, PH, Zhang, B, Boyle, P, Carter, D, Ward, YW, Zahm, SH. 2000. Exposure to electromagnetic fields from use of electric blankets and other in-home electrical appliances and breast cancer risk. Am. J. Epidemiol. 151: 1103-1111.

Zhu, K, Weiss, NS, Stanford, JL, Daling, JR, Stergachis, A, McKnight, B, Brawer, MK, Levine, RS. 1999. Prostate cancer in relation to the use of electric blanket or heated water bed. Epidemiology. 10:83-85.

Appendix

Supplementary EMF Data

Table A-1. Measured and Calculated Electric and Magnetic Fields at Boundaries of Facility Locations Categorized by the Connecticut Siting Council

The data in this table reflect measurements of electric and magnetic fields made at, or near, the closest boundary of the facility to the proposed line, and the calculated contribution from the existing transmission lines (if any) and proposed transmission line to field levels at that boundary.

Location#	Cross Section	Aerial Segment	Category	Measurements of Fields from Existing Transmission Lines & Other Sources			Calculated Fields from Existing & Proposed Transmission Lines (Transmission Line Sources Only)				
							Existing		Proposed		
				Measurement Location to ROW+ (ft)	Electric Field (kV/m)	Magnetic Field (mG)	Electric Field (kV/m)	Magnetic Field (mG) Average* Load	Electric Field (kV/m)	Magnetic Field (mG) Average Load*	Magnetic Field (mG) Peak Load**
Overhead Lines											
Connecticut Baptist Home Meriden 06450	3	12	Assisted Living Facility	115	0.05	4.1	0.09	2	0.19	2.7	1.7
B'Nai Jacob Congregation Woodbridge 06525	8	34	Playground/School	in ROW	0.81	7.5	1.48	8.1	2.72	25.3	96.5
Peck Place School Orange, CT 06477	8	40/41	Playground/School	500	0.01	0.2	0.00	0.1	0.01	0.1	0.8
Eisenhower Park Milford 06460	8	42	Bleachers/Playing field	24	0.12	4.6	0.10	2.6	0.84	5.4	30.7
Underground Lines											
Little Lamb Day Care Bridgeport 06608	9	51	Day Care Facility	3	- na -	1.5	- na -	- na -	- na -	0.2	0.2
Washington Park Bridgeport 06608	9	51/52	Park / Playground	0 Barnum Ave	- na -	0.8	- na -	- na -	- na -	0.2	0.2
Winslow Park Westport 06880	9	61	Park	5	- na -	2.2	- na -	- na -	- na -	0.1	0.2

+ Distances are best estimates based upon measurements (where possible) or distances scaled from aerial photographs.
# For locations within 500 feet of overhead line or 100 feet of underground line
* 15 GW Load Case (typical system loading in 2007)
** 27 GW Load Case (hour with the highest system loading in 2007)
- na - Not applicable

Table A-2. Summary of Calculated Electric and Magnetic Fields at Facility Locations Categorized by the Connecticut Siting Council

The data in this table reflect calculations of electric and magnetic fields at the nearest and most distant sides of the facility, or in the case of parks and playgrounds, the nearest and furthest boundaries from existing transmission lines (if any) and proposed transmission line.

Location#	Cross Section	Aerial Segment	Category	Depth of Facility Perpendicular to Future ROW+ (ft)	Calculated Fields from Existing & Proposed Transmission Lines (Transmission Line Sources Only)					
					Existing			Proposed		
					Electric Field (kV/m)	Magnetic Field (mG) Average Load*	Magnetic Field (mG) Peak Load**	Electric Field (kV/m)	Magnetic Field (mG) Average Load*	Magnetic Field (mG) Peak Load**
Overhead Lines										
Connecticut Baptist Home Meriden 06450	3	12	Assisted Living Facility	110 to 460	0.09 to 0.02	2.1 to 0.4	- nc -	0.19 to 0.03	2.8 to 0.3	1.8 to 0.2
B'Nai Jacob Congregation Woodbridge 06525	8	34	Playground/School	-20 to -320	0.31 to 0.01	4.5 to 0.2	- nc -	0.14 to 0.01	3.2 to 0.3	16.9 to 1.6
Peck Place School Orange 06477	8	40/41	Playground/School	-500 to -850	0 .00 to 0.00	0.1 to 0.0	- nc -	0.01 to 0.00	0.1 to 0.1	0.8 to 0.3
Eisenhower Park Milford 06460	8	42	Bleachers/Playing field	0 to 250	0.70 to 0.02	7.7 to 0.3	- nc -	1.48 to 0.04	8.6 to 0.5	49.5 to 2.9
Underground Lines										
Little Lamb Day Care Bridgeport 06608	9	51	Day Care Facility	125 to 175	- na -	- na -	- na -	- na -	0.0 to 0.0	0.0 to 0.0
Washington Park Bridgeport 06608	9	51/52	Park/Playground	0 to -285	- na -	- na -	- na -	- na -	0.2 to 0.0	0.2 to 0.0
Winslow Park Westport 06880	9	61	Park	5 to 780	- na -	- na -	- na -	- na -	0.1 to 0.0	0.2 to 0.0

+ Distances are best estimates based upon measurements (where possible) or distances scaled from aerial photographs
nc Not calculated, loading data not provided
na Not applicable
For locations within 500 feet of overhead line or 100 feet of underground line
* 15 GW Load Case (typical system loading in 2007)
** 27 GW Load Case (hour with the highest system loading in 2007)

Table A-3. Edge of right-of-way magnetic field values for proposed and alternative line configurations. Highest hour loading in 2007 – 27 GW

Electric field values are the same as for the 15 GW case.

Cross Section	Existing Magnetic Field (mG)	Proposed Magnetic Field (mG)	
	Existing Transmission System will not Support 27 GW Projected Load	East/South* ROW	West/North** ROW
Proposed Primary 345-kV Overhead Route			
1	- na -	58.8	41.2
2	- na -	58.4	39.4
3	- na -	12.0	10.7
4	- na -	5.5	17.1
5	- na -	45.0	61.6
6	- na -	16.3	39.9
7 and 7A	- na -	38.0	44.7
8 and 8B	- na -	28.1	49.5
"Supported Change" 345-kV Overhead and Relocation of 115-kV to Underground Line Sections			
7B *(25')****	- na -	19.4	54.6
8A *(-20')*****	- na -	14.1	49.1
*(-400')*****	- na -	14.1	49.1
Proposed and Underground Line Routes+			
9 (HPFF - East Devon to Singer)	- na -	0.2	0.2
9 (HPFF - Singer to Norwalk)	- na -	0.2	0.3
9A (Alternative A) (XLPE - Singer to Hawthorne)	- na -	4.6	4.4
10 (Alternative B) (XLPE - Singer to Seaview Loop)	- na -	6.1	5.1
11 (Alternative B)	- na -	9.7	15.7
12 (Alternative B)	- na -	38.4	46.2
13 (Alternative B)	- na -	20.1	38.1
14 (Alternative B)	- na -	63.5	6.7
15 (Alternative B)	- na -	63.5	11.5
16 (Alternative B)	- na -	42.2	14.7
17 Alternative A & B)	- na -	20.8	19.3
18 (Alternative A & B)	- na -	13.2	25.4
19 (Alternative A & B)	- na -	33.8	20.9
20 (Alternative A & B)	- na -	91.3	24.8
21 (Alternative A & B)	- na -	54.8	24.8
22 (Alternative A & B)	- na -	91.3	24.8

* Identified in documentation as left ROW
** Identified in documentation as right ROW
*** Distance from edge of ROW. +25' indicates 25' outside of the right (West/North) ROW.
**** Distance from edge of ROW. -20' indicates 20' outside of the left (East/South) ROW
\+ ROW edge taken as –20' left (East/South) ROW and +20' right (West/North) ROW.
\- na - Not applicable

TUTORIAL

UNDERGROUND ELECTRIC POWER TRANSMISSION CABLE SYSTEMS

Brian Gregory BSc, CEng, FIEE, MIEEE
David Notman BSc, CEng, MIEE

Cable Consulting International
www.cableconsulting.net

Contents

INTRODUCTION 1
WHAT IS ELECTRIC POWER? 1
WHAT IS AN AC POWER SYSTEM? 3
HOW IS AC POWER TRANSMITTED? 4
WHAT IS AN UNDERGROUND POWER TRANSMISSION CABLE? 5
UNDERGROUND POWER CABLE ACCESSORIES 7
WHAT ARE THE DIFFERENT TYPES OF TRANSMISSION CABLE SYSTEMS? 8
NEWER TYPES OF TRANSMISSION SYSTEMS 16
HOW ARE CABLE SYSTEMS INSTALLED? 17
MAINTENANCE AND REPAIR 21
HOW DO CABLE SYSTEMS AFFECT ME? 22
TUTORIAL SUMMARY 31

INTRODUCTION

This tutorial explains in a non technical way what an underground cable is, what it does, how it is installed, the types of cable systems that are available and how they affect me, the reader. The intent of this tutorial is to give a background understanding and not to compare the merits of each method of power transmission and each design of cable. Each design has advantages and disadvantages, many of them being highly technical.

WHAT IS ELECTRIC POWER?

Power is the rate at which work is performed. Work is something like boiling water, moving a locomotive on a railroad or lifting a weight in the gym. The faster the work is done, the higher the power that is expended.

A person who lifts a weight ten times in ten seconds does the same amount of work as a person who takes twenty seconds but the first person generates twice the amount of power.

Power is measured in Watts (after James Watt, the Scottish Engineer who is famous for improving the steam engine).

The faster the weight is lifted, the higher the power

Electric power is generated in power plants and is transported into homes, shops and factories by means of overhead lines and underground cables. It is then converted into heat, light, movement, etc. An example of conversion is in a refrigerator where electric power is converted to keep food cool.

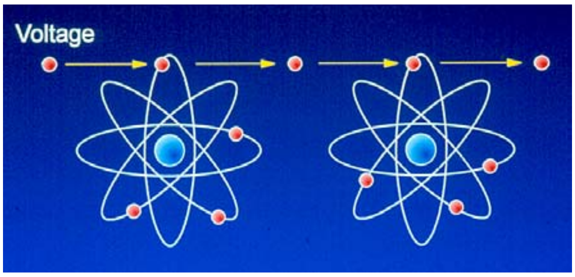
When electric power is transported within a town or street it is called ‘power distribution’.

When it is transported over long distances from the power plants to a town it is called ‘power transmission’.

This tutorial will concentrate on power transmission.

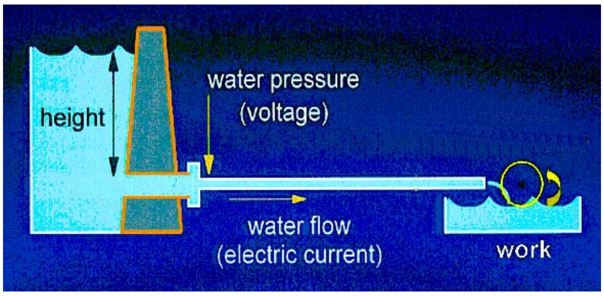
Electric power is carried by the flow of current (electrons moving from one atom to the next) along a conductor or wire.

The current is pushed along the conductor by voltage.



The voltage causes the current to flow

A good way to look at things is to consider water flowing from a reservoir behind a dam. Voltage is equivalent to the depth of water (the water pressure). Current is equivalent to the flow of water from the reservoir through the pipe.



The water pressure forces the water to flow and turn the wheel

Power is calculated by multiplying the voltage by the current.

Voltage is created by the power plant and it is always present in the conductor.

When the user at the far end of the conductor (at home or in a factory) throws a switch, the voltage pushes the current into the domestic or industrial appliance that has been switched on. Energy is then converted at the power plant from fossil fuel, nuclear fuel, water or wind into electric power and permits current to flow through to the appliance. At the appliance, the power is converted into heat (to keep you warm), cold (air conditioning to keep you cool) or movement (to turn your vacuum cleaner motor).

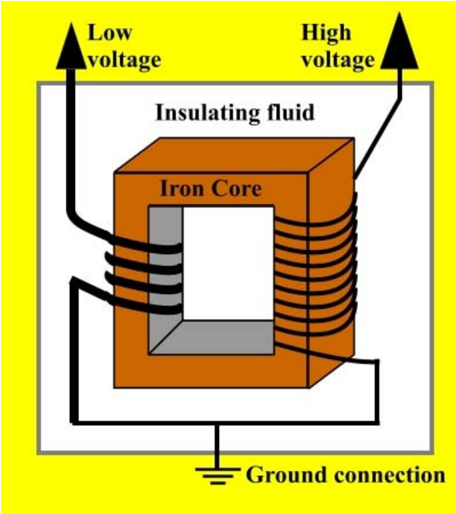
There are two types of electric power transmission. The first uses alternating current (AC) transmission and the second uses direct current (DC) transmission. In an AC system, the current flows to and fro in a push-pull fashion sixty times a second. Its main advantage is that transformers can be used.

Transformers permit voltage to be converted, 'transformed', from low values to high values and vice versa.

Transformers allow us to move large amounts of power in a highly efficient way at very high voltages along transmission lines and cables. The voltage is then transformed down so the power serves homes at a much lower and safer voltage.

AC systems are used for the majority of power transmission systems throughout the world.

Small transformers are used in the home, with an example being inside a mobile phone charger, where 110 Volt household voltage is transformed down to around 6 Volts.

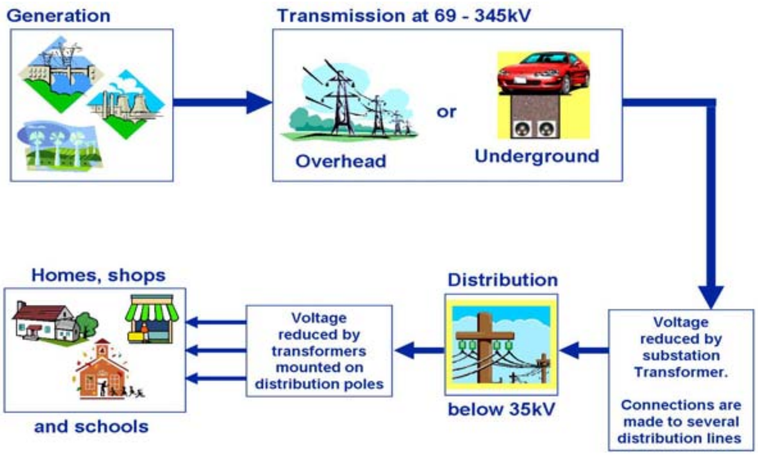


A transformer is used to increase or decrease voltage

In a DC system, the current flows in one direction only and transformers cannot be used. Converter stations are used to convert DC to AC but these are large and expensive so it is impractical to tap off power along the route. DC systems are generally used for specialized technical applications, such as long length undersea power connections and connections between independent AC power systems. This tutorial considers AC systems.

WHAT IS AN AC POWER SYSTEM?

An AC system typically comprises power plants, transformers, switches, circuit breakers, overhead lines and underground cables.



Basic electric power system

When power is transferred at voltages of 69,000 Volts, 115,000 Volts; 230,000 Volts; 345,000 Volts and above, this is known as power transmission.

Transmission voltages are usually expressed in terms of kilovolts, shortened to kV. One kV is equal to one thousand Volts. The voltages stated in the previous paragraph can be written as 69kV, 115kV, 230kV and 345kV. To give a comparison, 345kV is over 1,000 times higher than the voltage of 110 Volts that is used in peoples' homes.

A transmission circuit is usually comprised of three parallel overhead lines or underground cables. The underground cables can be three separate cables or three cables within a common pipe. Each of the three lines or cables must be in operation for the circuit to work properly.



Three parallel lines or cables are required to form a circuit

HOW IS AC POWER TRANSMITTED?

Power can be transmitted overhead by means of overhead lines or underground by means of cables.

The majority of circuits use only overhead lines, some use both overhead lines and underground cables and only a few use cables only. This mixture is somewhat similar to a railroad which is above ground outside a city and underground in dense urban areas.

The first choice of a utility is usually to install circuits overhead as this is the most efficient and reliable. There are technical problems that prevent underground cable circuits from carrying power efficiently over long distances. These can be overcome by installing additional equipment at regular distances along the route. These pieces of equipment are called "reactors" and they allow the cable system to carry more power.

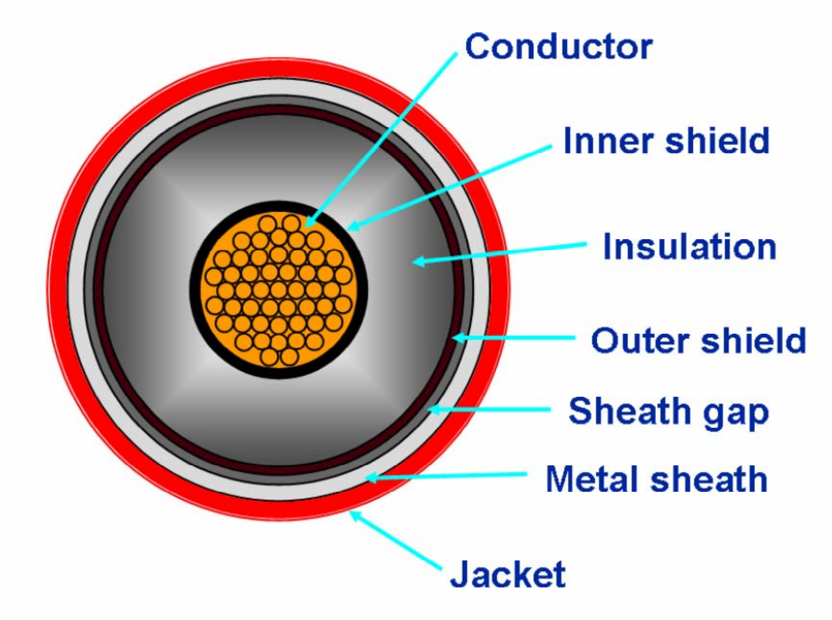
Underground cable transmission systems may be used when it is impractical or undesirable to use overhead lines. Cables might be used in the following situations:

- a water crossing
- a bridge crossing
- a tunnel
- a densely populated area of a city
- next to an airport
- an area of outstanding scenic beauty

This tutorial describes the proven types of underground cable systems that are in use throughout the world.

WHAT IS AN UNDERGROUND POWER TRANSMISSION CABLE?

A power cable provides the means to carry current from one location to another. It is circular in shape. The voltage is contained within the cable so none escapes by sparking across to the ground.



Typical cable construction

The conductor carries the electric current. The current causes the conductor to heat up to a temperature of around 195 degrees Fahrenheit when the cable is working at its maximum capacity. The installation design must allow for this heat to escape to the surroundings.

The inner shield provides a good, smooth, surface for the insulation to sit on.

The insulation prevents the voltage from sparking to ground. The plastic covering on an extension cord for a domestic appliance does the same thing so you don't get an electric shock or short circuit the house supply.

The outer shield further ensures that none of the voltage escapes.

Depending on the cable type, the sheath gap is either filled with fluid or wrapped with swellable tapes to prevent the flow of water along the cable if it is damaged.

The metal sheath keeps the cable completely sealed, it prevents water from entering the cable and, in some types of cable, it prevents the filling fluid from escaping from the cable. The metallic sheath also has some important electric uses.

When included in the design of a cable, the jacket prevents the metal sheath from being corroded by water and salts in the surrounding soil. It is also used to insulate the metal sheath from ground, something that is important in the electric design of a system.

Reels of cable are transported by large trucks

Cables can be manufactured in long lengths of several miles but can only be transported by road or rail in comparatively short lengths (1500 – 2000 feet, typically). A difficult installation terrain, such as a steep or winding route, may mean it is only practical to install short lengths.

The cables are transported from the factory to the construction site on large and heavy reels.

The reel lengths are joined together end to end by connectors called joints (sometimes called splices). These and cable terminations (sometimes called potheads) are described in more detail in the next section.

The main requirements of a power cable are reliability and safety. The cables are installed underground in a hostile environment and are inaccessible for visual inspection during their service lives. A cable system is normally designed to have a prospective life of 40 years.

UNDERGROUND POWER CABLE ACCESSORIES

The joints that are used to connect reel lengths together and the terminations that are used to connect the cable system to switchgear, transformers, reactors and overhead lines are called accessories.

Joints near completion in a joint bay, they will later be buried with soil up to street level

Transition stations are used to connect lines and cables together

The locations where underground cable terminations are connected onto overhead lines are called transition stations.

These accessories are every bit as important as the cable and are recognized as being the weakest link in the cable system in terms of reliability.

All the accessories must be assembled by hand on the construction site without the advantages of being in a clean, dry, factory.

A kiosk used to make electrical connections to ground

Other accessories, such as ground connection boxes, alarm systems, monitoring systems and communication cables are also necessary.

Together, cables and accessories comprise a cable system.

WHAT ARE THE DIFFERENT TYPES OF TRANSMISSION CABLE SYSTEMS?

With the exception of a very small number of special circuits operating at 525kV, 345kV is the highest voltage for underground cables in the USA. Underground circuits at 345kV require advanced technology and each individual circuit must be custom designed and manufactured to suit the particular application. These cable systems cannot be purchased "off the shelf".

Several different types of cable systems are in use throughout the world. Each system has advantages and disadvantages. For any given project, the most appropriate type of system must be selected by a utility after they have taken due account of their own technical and commercial requirements together with the views of the general public, land owners, local and state government, and other interested parties.

In this section the various types of cable systems are described and their main advantages and disadvantages are given. Where systems are not suitable for use at 345kV, this is indicated.

High Pressure Fluid Filled Systems

High pressure fluid filled is usually shortened to HPFF.

Here the three individual cables, called cores, necessary to form a circuit are installed in a steel pipe.

The pipe is first installed in lengths of up to 40 ft and these are welded together in sections that are typically 1500ft long. The three cables are then pulled into the pipe.

The joints that are necessary to join individual reel lengths together are installed in chambers in the ground called splicing vaults that are up to 30 feet long.

At the end of the process, the pipe is filled with a filling fluid and is then pressurized with pumps to around 200 pounds per square inch to achieve full insulation strength.

The key elements of each HPFF cable core are:

Conductor:	This is made from several small copper or aluminum wires that are twisted together.
Insulation and shields:	Many layers of thin tapes measuring less than one hundredth of an inch thick and less than one inch wide are wound onto the conductor in the factory. The layers of tape are applied until the insulation is around one inch thick. Carbon or metalized paper tapes are used as shields to maintain the circularity of the conductor and around the outside of the

insulation to contain the electric field within the insulation. Metal and plastic tapes are also applied over the outer shield.

Two types of insulating tape are available:

- high quality paper that has been washed, treated and dried to remove any impurities and moisture or
- a sandwich of paper-polypropylene-paper (PPP). Polypropylene is a plastic with good electric, mechanical and temperature capability.

Cores insulated with PPP are up to 60% smaller than cores insulated with paper. Also, PPP cores are electrically more efficient than paper cores and so the cost of transferring power is reduced. Today, PPP is the preferred choice of insulating tape.

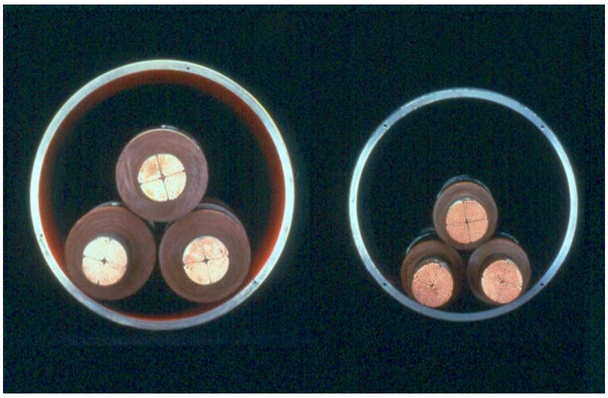
Filling fluid: The tapes are only one part of the insulation. The other part is provided by the fluid that is used to fill the steel pipe after the completion of installation. The fluid permeates through and between the insulating tapes and fills up the gaps and spaces between the tapes.

Skid wires: These are thin D shaped wires, about ¼" across, which are wrapped round each core in an open spiral. Their purpose is to protect the core when it is installed into the pipe, allowing it to 'skid' over the surface of the pipe.

Main Advantages

- HPFF cable systems are a mature technology and have a proven reliability. They provide the backbone of America's underground power transmission systems and many hundreds of miles have been installed since the 1950's in circuit lengths of up to around 15 miles.

- Steel pipes can be laid quickly in short lengths. This means that it is only usually necessary to keep trenches of about 40-60 feet long open at any one time during installation. Sometimes, when obstacles need to be bypassed, much longer trench lengths are necessary. The cable cores are pulled into the pipe after installation of the whole pipe length is complete.



Typical HPFF cable constructions inside steel pipes. Paper insulation is applied to the cores on the left and PPP insulation to those on the right

- Local manufacturing, installation

and maintenance expertise is readily available in the USA.

- Steel pipes provide good, but not perfect, mechanical protection to the cable cores in the event of a 'dig-in' by a contractor digging up the roadway.
- Steel pipes reduce the magnetic field effects that are generated by the cable cores.
- The splicing vaults that are used to house the cable joints allow access to the joints for maintenance.
- Long circuit lengths can be easily tested during circuit commissioning. Suitable test equipment is readily available in the USA.
- Cable cores can be pulled out and replaced through the splicing vaults without the need to dig up the road.

Main Disadvantages

- If a leak occurs in the steel pipe, fluid will leak out into the surrounding soil. (Monitoring systems can be used to give an early indication of the presence of a leak).
- The filling fluid is at high pressure, it is stored in large reservoirs situated at various points along the cable route and can flow easily and quickly to the point of any leak.
- Steel pipes will corrode if they come into contact with water and salts in the soil, just like a car kept at the coast will rust quickly. If the protection over the surface of the pipes is damaged, corrosion is likely to occur and, eventually, the corrosion will travel through the pipe wall and result in a fluid leak. Special equipment is necessary to reduce the risk of corrosion. Corrosion is seldom a problem in a properly designed and installed system.
- Cable cores are free to move and slide within the steel pipe. Special design measures must be taken on routes with steep slopes in order to prevent cable damage. The severity of a slope may mean that a HPFF system can not be used at all.

High Pressure Gas Filled Systems

High pressure gas filled is usually shortened to HPGF.

HPGF systems are similar to HPFF systems with the key difference being that the steel pipe is filled with nitrogen gas at 200 pounds per square inch rather than a filling liquid.

Main Advantages

- A leak of nitrogen gas from the steel pipe has a far lower environmental impact than a leak of filling fluid.

- Nitrogen gas is readily available and does not require any special formulation.
- Nitrogen gas is non-flammable so there is not a fire risk if a cable system is installed in a tunnel or substation.

Main Disadvantage

- An HPGF system is relatively weak electrically (because the nitrogen gas is not as good an insulator as fluid) and so HPGF systems are limited to voltages of 230kV and under. They are not suitable for 345kV so this tutorial will not consider these further. Dropping the power transmission voltage to 230kV or below is not usually a practical option as this would increase the current to be carried by 50% and twice the number of cables would be required to carry the same amount of power. The power transmission would be less efficient.

Self Contained Fluid Filled Systems

Self contained fluid filled is usually shortened to SCFF cable.

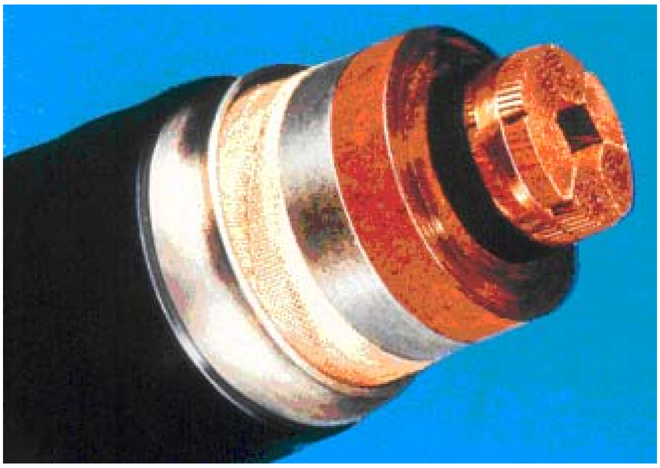
SCFF cables are sometimes also called low pressure fluid filled cables (LPFF).

Three single core cables are necessary to form a circuit.

The cables are buried directly in the ground.

For installation, a trench at least as long as the cable reel length is excavated and the cables are individually pulled into the trench. The open trench may be 1500 to 3000ft long.

Each individual cable comes filled with a fluid.



Typical SCFF cable construction

Joints, which are also buried direct in the ground, are used to connect the reel lengths together.

After installation, the filling fluid is pressurized up to 75 pounds per square inch.

The key elements of each SCFF cable are:

Conductor: This is similar to the conductor used in HPFF cables. The main difference is that a hole, about ½" in diameter, is present in the center of the conductor to allow the filling fluid to flow from one end to the other when the cable heats and cools.

Insulation and shields: These are similar to the insulation and shields used in HPFF cables. As with HPFF, the paper or PPP tapes are only one part of the insulation. The other part is provided by the filling fluid that is contained within the cable.

Metal sheath: This is a tube made from lead or aluminum that is applied over the insulation by means of a process called extrusion. The purpose of the sheath is to prevent the filling fluid from leaking out of the cable and to prevent air or water from leaking into the cable. It also has several important electric functions.

Jacket: This is a tube made from polyethylene or PVC that is applied over the metal sheath by an extrusion process.

Main Advantages

- SCFF cable systems are a mature technology and have a proven reliability. Outside of America, they provide the backbones of the power transmission systems in most European, Middle Eastern and Asian countries. Many thousands of miles have been installed since the 1960's.

- SCFF systems are buried direct in the ground. This and the use of special anchor joints means that cable movement on steep slopes can be prevented.

- The three cables can be spaced apart in the ground giving improved heat dissipation to the ground surface.

- Long circuit lengths can easily be tested during circuit commissioning. Suitable test equipment is readily available in the USA.

Main Disadvantages

- If a leak occurs in the metal sheath, fluid will leak out into the surrounding soil. (Monitoring systems can be used to give an early indication of the presence of a leak).

- At the higher transmission voltages, where conductor sizes tend to be large and generate high mechanical forces, SCFF systems are not suitable for installation inside long lengths of ducts or pipes as the metal sheath may fatigue and fail.

- Long lengths of trench must be open for longer periods. Long trench lengths present a safety hazard particularly for trenches dug in busy streets. Also, traffic disruption may occur.

- Fluid reservoirs must be installed at regular intervals along the route to allow for expansion and contraction of the filling fluid.

- Corrosion of the cable sheath will result in fluid leaks so regular maintenance testing is necessary, requiring the circuit to be switched out of service.

- The spacing necessary to allow good heat dissipation may result in a wider trench and in higher magnetic fields.

- Special grounding techniques are necessary. These require connection boxes or kiosks to be installed. They must be maintained regularly. The boxes and kiosks must be designed and located to protect the public from the effects of a cable system fault.

- SCFF cable systems are not manufactured in the USA and are not regularly installed by USA based contractors. There is, therefore, very little specialist installation and operational expertise available within the USA.

- Many European and Asian manufacturers of SCFF systems are currently beginning to switch from the production of SCFF systems to XLPE cable systems (see below). The availability of SCFF spares and expertise in the future may be a problem.

Cross Linked Polyethylene Systems

Cross linked polyethylene is usually shortened to XLPE.

XLPE cables are also called extruded or solid insulation cables. A technical term used to describe the insulation is 'dielectric'.

Three single core cables are necessary to form a circuit.

The cables may be buried directly in the ground or pulled into individual non metallic pipes or ducts.

For installation, either a trench at least as long as the cable reel length is excavated and the cables are pulled into the trench, or individual ducts, usually manufactured from a plastic material, are laid in short lengths and joined together before the cables are pulled into them.

Typical XLPE cable construction

Each individual cable is dry inside and is not filled with a fluid.

Joints, which are encased in conduit or buried direct in the ground, are used to connect the reel lengths together.

XLPE systems have a proven reliability at voltages up to 161kV. At higher, power transmission, voltages, their use is relatively recent.

The key elements of each XLPE cable are:

Conductor:	This is similar to the conductor used in HPFF cables.
Insulation and shields:	The XLPE insulation is extruded over the conductor together with the inner (underneath) and outer (over) shields by means of a process called triple extrusion. Squeezing toothpaste out of a tube is a form of extrusion. Some grocery bags that are supplied by supermarkets are made from polyethylene. The crosslinking process links individual polyethylene molecules together and has the effect of increasing the melting point of the insulation. This allows the XLPE cable to operate at the same higher temperature as HPFF and SCFF cables and thus carry a similar power level.
Metal sheath:	This is similar to the metal sheath used in SCFF cables. As the metal sheath does not have to contain a pressurized filling fluid, a number of alternative, less robust, types of metal sheath are available for some applications.
Jacket:	This is similar to the jacket used in SCFF cables.

Main Advantages

- XLPE systems don't contain fluid so the environmental effects of leaks are not a problem. Fluid system maintenance is not necessary.
- XLPE systems do not burn as readily so there is a reduced fire risk in tunnels and sub-stations.
- Special anchor joints are available that prevent the cable core from sliding into and out of the joints when XLPE systems have to be installed on steep slopes.
- The insulation is electrically efficient, so relatively long underground circuits can be installed which helps to keep the cost down.

Main Disadvantages

- At power transmission voltages, XLPE cable systems were developed after the other types of systems discussed in this tutorial. The first long length system at 345kV or at higher voltages was not commissioned until the mid 1990's. The circuit length was 7.5 miles. Reliable, long term, service experience is still to be proven.

- Most XLPE systems are installed in tunnels which provide easier access for installation, inspection, maintenance, repair and replacement.

- There are only three long circuits containing joints installed direct in the ground. These are in Denmark and Saudi Arabia. The longest circuit is 7.5 miles.

- The cables are larger in diameter as a thicker layer of insulation is required. Reel lengths tend to be reduced and sometimes the number of joints has to be increased.

- The technology has been held back by difficulties in producing and assembling reliable joints. Several different types have been tried throughout the world and manufacturers are still improving them. The joints are recognized as the weakest link.

- 345kV XLPE cables and accessories are not manufactured in the USA. The expertise of USA based installation contractors is growing with time.

- In the event of undetected damage to the metal sheath, moisture can enter the XLPE insulation and weaken it. Premature cable failure is likely.

- If cable circuits are to be tested at a high voltage before being energized, the circuits must be tested during commissioning with test equipment special to XLPE cable systems, using an AC test voltage. This equipment is not readily available and may not have a capacity to test longer length circuits.

- International standards require long term proving tests for XLPE cable systems to be carried out. These can be up to one year long and thereby increase project lead time.

- The manufacture of XLPE cable is slower and so longer project lead times are required.

- Magnetic field effects and the need for special grounding equipment are similar to SCFF systems.

Ethylene Propylene Rubber Systems

Ethylene propylene rubber is usually shortened to EPR.

Three single core cables are necessary to form a circuit.

The cables are either buried directly in the ground or pulled into non-metallic pipes.

For installation direct in the ground, a trench at least as long as the cable reel length is excavated and the cables are pulled into the trench.

Each individual cable is dry inside and is not filled with a fluid.

Joints, which are either buried direct in the ground or installed in splice chambers, are used to connect the reel lengths together.

Main Advantages

- EPR systems are more resistant to water and can be exposed to water for a longer time without a metallic sheath.
- EPR cable is more flexible and can be bent into tighter locations without damage.
- EPR systems can carry a higher overload under emergency situations with less risk of damage.

Main Disadvantage

- EPR systems are relatively weak electrically and are usually limited to voltages of 150kV and under. They are not suitable for 345kV so will not be considered further in this tutorial.

NEWER TYPES OF TRANSMISSION SYSTEMS

Newer types of transmission systems, which are still at the proving stage, are gas insulated lines (GIL) and superconducting cables.

A GIL system comprises three aluminum alloy pipes each some 2 feet in diameter and 40 feet long. A solid tubular aluminum conductor is inserted into each pipe. Many pipes are then welded or bolted together. GIL has the advantage that higher levels of power can be carried over longer distances because of the larger size of the conductor and pipe.


GIL installed on short stilts (diagrammatic representation only)

The pipes can be installed above ground on stilts, in a tunnel or they can be direct buried underground. After installation, the pipe is filled with an insulating gas.

To date, little long length GIL has been installed worldwide. These installations have been above ground in power plants or in tunnels. Only short, trial, lengths have been installed direct buried underground.

GIL systems are comparatively new and do not yet have a proven reliability and service life.

Above ground, GIL systems present a considerable visual impact. Where GIL is direct buried in the ground, there is concern over the additional mechanical stresses that will arise in the aluminum pipes. Aluminum is a metal that corrodes easily and the protection of direct buried pipes is extremely important.

Superconducting cable systems use the property that at low temperatures some materials have no electric resistance. This allows high levels of current to flow in a smaller conductor. These systems have to be kept extremely cold by having liquid helium or nitrogen pumped through them at a temperature down to as low as minus 450 degrees Fahrenheit and they have to be thermally insulated from their surroundings within a vacuum filled tubular layer. Superconducting systems are very much at the experimental stage and there are no systems in full commercial service.

HOW ARE CABLE SYSTEMS INSTALLED?

HPFF Systems

First of all the steel pipes are installed in the trench. The pipes are installed at a depth of around 4 feet. Each pipe section is about 40 feet long and the individual sections are welded together and x-rayed to ensure the quality of the weld.

Pipe installation moves progressively along the route and it is only necessary to keep a short section of trench open at any one time. Trench lengths of 200 feet are possible. This minimizes disruption to pedestrians, traffic, landowners and so on.

The pipe trench is either part filled with concrete, soil that was removed from the trench, or with a special material, called thermal backfill, which helps remove the heat from the cables.

After installation of the pipe, the three reel lengths of cable core are pulled into the pipe together. The inside of the pipe and the welded pipe joints must be smooth so that the skid wire protected cable cores can slide easily and prevent damage to the cores.

Splicing vaults can measure up to 8 feet wide, 8 feet deep and up to 30 feet long and are constructed to allow individual cable reel lengths to be connected together.

The joints that are used to connect the reel lengths together are installed in the splicing vaults. A larger steel casing is then welded to the steel pipes thereby sealing the joints into the pipe system.

At each end of the route, terminations are connected onto the ends of the three cable cores to allow them to be connected to switches, transformers or overhead lines.

Pumping stations are positioned periodically in long routes to house fluid reservoirs and associated pumping equipment. These reservoirs permit thermal expansion and contraction of the fluid.

Filling fluid is pumped into the steel pipe after completion of joint and termination installation and is pressurized to around 200 pounds per square inch. In some applications the fluid is circulated to cool hot spots along the cable.

Finally, the circuit is tested and is put into service.

SCFF Systems

Open cable trench

SCFF systems are most suited to direct burial in the ground.

A trench length at least equal to the reel length, around 1,500 – 2,000 feet, must be open. Trenches are typically 3-4 feet deep and 3-4 feet wide. Wooden boards or steel shuttering are installed along the trench length to prevent collapse.

Three cables are pulled in one after the other. Often a technique, called ‘bond pulling’, is necessary whereby each cable is supported by a tensioned wire rope as it is pulled in so that it is not stretched or crushed.

After the cables are pulled in, the trench is filled with either the soil that was removed or with thermal backfill, if help to remove heat from the cables is necessary.

Cable joints are then installed in pits containing a concrete base. These pits are sometimes called joint bays and typically measure 9 feet wide, 6 feet deep and 24 feet long. A large tent or building is erected over the pit. A clean working environment is established and the inside may be air conditioned.

A buried joint bay during the backfill operation

Joint bays cannot be backfilled until two consecutive cable section lengths have been pulled in and connected together. The joints have to be sealed inside a waterproof casing and also protected from loads arising from the soil and road surface.

115kV cable system terminations

Terminations are connected to the cable ends at the ends of the route in order to allow them to be connected to switches, transformers or overhead lines.

SCFF systems operate at a maximum pressure of 75 pounds per square inch. Sectionalizing joints, called stop joints, are used to limit fluid pressures along a steep route. These joints also anchor the cable system mechanically in order to prevent movement downhill.

Fluid reservoirs to permit expansion and contraction of the filling fluid must be buried in the ground next to stop joints and at the ends of the route.

Finally, the circuit is tested and is put into service.

High voltage test set connected to SCFF terminal

Pit housing fluid feed tanks

XLPE Systems

XLPE systems are suited both to direct burial in the ground and for installation in ducts (one cable) and pipes (three cables). 345kV XLPE cables are of large size and are installed in ducts. The mechanical performance of XLPE systems installed in ducts and pipes is not yet fully understood and special studies are presently being undertaken. Results are expected soon.

Installation of direct buried XLPE systems is similar to installation of SCFF systems.

Joints are by far the weakest link and must be installed in a carefully controlled ultra-clean environment. The joints are highly complex to manufacture and special care and techniques are necessary during assembly.

Anchor joints to secure the cable system on steep slopes are available.

Some designs of termination must be filled with silicone oil.

Connecting XLPE cables together in an ultra-clean environment within a buried joint bay

It may be necessary to insert intermediate substations in longer circuits to separate them into short lengths and so permit the cable system to be voltage tested prior to commercial operation.

MAINTENANCE AND REPAIR

The technology used for HPFF and SCFF systems is mature and well proven. Provided systems are designed, manufactured, installed and maintained properly, a long, reliable, service life should follow. XLPE systems are still being developed and have not been in service long enough for their reliability to be proven. Manufacturers are investing heavily into XLPE systems and this gives confidence that, in time, designs should evolve and reliability should match that of HPFF and SCFF systems.

Maintenance

Regardless of the type of cable system, routine maintenance is necessary to keep it in as good a condition as possible. This will help to prevent unexpected failures.

Each system has its own specific, detailed, maintenance requirements but these can be generalized as follows:

- A regular patrol along the cable route to look for evidence of anything that may indicate the system has been or is likely to be damaged. Roadworks by another utility is a good example.
- A regular inspection of all exposed pipework and pressure gauges to look for any signs of fluid leakage.
- Regular testing of ground bonding connections, alarm connections, corrosion protection systems (including cable jackets) and surge limiters that protect the cable system from lightning strikes and other abnormal electric events.

Fluid pipe and gauge inspection

Repair

In the event of a failure of a cable system component, a system repair will be necessary.

Failure of a minor item may mean that a repair can be carried out while the circuit remains in service.

Failure of a major component, such as the cable itself, the metal sheath, the jacket, a joint, a termination or a grounding connection will mean that the system must be taken out of service to permit the repair to be carried out safely.

Fault location and repair times will range from one week (a jacket repair, for example) through several weeks to more than a month (a failed cable or joint, for example).

In the event of a failure, a utility must do everything reasonable to limit further system or environmental damage.

The failure must first be located. Electronic location techniques are used as the cable system is buried and cannot be inspected visually. This can take several days. Any other adjacent equipment (transformers, switches, etc) must also be examined to check for damage.

After successful location, the most appropriate repair solution must be established. This may mean that a specialist from the supplier of the cable, joint or termination must visit the site.

Each cable system is designed specially for each utility and a supplier is not likely to have spare parts in stock. Manufacturing times are a few months and so each utility should hold its own set of spares. Typically a utility will hold a spare reel of cable, two spare joints and one spare termination.

Skilled personnel must be available to carry out the repair.

A transmission cable system is designed to have a service life of 40 years. It therefore follows that spare parts, materials and tools must be available over the service life. In selecting a particular cable system type a utility must ensure, as far as they can, that direct spares or suitable substitutes remain available.

HOW DO CABLE SYSTEMS AFFECT ME?

As part of the project planning process, the utility will have negotiated the right to install the cable circuit with local authorities, land owners, etc. Often, in the countryside, a dedicated right-of-way will be granted that gives a utility the right to install cables or overhead lines and to access them for maintenance and repair purposes. The right-of-way is effectively a continuous path of land that is leased to the utility.

In towns and cities, it is not usually practical to dedicate a right-of-way to a utility as other utilities often have to install their services in close proximity and the public need to be given access to roadways after the completion of installation.

During installation, trenches will have to be excavated. Depending on the number of circuits being installed, an access width of up to 36 feet may be necessary. Traffic flow may be disrupted and, on some occasions, partial or total temporary street closures will be necessary.

Also, as part of the project siting process, an environmental impact analysis is typically performed. This will have covered installation, in-service operation and repair and maintenance of the cable system.

During Installation

During installation as much work as possible, such as trench excavation, splicing vault construction and the storage of excavated soil, will be performed within the right-of-way or the area negotiated with a town or city authority. However, additional areas will probably be required and these will be negotiated on a case by case basis.

At all times during installation, public safety is paramount and, by means of a risk analysis process, all risks will be identified, analyzed, quantified and measures adopted to minimize each risk and its effects. A typical example is the construction of a splicing vault. This will be protected by crash barriers, signs warning about the presence of the splicing vault will be posted and the splicing vault location will be lit at night. In some circumstances, security guards will be employed.

Installation will typically progress at a rate of about one mile per month and will move progressively along the route so not all parts will be affected all of the time.

The key areas with the greatest impact are as follows:

- Increased construction traffic. Large, heavy trucks will need to access the construction site. Drivers will be instructed to only use approved access routes. Wheel washing and measures to minimize dust will be employed. In particular, increased traffic will result from
  - Trucks carrying excavating machines.
  - Trucks carrying cable reels, transformers and switches.
  - Trucks taking away excavated soil and returning with concrete and thermal backfill.
  - Cars and pickups carrying engineers and construction workers.

Three reels of cable are parked in the street ready to be pulled into a steel pipe

Installation of ducts to house the cables that will cross the river

- Open trenches and splicing vaults or joint bays
  - If a HPFF pipe or XLPE duct system is being installed, trenches up to 200 feet will be opened. Depending on trench length, excavation, pipe installation and backfill of 1-4 trenches can take place in less than a day. Work will proceed along the route by completing adjacent short trench sections.

  - Each splicing vault will be installed in less than a week. Cable pulling of three lengths of 1,500- 2,000ft of cable will take place in less than a day. Jointing work will continue inside the splicing vault for around 2-3 weeks.

  - If a SCFF or XLPE buried direct system is being installed, trenches of up to 2000 feet will have to be opened in one operation. The excavation, cable laying and backfilling cycle takes about 2 weeks. Each vault will have to be open for joint assembly and backfill for an additional period of 2-3 weeks.

Temporary trench reinstatement

  - Once trenches and splicing vaults have been filled in, the road surface will be 'reinstated' to its original condition. Reinstatement is usually a two stage process; temporary reinstatement to allow the filling to settle followed by permanent reinstatement which can be several months later depending upon the road surface type.

- Access to vehicular traffic and pedestrians. Access will inevitably be restricted during construction of those parts of the route passing alongside and underneath roads and sidewalks. On a long length route of tens of miles the work may occupy a period of many months to over a year. Work will proceed at different locations along the route at the same time. The schedule of work and necessary measures are agreed in advance with the appropriate State, City and Town Traffic Departments. Examples of the impacts and measures that may be taken to ease access are:

  - An open trench will be fenced off and lit at night. The trench will be typically 3-4 feet wide for HPFF pipe and XLPE duct installations comprising 3-6 cables and also for XLPE and SCFF buried direct installations comprising 3 cables. For XLPE and SCFF direct buried installations of 6 cables, either the trench width will be increased to 4-6 feet or a second trench excavated. Sufficient additional road width must be allowed to permit the excavated soil to be stored, removed and replaced.

– Access must also be provided for the excavation machines and trucks. This is likely to require that one lane of the road be closed and temporary traffic lights be used to control traffic flow.

Ducts being positioned in a deep trench before pouring concrete

– When two trenches are to be installed under opposite sides of the road, one section length of pipes, ducts or cables will be completely installed and the road surface reinstated before the trench on the opposite side is opened.

– Typically, vehicles can not be parked along the roadside during trenching operations.

– The time that a trench may be open depends upon a number of factors, including the weather. The presence of other buried services in the ground, such as water pipes, gas pipes, water drains, communication cables and domestic electricity cables will require that the trench be excavated to a greater depth using hand tools. The presence of a high water table will require that the trench be continuously pumped dry. Loose, running ballast will require special measures to support the trench walls. Rock and concrete will require special cutting and drilling equipment.

– In some locations it may be necessary to lay the cable close to, or under, a sidewalk. A fenced off safe passage is then provided for pedestrians.

– The crossings of major road intersections and civil constructions such as bridges and tunnels will require special arrangements. The trench may be opened at night requiring that either the lane or road be temporarily closed. One possibility is to lay pipes or ducts and to quickly reinstate the road surface such that the cables can be pulled under the intersection at a later date without the need to interrupt traffic.

– At certain intersections steel plates may be laid to bridge the trench.

– Access to domestic and public premises for vehicles and pedestrians may be provided across the trench by a temporary crossing if access is to be restricted for a prolonged period.

– Special measures are taken to provide access for emergency vehicles to public premises such as hospitals, schools and fire and police departments.

- In some special circumstances, as an alternative to temporary trench crossings, unrestricted access can be achieved by the use of pipe-jack tunnels, miniature tunnels or by directional drilling. However these techniques have technical limitations dependent on the location and type of cable.
- The installation of joints in either splicing vaults (HPFF pipe and XLPE duct cables) or bays (XLPE and SCFF buried direct cables) requires the excavation of a wider and deeper hole than the trench. The construction time for the splicing vault and the installation time for the joints is significantly longer than for the trench and cables. Wherever possible a location for the splicing vault is chosen to reduce the disruption to vehicular and pedestrian access.

Ducts entering a single, pre-cast concrete splicing vault

- In applications where two parallel configurations of six cables are required, combinations of double length splicing vaults and double width splicing vaults may be selected to separate the joints for maintenance purposes.

- To reduce site construction time the splicing vaults may be prefabricated in pre-cast concrete and transported to site and lowered into position using large trucks and cranes. The traffic flow may require to be halted during this activity.

- Jointing activities will take 2-3 weeks. It is usual during this time to cover the two access positions in the roof of the splicing vault chamber by small tents, small temporary buildings or special vehicles. A joint bay in a buried direct system has to remain open for this period and it will be necessary to completely weatherproof it with a large sealed tent, large temporary building or a custom designed shipping container. An additional period of 1 week may be required to remove the temporary building from the bay and to reinstate the road surface. It will be necessary for the specialist support vehicles to park along the road during the jointing period. The support vehicles will also include electricity generators for air conditioning equipment, pumps, lighting and power tools as well as washing and changing facilities for the jointers.

– During cable installation it will be necessary to park three large trucks next to the splicing vaults and use a crane to lift the large and heavy cable reels onto axle stands that will permit them to rotate. Traffic flow may require to be halted during this activity. Powered winches are located at the next splicing vault or joint bay to pull the three cables into position. A number of workers and vehicles are necessary during this activity, which will usually be completed within 1-2 days.

Reel being prepared for cable pulling

- Construction work may be performed at night and covered with steel plates during the day.

- Plants and animals. There is likely to be some disruption to the local ecosystem. Any plants or flowers that are covered by any preservation order will be identified and through consultation with the right representative bodies, a plan will be put into place to mitigate any environmental impact. The same is true for animals.

- Noise from construction machinery. This may be minimized by the use of acoustic shielding where necessary.

- Visual impact. This can be minimized by the use of appropriate screening.

In Service

In service, the cable route will be completely hidden. The tops of trenches and splicing vaults or joint bays will be covered with a surface that best blends in with the surrounding surfaces. This could be grass, concrete or tarmac.

At certain locations, small kiosks or boxes that house grounding equipment and filling fluid monitoring equipment will be present.


Kiosk containing ground connection links

It may be possible to locate some of these underground.

The key areas with the greatest impact are as follows:

- Visual impact.
  - Apart from boxes or kiosks there will be very little visual impact along the length of the route. In the photograph, 12 SCFF transmission cables cross this farmer's field in the UK.

    Kiosks protected by a fenced enclosure can be seen in the middle of the field.

Only the fenced enclosure is evidence that 12 transmission cables cross this land

  - At the ends of the route in transition stations, where the terminations connect onto transformers, switches or overhead lines, secure fenced yards will be necessary.
  - Depending on the circuit configuration, it is possible that smaller yards will be necessary at one or two points along the route.

- Boxes and kiosks. These will only be visible when it is not possible to house them underground. The electric design of SCFF and XLPE circuits requires that any accessories are connected to the cable system at no greater a distance than 30 feet. All boxes and kiosks will be of a strong steel construction and will be locked to prevent unauthorized access. They will be located in a position where accidental damage by the public is minimized.

Transition stations where cable terminations are connected to overhead lines

- Fluid leaks. The filling fluids contained in HPFF and SCFF cables are not listed in the Environmental Protection Agency's hazardous waste regulations. They also do not trigger any of the four criteria (corrosivity, reactivity, ignitibility and toxicity) for determining the status of those wastes not specifically listed by the EPA.

  One fluid, alkylbenzene contains a benzene ring. It is considered to have a low toxicity. A water soluble form of alkylbenzene is used in household detergents.

  If ingested at full strength by humans, it can cause nausea. It is non-carcinogenic and has no adverse reproductive effects.

Kiosk containing pressure gauges and fluid leak alarms

Cable filling fluid is classified as a non-indigenous substance by the State of Connecticut and the State has a formalized program to remediate releases. The Remediation Standard Regulations (RCSA 22a-133k-1, 22a-430) place a high level of scrutiny on the cleanup of contamination. The State also administers a permitting program to prevent future releases.

Cable systems are monitored so that the presence of a leak is indicated as early as possible.

It is in the best interest of all parties that HPFF and SCFF systems are designed and installed to be as leak tight as possible.

- Magnetic fields. When power flows along an overhead line or underground cable conductor, an electric and a magnetic field are generated. In an overhead line both fields spread out from the conductors, and progressively reduce in strength as the distance from the conductor increases.

  In a cable, the electric field is completely screened by the outer shield and the metallic sheath and does not spread out into the surrounding environment. Only the magnetic field spreads out. The magnetic field decreases in strength as the distance from the cable increases.

  For SCFF and XLPE systems, the installation configuration of the cables has an effect on the magnitude of the magnetic field and how fast it drops off. The magnetic field strength at the ground surface can be reduced by burying the cables deeper and closer together.

  Whenever practical the configuration that produces the lowest field will be used. It should be noted, however, that some configurations may severely restrict the cables' capability to transfer sufficient power and may not be suitable.

- Plants and animals. When carrying maximum power, the cable conductor reaches a temperature of around 195 degrees Fahrenheit. The temperature drops as the distance from the conductor increases but there will be some localized heating of the soil in the immediate vicinity of the cables. Such additional heating would normally have reduced to zero some 12 to 15 feet away from the cables.

  In some locations the local temperature increase may result in the moisture content of the surrounding soil decreasing, so some plants and animals may be affected by the temperature and a lack of moisture.

- Noise from transition stations. Sometimes a low pitched 'hum' can be heard to come from transition stations when transformers are present. This effect is minimized by installing transformers on anti-vibration pads and by the use of acoustic baffles.

- Risk of damage by contractors and other utilities. There is a risk to cable circuits from dig-ins. Detailed 'as installed' route plans will be made available to a central agency ("Call Before You Dig" in Connecticut) so the location of cables can be identified in the future.

Transmission circuit warning sign

  Warning signs may be placed at discrete locations.

  Portable scanners are available for use by contractors and are called Cable Avoidance Tools. These detect the magnetic field from a cable circuit and warn of its presence.

Protection and warning signs over buried cables

  If someone commences digging without taking sensible precautions, they will find that the cable circuits are covered with warning tapes, steel plates or concrete slabs that state 'Caution Electricity' or something similar.

  They may also find that the cable trenches have been filled with a type of concrete for heat dissipation reasons.

  The likelihood of from dig-in damage is therefore small.

- Plowing restrictions on farmland. Cables buried across farmland may restrict the depth to which a farmer may operate a plough. Prior to installation, the depth of the cables would have been agreed with the farmer.

During Maintenance and Repair

Regular patrols are necessary to check the cable route for damage and to check all HPFF and SCFF connections are leak tight. Access to boxes or kiosks will be necessary but as checks are carried out annually the impact is likely to be small.

The impact will be similarly small during routine maintenance tests on the cable system's grounding connections and during minor system repairs.

In the event that a major system repair becomes necessary, such as a failed cable or joint, significant disruption in the vicinity of the failure site can be expected. Localized trench, splicing vault or joint bay excavations may be necessary and, in some circumstances it will be necessary to install a new length of cable. For HPFF systems in pipes and XLPE systems in ducts this can be achieved without trench excavation as the new cable core can be pulled into the existing pipe or duct.

TUTORIAL SUMMARY

- Underground cable transmission systems may be used when it is impractical or undesirable to use overhead lines, however there are technical limitations that prevent cables carrying power over long distances.

- Transmission cables are installed underground in a hostile environment where they are inaccessible for visual inspection and easy maintenance. The main cable requirements are therefore safety and reliability during a long service life.

- A choice of cable types exists for transmission voltages up to 345kV. At this high voltage level the cable systems are custom designed to suit each application and the highest levels of technology and quality are required.

- The more mature cable types are highly evolved and have already demonstrated a reliable service life. Examples are HPFF cable (high pressure fluid filled) installed in a steel pipe and SCFF cable (self contained fluid filled) installed directly in the ground. The newcomer, XLPE cable (extruded crosslinked polyethylene) installed in ducts or in the ground, does not contain fluid but is too new to have demonstrated a long service life. In particular the joints that connect the XLPE cable lengths together are the weakest part of the cable system.

- Careful installation and protection of the cables is every bit as important as the cable design and manufacture, as the cables can initially be damaged during pulling in and jointing operations and later by third party dig-ins.

- Some disruption to pedestrian and traffic flow and some effect to the environment is inevitable during the comparatively long construction period when trenches are dug and cables and joints are installed. However these can be reduced with responsive project planning and co-operation with the appropriate public bodies.

- Regular maintenance in the form of diagnostic monitoring of the underground cable and visual inspection of the above ground equipment is important in reducing the need to re-excavate and repair the cable; the circuit outage times for which would be long.

- Careful selection of the cable and installation type, the cable manufacturer and the installation contractor, together with good project management, will lay a sound foundation for a reliable and long service life.

EVALUATION OF POTENTIAL 345-kV AND 115-kV CABLE SYSTEMS AS PART OF THE MIDDLETOWN-NORWALK PROJECT

SEPTEMBER 30, 2003

A REPORT TO CONNECTICUT LIGHT & POWER AND THE UNITED ILLUMINATING COMPANY

Prepared by:

Power Delivery Consultants, Inc.
28 Lundy Lane, Suite 102
Ballston Lake, NY 12019
Telephone 518 384-1300

Principal Investigator
Jay A. Williams, P.E.

EVALUATION OF POTENTIAL 345-kV AND 115-kV CABLE SYSTEMS AS PART OF THE MIDDLETOWN - NORWALK PROJECT

SEPTEMBER 30, 2003

Table of Contents

1.0 Introduction 1
2.0 Potential Routes 2
2.1 Introduction 2
2.2 General Route Description 2
2.3 Route Characteristics 2
2.3.1 Rural and Right-of-Way Areas 2
2.3.2 Suburban and City Streets 2
2.4 Special Considerations 3
3.0 Cable Types for 345-kV Operation 3
3.1 High-pressure Fluid-filled (HPFF) Pipe-type Cables 3
3.2 Extruded-dielectric (XLPE) Cables 4
3.3 Self-contained Fluid-filled (SCFF) Cables 4
3.4 Gas-insulated Lines (GIL) 4
3.5 High-pressure Fluid-filled and XLPE Cables Evaluation 4
4.0 Cable System Requirements for 345-kV System 5
4.1 Assumed Installation Conditions 5
4.2 Cable Size, Electrical Parameters 7
4.2.1 HPFF Cables 7
4.2.2 XLPE Cables 10
4.3 Cable Design Considerations 12
4.3.1 HPFF Cables 12
4.3.2 XLPE Cables 15
4.4 Reactive Power Requirements 19
5.0 Installation, Maintenance and Repair 21
5.1 HPFF Cable Systems 21
5.1.1 Installation 21
5.1.2 Maintenance 22
5.1.3 Repair 22
5.2 XLPE Cable Systems 23
5.2.1 Installation 23
5.2.2 Maintenance 24
5.2.3 Repair 24
6.0 115-kV CABLES 26
6.1 115-kV Cable System Types 26
6.2 Cable Requirements, Assumed Installation Conditions 28
6.3 Calculated Ampacities and Power Transfer 29
6.4 Accessories 29
6.5 Reliability 30
7.0 UNDERGROUND CABLES – SYSTEM EFFECTS 32
7.1 Cable Capacitance 32
7.2 Cable Inductance 32
7.3 Cable Rating 32
8.0 Multiple Short Underground Sections 33
APPENDIX A: HYDRAULIC, PRESSURIZING PLANT REQUIREMENTS FOR POSSIBLE 345-kV HPFF CABLE CIRCUITS A-1

EVALUATION OF POTENTIAL 345-kV AND 115-kV CABLE SYSTEMS AS PART OF THE MIDDLETOWN - NORWALK PROJECT

SEPTEMBER 30, 2003

1.0 Introduction

Connecticut Light & Power (CL&P) in cooperation with the United Illuminating Company (UI), hereinafter called “the Companies” requested Power Delivery Consultants, Inc. (PDC) to evaluate 345-kV underground cable alternatives for portions of a potential 345-kV line from the Scovill Rock Switching Station in Middletown, Connecticut, to the Norwalk Substation in Norwalk, Connecticut.

PDC evaluated cable types used at 345-kV, determined the ones that would be suitable for the potential application, and performed a conceptual design of cable systems that would meet CL&P’s and UI’s requirements.

CL&P and UI engineers provided significant information on line requirements, company practices, and route considerations, and Burns & McDonnell Engineers provided the route analysis and comments on the civil aspects of the installation described in this report.

The major length being considered for underground, a total of 23.6 miles from East Devon Substation to Singer Substation and Singer Substation to Norwalk Substation, would be high-pressure fluid-filled pipe-type cable. An alternative route from the Singer Substation to a transition station located adjacent to the right-of-way in Fairfield, CT, includes a potential 5.5 mile section of 345-kV cross-linked polyethylene (XLPE) cable

In addition, as part of a “supported change,” an 0.8-mile length of 115-kV XLPE cable is being considered for a section of the route in the Cheshire area.   A 115-kV XLPE cable is also being considered for a 3.6-mile segment from Norwalk to Norwalk Junction as identified in Volume 1, Sections I.2 and I.3.

2.0 Potential Routes

2.1 Introduction

The 69-mile length of the 345-kV transmission line from Scovill Rock Switching Station to the Norwalk Substation consists of six segments, connecting individual stations along the route. In evaluating the potential routes, the Companies in conjunction with their engineering consultants determined that underground cables should be considered for the following sections:

Stations	Underground Length
Scovill Rock to Chestnut	*
Oxbow to Beseck	*
Black Pond to Beseck	*
Beseck to East Devon	*
East Devon to Singer	8.1 miles
Singer to Norwalk	15.5 miles
Total	**23.6 miles**

* Underground cable is not being considered for this length

2.2 General Route Description

CL&P, UI, Burns & McDonnell, and PDC teamed to evaluate potential underground routes and identify those that were most suitable for the potential cable systems. Details of the proposed route and several alternatives are described in Volume 1, Section I, of the Connecticut Siting Council application.

2.3 Route Characteristics

Two general types of installation conditions would be encountered along the route segments:

2.3.1 Rural and Right-of-Way Areas

No pavement removal or restoration would generally be required except for street crossings. However, the terrain may be rough, and an access road would have to be built along the length of the cable trench to allow access for trenching equipment, pipe or duct transport and installation equipment, concrete backfill, cable reels, etc.

2.3.2 Suburban and City Streets

In suburban streets, pavement breaking / restoration would be required, and other underground utilities would have to be avoided, or relocated. One full traffic lane would be required for excavating the trench; and a travel lane would be needed occasionally for truck traffic to remove spoils, bring pipe or duct, concrete, etc. Traffic control would be required, depending upon the road.

City street installations would be similar, except that significantly more traffic would be encountered and traffic control plans and procedures would be more elaborate, accommodations would be necessary to maintain access to businesses, it would take significant time to cross intersections so as not to impede traffic flow, and because of the number of utilities, etc.

Night construction would have to be considered to reduce construction impact on traffic and businesses.

2.4 Special Considerations

Several highway crossings would be required, sometimes at entrance/exit ramps. Steps would be taken to maintain traffic flow, and nighttime construction would most likely be necessary in these areas.

At least three major horizontal directional drills would be required, for a crossing of the Housatonic River in Milford/Stratford, the Pequonnock River in Bridgeport, and the Saugatuck River in Westport. In addition, several other directional drills would be required under smaller watercourses, and two separate jack-and-bore crossings would be required under the Norwalk River. Section 4.1 provides comments on the potential directional drills and jack-and-bore installations.

3.0 Cable Types for 345-kV Operation

Four types of power transmission cable have been used commercially for applications at 345-kV and higher voltages. They are summarized briefly as follows:

3.1 High-pressure Fluid-filled (HPFF) Pipe-type Cables

High-pressure fluid-filled pipe-type cable, pressurized with a dielectric fluid, is the most common type of EHV transmission cable used in the United States and has been the only type of cable applied for land installations of long lines above 230 kV in this country. A vast majority of the underground 345-kV lines are of the HPFF type. Its use at all transmission voltages has declined because utilities have experienced leaks on HPFF cables, and because the XLPE cable provides a simpler and much more environmentally-friendly system. Almost all leaks have been due to corrosion pinholes, and a few have been caused by dig-in. However, a well designed, installed, and maintained HPFF cable system should operate essentially leak-free throughout its expected life. HPFF cables are described in more detail in Section 4.2.

Note that the pressurizing medium can be nitrogen, to give a high-pressure gas-filled (HPGF) cable. However, the electrical strength is substantially lower than with a dielectric fluid-pressurized system, and the HPGF cable is only used up to 138 kV.

3.2 Extruded-dielectric (XLPE) Cables

Extruded dielectric cable, with cross-linked polyethylene (XLPE) insulation, is the most common type of cable used for new installations up to 138 kV in the U.S. and it has recently been used successfully up to 500 kV for lines as long as 20 miles in other areas of the world. There are several short installations at 345 kV in the United States (lengths less than a thousand feet, with no splices) and a total of approximately 40 miles of 230-kV XLPE transmission cables in this country. Although XLPE cables are considered acceptable for 345-kV operation and have an excellent, but limited, operating history overseas, the potential installation would be the first long length 345-kV extruded-dielectric cable in this country. XLPE cables are described in more detail in Section 4.2.

3.3 Self-contained Fluid-filled (SCFF) Cables

Self-contained fluid-filled (SCFF) cable has individual conductors with taped insulation within a lead or aluminum sheath, pressurized with dielectric fluid via a hollow core in the conductor. It has a long, acceptable operating history both in this country and overseas. It has historically been applied for long submarine cable crossings where long manufacturing lengths are desirable to avoid field splices. No EHV SCFF land cable (other than replacement sections) has been installed in the United States in several decades. It is being superseded with extruded-dielectric (XLPE) cable worldwide except for long submarine applications and a few specialized applications. We did not evaluate SCFF land cables for any underground segment of the preferred route for the potential Middletown-Norwalk Project.

3.4 Gas-insulated Lines (GIL)

Gas-insulated lines, which have tubular aluminum conductors held centered in tubular aluminum enclosures, insulated with a gaseous mixture of nitrogen and SF_6, have been in service at 345-kV and higher in the United States since the early 1970’s. Although they can have a very high power transfer – 2000 MW or greater – they are not considered suitable for buried applications of any appreciable length, and they are appreciably more costly than the other types of underground transmission lines. We therefore did not evaluate them further.

3.5 High-pressure Fluid-filled and XLPE Cables Evaluation

Based upon experience in this country and overseas, and suitability for the potential application, we selected HPFF and XLPE cables for further analysis.

For both cable types, we developed a conceptual cable design for the assumed installation conditions, determined the cable sizes required, and evaluated design, installation, and operation approaches for the cable systems.

4.0 Cable System Requirements for 345-kV System

4.1 Assumed Installation Conditions

We calculated cable requirements for the following assumed conditions:

Table 1
Assumed Cable and Installation Conditions

Parameter	Value
Voltage	345 kV
Daily Load Factor	0.75 per unit
Conductor type, size	2500 kcmil segmental copper conductor for HPFF, 3000 kcmil segmental copper conductor for XLPE [1]
Insulation thickness	0.60 inches laminated paper-polypropylene for HPFF; 1.1 inches XLPE for the extruded-dielectric system
Sheath for XLPE cable	0.170 inches lead
Jacket for XLPE cable	0.160 inches low density polyethylene
Sheath bonding for XLPE cable	Cross bonding (See Section 4.3.2)
Pipe or duct size	8.625-in OD steel pipe for HPFF 6.625-in OD PVC duct for XLPE
Trench cross-section	See Figures 1, 2
Native soil thermal resistivity	90 C°-cm/watt
HPFF backfill; XLPE concrete thermal resistivity	55 C°-cm/watt
Ambient earth temperature, summertime	25°C

If a cable alternative proceeds to detailed design, the Companies should have a soil thermal survey conducted for the preferred route. Soil thermal resistivity measurements should be performed every few thousand feet, and ambient earth temperature should be measured at a number of locations along the potential cable route. Data from these measurements would permit a more accurate calculation of the required conductor size for each cable type.

Figures 1 and 2 on the following page show the trench configurations that would be used for the two cable types.

[1] 2500 kcmil is the largest conductor size commonly used for 345-kV HPFF cables. A larger conductor size does not produce much of an ampacity increase because of magnetic effects from the steel pipe, and a larger conductor might require a larger cable pipe. XLPE cable does not have these constraints, and is produced in very large conductor sizes (5000 kcmil) overseas.

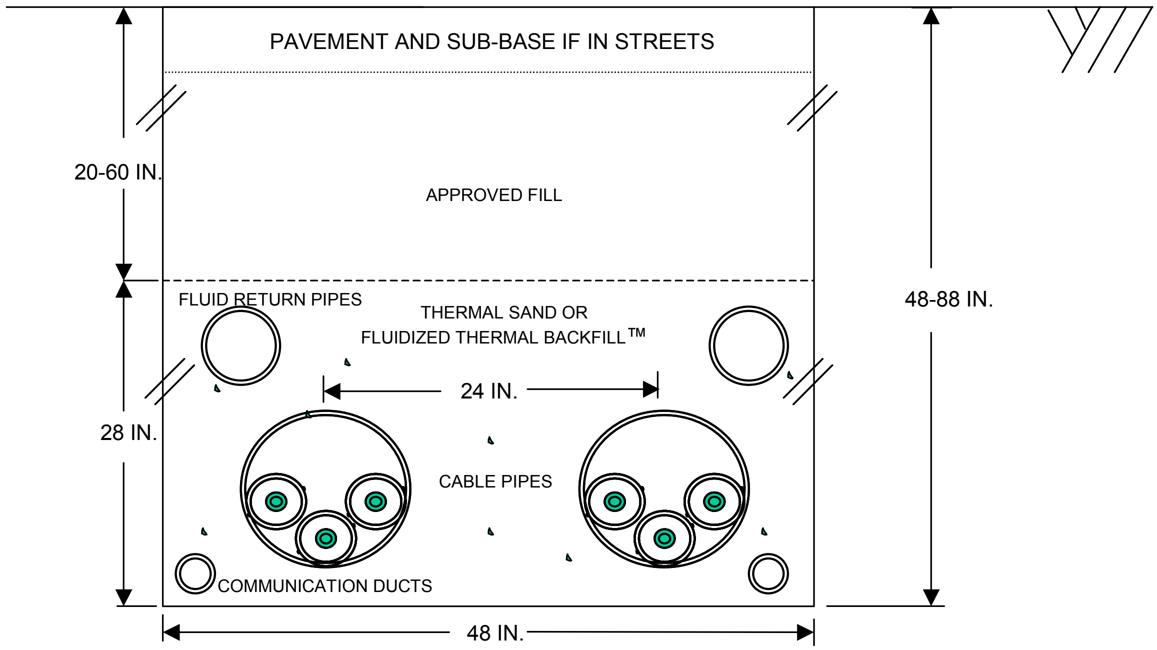


Figure 1. Assumed trench cross-section, two HPFF lines (one circuit) with fluid return pipes and communication ducts

The HPFF design shows two smaller pipes above the cable pipes. These nominal 5-inch diameter pipes are placed in the trench for possible use as fluid return pipes if there is ever a need to circulate the dielectric fluid in the lines. Circulation is commonly employed to reduce the effects of hot spots along the route (e.g. areas where the cable pipes must be installed close to distribution duct lines), or to increase the rating of the lines if needed in the future. Communications ducts are also placed in the trench, for relaying and other communications.

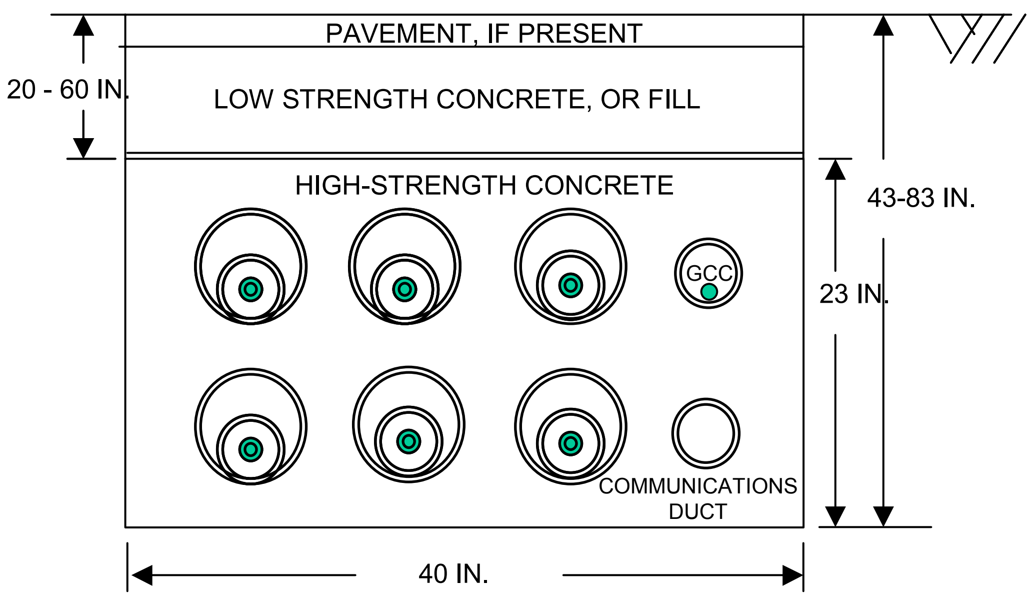


Figure 2. Assumed trench cross section, two XLPE lines (one circuit) with a communications duct and ground continuity conductor (GCC)

The Companies would design the trench to a minimum 20-inch depth from surface to top of backfill for the HPFF line, or concrete duct encasement for the XLPE line. However, there would be areas where depth must be greater in order to dip under existing utilities – water lines, sewers, gas lines, etc. Since the hottest section limits the overall cable loading, our cable sizing calculations were based upon a 60-inch depth to the top of the ductbank. Detailed engineering design, and actual construction, may show areas where the cable must be installed even deeper, perhaps via directional drilling. In trenched areas, the contractor would probably be required to place additional high-quality thermal backfill in the trench to maintain cable rating at the desired values.

For the horizontal directional drills that would be required under the Housatonic, Pequonnock, and Saugatuck Rivers (and elsewhere) one 8-in. cable pipe and its companion 5-in. fluid return pipe would be installed in a bore approximately 22 inches in diameter. An outer casing pipe might be required if the soil conditions were not favorable. The bore would need to be approximately 28 inches diameter to accommodate an 18-inch casing pipe. In either case, two bores would be installed, separated by approximately twenty feet. Depth below the water bottom would typically be 20 – 30 feet.

If XLPE cables were installed in these sections, each line would have four 6-inch ducts (one would be a spare), plus communications ducts, installed in a 30-32-inch diameter bore. If a casing pipe were needed, the bore would need to be 40 – 42 inches in diameter to accommodate a 28-inch casing pipe. In either case, two bores would be installed, separated by approximately twenty feet. Depth below the water bottom would typically be 20 - 30 feet.

A jack-and-bore may be required at other locations, such as two crossings of the Norwalk River. The diameter would be larger – typically 42-48 inches, and the casing material would be steel or concrete. There would still be two bores to minimize mutual heating between the two lines, although the bore separation could be as little as 10 feet.

4.2 Cable Size, Electrical Parameters

4.2.1 HPFF Cables

For the HPFF cables, we calculated that two lines, each with 2500-kcmil copper conductors, would have a 1058-ampere steady-state rating per conductor, or a total capability of 1265 MVA for the two lines. The cables would be supplied in accordance with the Association of Edison Illuminating Companies (AEIC) Specification CS-2 “Specification for Impregnated Paper and Laminated Paper Polypropylene Insulated Cable, High-Pressure Pipe-type.” That specification states a maximum steady-state cable operating temperature of 85^{o}C. The cables would be insulated with 0.600 inches of helically-wound tapes of laminated paper-polypropylene insulation, factory-impregnated with a high viscosity dielectric fluid.

Cable system parameters are summarized in Table 2.

Table 2
Cable System Parameters for 345 kV HPFF System
(1058 Amperes per Cable)*

Item	Description
Conductor	2500 kcmil compact segmental copper
Insulation	0.600 inches laminated paper-polypropylene
OD	3.24 inches, approximately
Weight	11.2 lb/ft, approximately
Dielectric loss	15.9 kW/mile, 3-phase, per line
Charging current	34.6 amperes/mile, per phase
MVAR	20.7 MVAR/mile, 3-phase, per line

*Calculations are based upon two cables in a common trench.

These values are based upon standard industry cable constructions and insulation characteristics.

Figure 3 shows a cross-section view of a 345-kV HPFF cable. This photo is provided courtesy of the Okonite Company, the U.S. supplier of HPFF cable.

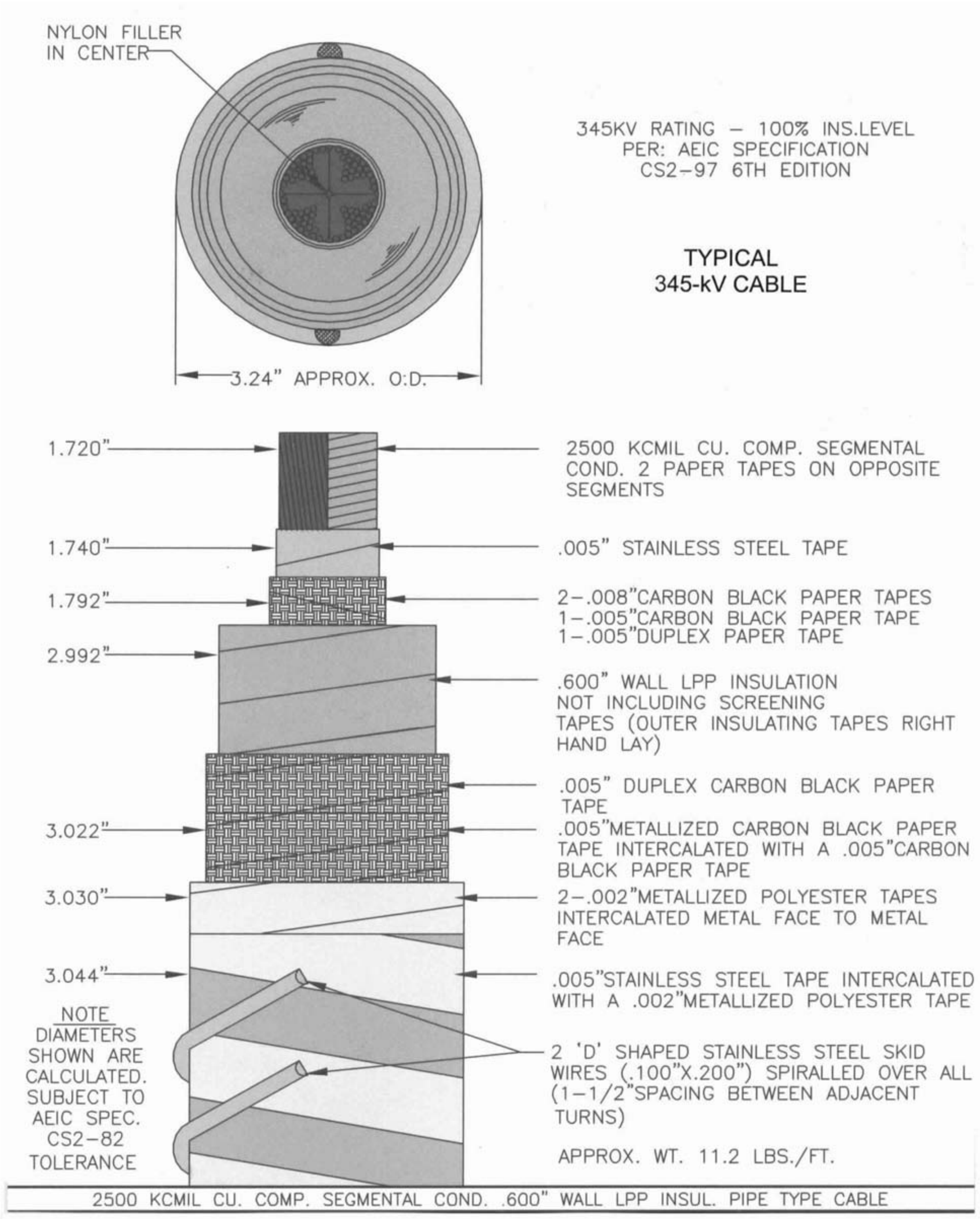


Figure 3. Cross-section view of HPFF cable

4.2.2 XLPE Cables

For the XLPE cables, we calculated that two lines with 3000-kcmil copper-conductor cables would provide a 1380-ampere steady-state rating (1650 MVA for the two lines), at the 90°C conductor temperature that AEIC allows in the specification for XLPE cables up to 138 kV. (There is currently no AEIC specification for higher-voltage XLPE cables, but the 90°C is also generally applied for 345-kV cables). Data on the cable system are summarized in Table 3.

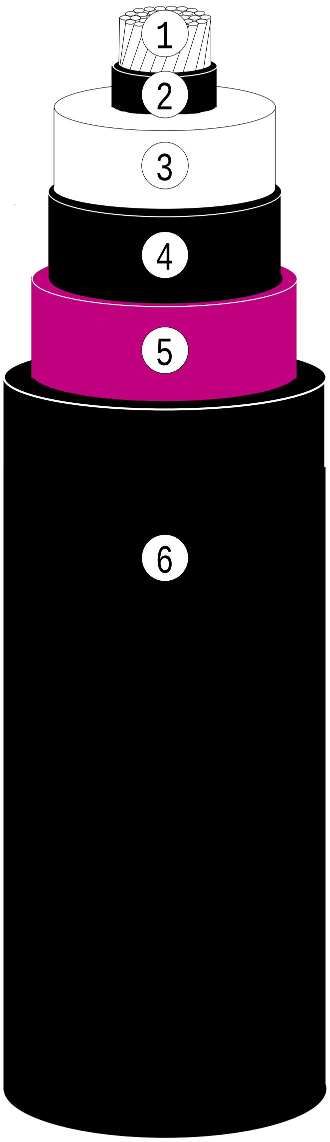
Table 3
Cable System Parameters for 345 kV, XLPE System
(1380 Amperes per Cable)*

Item	Description
Conductor	3000 kcmil compact segmental copper
Insulation	1.1 inches XLPE
Sheath	0.17 inches lead
Jacket	0.16 inches polyethylene
OD	5 inches, approximately
Weight	24 lb/ft, approximately
Dielectric loss	1.32 kW/mile 3-phase, per line
Charging current	20.8 amperes/mile, per phase
MVAR	12.4 MVAR/mile, 3-phase, per line

*Calculations are based upon two cables in a common trench.

These values are based upon standard industry cable constructions, extended for 345-kV cable designs, and standard XLPE insulation characteristics

Figure 4 provides a cutaway drawing of the 345-kV XLPE cable that was installed by an independent power producer in the Boston area in 2001 and is being shown here for illustration purposes only. The conductor size is less than half the size of the one that is required for the Middletown-Norwalk Project. The cable for the Middletown-Norwalk Project would therefore be of a larger overall diameter and appreciably heavier.



1 - CONDUCTOR
Cross-section : 630 mm² (Approx. 1250 kcmil)
Material : copper
Indicative diameter : 1.21 in

2 - INNER SEMI-CONDUCTIVE LAYER
Indicative thickness : 67 mils
Minimum average thickness : 53 mils

3 - INSULATION
Material : cross-linked polyethylene
Minimum average thickness : 1063 mils

4 - OUTER SEMI-CONDUCTIVE LAYER
Indicative thickness : 63 mils
Minimum average thickness : 8mils

5 - LEAD SHEATH
Minimum average thickness : 169 mils

6 - OUTER SHEATH AND EXTRUDED SEMICONDUCTING LAYER
Material : low density polyethylene
Minimum average thickness : 157 mils

INDICATIVE EXTERNAL DIAMETER : 4.35 in

INDICATIVE WEIGHT : 19 lbs/ft

MINIMUM BENDING RADIUS
- below termination : 65 in
- in cable route : 87 in

MAXIMUM PULLING TENSION : 11300 lbs

MAXIMUM SIDEWALL PRESSURE : 2000 lbs/ft

Figure 4. Typical 345-kV XLPE cable (Figure courtesy of Sagem, Inc.)

4.3 Cable Design Considerations

4.3.1 HPFF Cables

More than 300 circuit miles of 345-kV HPFF cables have been installed in this country since 1964. There is one U.S. manufacturer (plus others overseas) and there are three qualified U.S. installers. In the 1970's, 345-kV HPFF cable installations had a series of failures, due to flexure in the joint casings. That problem occurred several years following installation and was corrected on existing joints. Since then, design changes were made on joints for new cable installations. Following modification of the joint design, there have been virtually no TMB failures in the joint, and only occasional electrical failures due to mis-operation (e.g. loss of fluid pressure), external damage, or other causes. The fluid leaks mentioned earlier have also resulted in circuit outages, but many utilities have had good leak-free performance for many decades.

Cable

The insulation material used almost exclusively since 1985 has consisted of helically-wrapped layers of laminated paper-polypropylene (a layer of polypropylene plastic is laminated between two layers of Kraft paper) to provide superior electrical strength and lower electrical losses compared to the all-Kraft insulation used until 1985. The cable design is well established, and is identified in the AEIC specification referenced earlier.

A brief summary of cable design is given in Table 4:

Table 4
Cable and Pipe for 345-kV HPFF System

Component	Brief Description
Conductor	2500 kcmil (approximately 1.72-in. diameter) compact segmental copper
Insulation	0.600-inches laminated paper-polypropylene
Pipe	8.625-in OD steel pipe with an extruded polyethylene corrosion coating. 5.615-in OD steel fluid return pipe, same coating
Dielectric fluid	Polybutene synthetic liquid

Splices

The cable is supplied on reels, with an average length of approximately 2400 feet. Up to 3500 – 4000 feet can be provided and shipped over the road if there are no overhead obstructions, and can be installed if there are no major dips or bends in the route. Three cables (each being a phase of the circuit) from three separate reels are bundled together and pulled into the pipe from splicing vault to splicing vault. Splices are used to join adjacent cable sections. A schematic diagram of a splice assembly is shown in Figure 5. The splices for the two lines can be placed in a common concrete splicing vault, which would have inside dimensions approximately 18 feet long, 8 feet wide, and 8 feet high.

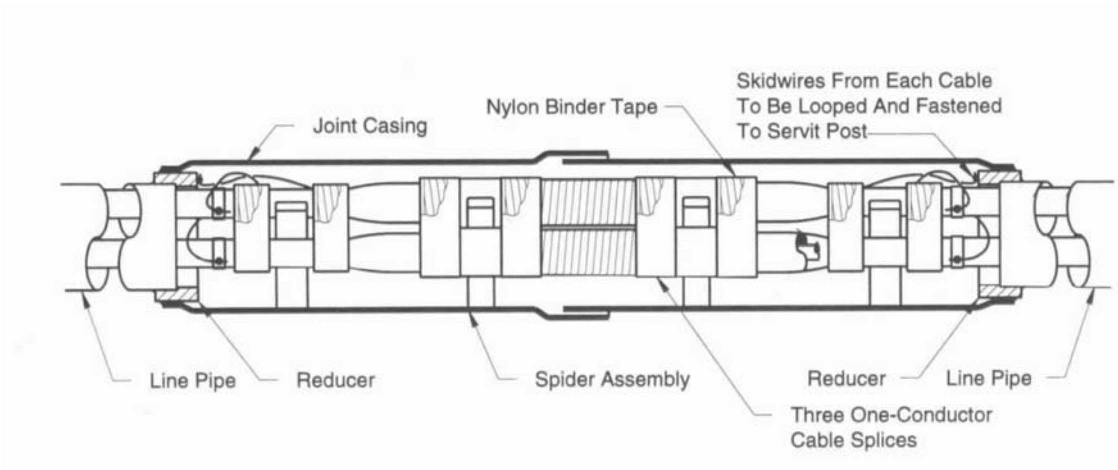


Figure 5. HPFF splice

Most splices are "normal joints" which have the function of joining adjacent cable sections.

Two other splice types are commonly used:

- Trifurcating joints take the three cables from a common 8.625-inch steel pipe, and transition each cable into an individual 5-inch stainless steel pipe. The individual cables are then led to the terminations , which are typically spaced 15-20 feet apart and located within the fenced-in area of a switching station, substation, or transition station.

- Stop joints, which can isolate the dielectric fluid into discrete sections (via bypass valves across the joint, which can be closed when required) accommodate severe elevation change, and the valves can be closed when the utility is performing maintenance or repairs on the de-energized cable system.

Two other joints may be used, "anchor joints" and "skid joints" which are used along with a special stainless steel armoring on the cable, to accommodate very steep slopes such as tunnel shafts to prevent cable stretching over time.

Terminations

Terminations, also called "potheads," make the transition from pressurized fluid in the pipe, to open-air bus or gas-insulated bus in substations. Figure 6 shows a typical termination.

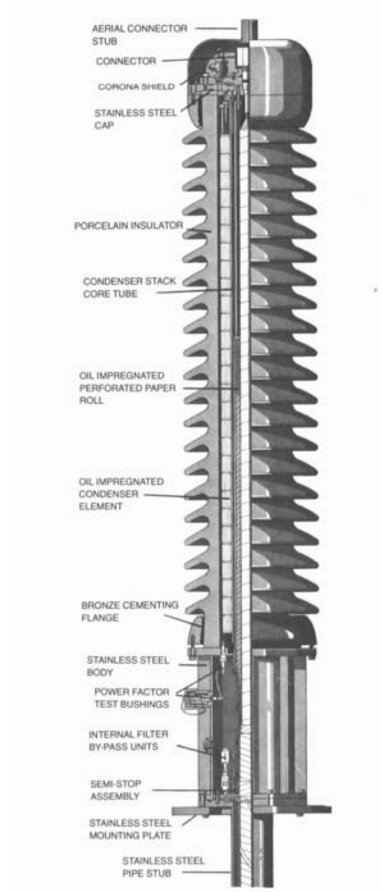


Figure 6. 345-kV HPFF termination

Dielectric Fluid

The wrapped paper tape insulation must be pressurized with dielectric fluid to a minimum 200 psi to have adequate electrical strength for trouble-free operation. The dielectric fluid would be polybutene, a synthetic liquid distilled from gases in the petroleum refining process. Polybutene is non-toxic and non-hazardous, and it biodegrades, although slowly.

Approximately 1.6 gallons of dielectric fluid would be required per foot of cable pipe. In total, the system will require 16,900 gallons per mile for the two lines making up the circuit. The fluid return pipe would contain another one gallon per foot, or 10,600 gallons per mile for the two return lines. Note that these return lines do not have to be filled with fluid until a future date when fluid circulation is implemented.

Pressurizing Pump Plants

The volume of dielectric fluid changes as the cable system expands and contracts with load changes and seasonally with ambient earth temperature changes. A pressurizing plant must be installed to maintain proper pressure while accommodating these volume changes. The plant consists of pumps, controls, alarms, monitoring equipment, and a storage tank for the dielectric fluid.

The cable must be de-energized to avoid electrical failure if fluid pressure is lost. Most utilities install a plant at each end of the cable, to assure safe operation even if one plant is completely out of service – e.g. from loss of power to the plant. In major metropolitan areas with many HPFF cable circuits, the utility may have interconnected hydraulic systems among their HPFF lines, thereby reducing the total number of plants needed. Figure 7 shows a pressurizing plant in the factory, before it is placed in the enclosure that would be located within the switching station, substation, or transition station.

Generally, a pair of 10-mile cable pipes would require a total tank volume of about 20,000 gallons. This includes 2,000 gallons reserve, 12,000 gallons for expansion and contraction, and a volume equal to 7,000 gallons above the fluid to allow a nitrogen pressure to rise and fall with fluid volume changes. The utility would probably have one reservoir tank at each end, each with a 10,000-gallon capacity. For the proposed East Devon-Singer and Singer-Norwalk cable installations, we anticipate that 18,000 – 24,000 gallon reservoir tanks would be placed in each station. Appendix A provides further details of hydraulic system design for HPFF cables.

Figure 7. Fluid pressurizing plant

Corrosion Control and Cathodic Protection

The cable pipes have a tough, durable corrosion coating consisting of a layer of mastic followed by a thick layer of extruded polyethylene. This coating has an excellent operating history, and is superior to coatings installed on early HPFF cable systems.

HPFF cables also have an impressed-current cathodic protection system to reduce the chance of pipe corrosion in case the protective corrosion coating on the outside of the pipe is damaged. This typically includes a rectifier to provide the DC cathodic protection voltage. Since the pipe is isolated from ground, a device is installed to block the DC cathodic protection voltage, yet allow a path to ground for the AC fault currents. Two types of device can be used: a polarization cell – which resembles a large automobile battery – or its solid-state equivalent.

Leak Detection, Location, Repair

Although many HPFF cable systems have operated satisfactorily for decades with no leaks, it is possible for a leak to occur due to corrosion (which is by far the most common cause of leaks), a dig-in, or an electrical fault (very uncommon). There has been significant industry research into leak detection, location, and repair. Pressurizing plants have several levels of leak detection and monitoring, and special wires have been developed that can be placed in the trench to provide an alarm if they detect a product such as dielectric fluid.

Temperature Monitoring

Distributed temperature monitoring along the length of the line permits the most efficient utilization of the cable system. It is commonly added to XLPE cables (see Section 4.3.2); however, it is difficult to install inside the pipes of HPFF cable systems. The common practice of slowly circulating the dielectric fluid in HPFF cables reduces the effect of localized “hot spots” and therefore reduces the need for distributed temperature monitoring. Some utilities strap the fiber-optic cable to the outside of the steel cable pipe. This gives an indication of the temperature of the cables within the pipe, but it does not indicate transient temperature changes as quickly or accurately as a fiber would, if installed within the pipe. If HPFF cable were chosen, the Companies would need to evaluate the need and benefit for distributed temperature monitoring as well as circulating the dielectric fluid.

4.3.2 XLPE Cables

As of late 2003, there is less than a mile of 345-kV XLPE cable in service in the United States; it consists of several short lines without splices. There are more than one hundred miles of 300+ kV XLPE cables in service world-wide, at voltages up to 500 kV. The service experience of XLPE-insulated cable at this voltage is less than five years whereas HPFF cable has a long history of acceptable service experience. There are no U.S. suppliers of XLPE cables at this voltage, but more than a half-dozen qualified overseas suppliers are available. Several U.S. firms are capable of installing the cable although the splicing and terminating are best performed by personnel from the cable supplier.

Cable

The insulation material is cross-linked polyethylene, extruded around the conductor to a thickness of about an inch. An AEIC Specification for this type cable describes cables up to 138 kV. An extension to 345 kV is underway. Several overseas standards are available for voltages up to 500 kV.

A metallic sheath is mandatory to keep moisture out of the insulation . Lead has the longest, best service history, but it is heavy, and there might be concerns about environmental problems if the cable is ever scrapped. Corrugated aluminum and copper sheaths can be considered, but they significantly increase the cable diameter, reducing lengths that can be shipped and installed, and possibly requiring the Companies to use a larger duct size. Some manufacturers can provide a thin foil wrap of aluminum or copper, and add copper neutral wires to accept the cable fault current. This design is not a true hermetic seal, but the moisture penetration rate is extremely slow – the manufacturers believe there will be no detrimental effect for more than 40 – 50 years.

A brief summary of the assumed cable design is given in Table 5:

Table 5
Cable and Duct for 345-kV XLPE System

Component	Brief Description
Conductor	3000 kcmil (approximately 1.91-in. diameter) or corresponding metric size of 1600 mm^2 (about 3160 kcmil, approximately 2-in. diameter). Compact segmental copper.
Insulation	Approximately 1.1 inches cross-linked polyethylene (Actual value would be optimized by the manufacturer and the Companies)
Sheath	0.17 inches extruded lead
Jacket	0.16 inches polyethylene
Duct	6.625-in OD, 0.280 wall thickness PVC

Splices

The XLPE cable is larger in diameter and heavier than its HPFF equivalent. Cable pulling lengths between splicing vaults are therefore shorter, approximately 1800 feet versus approximately 2400 feet. The XLPE cable system differs from the HPFF installations in that the individual phases are pulled into individual ducts, versus HPFF cables where the three cables are bundled and pulled into the steel pipe together.

The cable splicing would be performed in large concrete splicing vaults, with inside dimensions approximately 28 feet long, 8 feet wide, and 8 feet high. The three splices would be mounted on rack arms along one wall of the splicing vault. Each set of three phase conductors would have its own splicing vault. Repair personnel would therefore avoid safety concerns about having an energized cable in the same location as the de-energized circuit they are working on, for the period of time it would take to make repairs. Note that most utilities do permit personnel to make visual inspections in splicing vaults while the cables are energized.

For any transmission-voltage XLPE cable application, it is mandatory that the splices are furnished by the cable supplier, and that the cable/splice combination is laboratory-tested as a unit. Today virtually all transmission-voltage splices are premolded, and each splice is factory tested. To ensure satisfactory installation, a cable manufacturer's representative should conduct all splicing operations.

Figure 8 shows a premolded splice for an EHV XLPE cable.

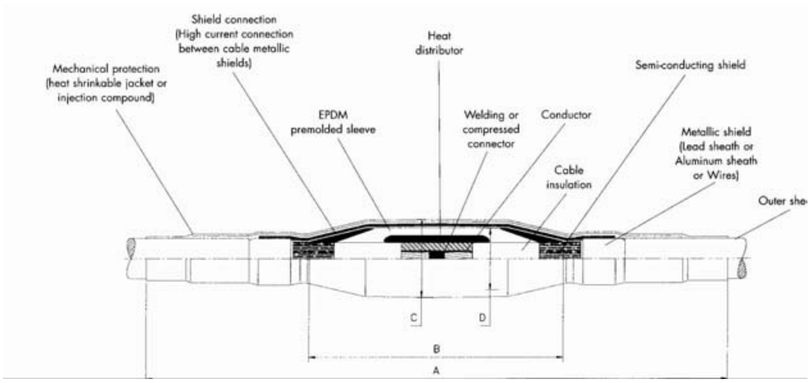


Figure 8. Premolded splice for EHV XLPE cable

Since the XLPE cables are inherently single-phase designs, the trifurcating joint (used in HPFF cables) is not required. Since there is no dielectric fluid present, stop joints are not required. Large slopes are handled by installing clamps around the cable at intervals to help support the cable. This may be done in small handholes in the ductbank.

Terminations

Cable terminations resemble those for the HPFF cables, and they can be supplied in either open-air or gas-insulated substation designs. The terminations have SF_6 gas or silicone dielectric fluid in them to improve electrical strength. Figure 9 shows an open-air termination.

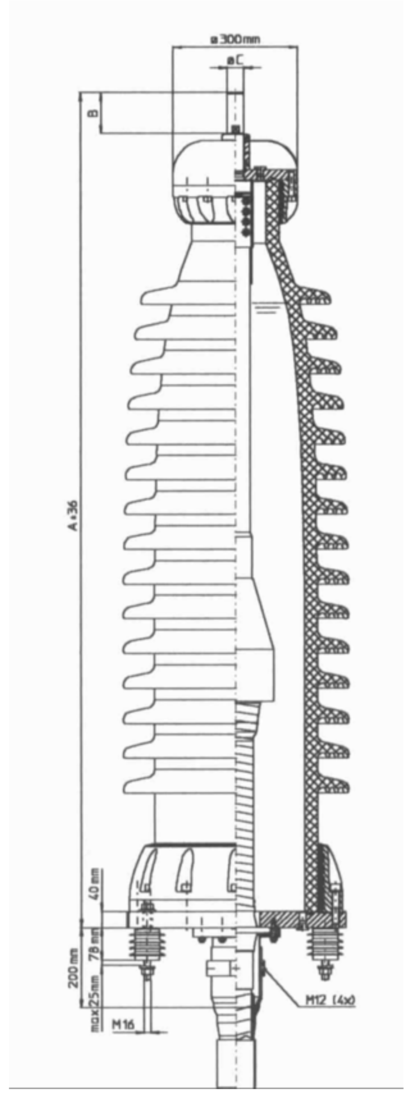


Figure 9. XLPE cable termination

Link Boxes, Sheath Voltage Limiters

As described in the following sections, methods for bonding the cable sheaths together and grounding them form one of the most challenging parts of XLPE cable system design. The sheaths are connected via special high-current links in waterproof, stainless steel enclosures called “link boxes.” Many of these link boxes also contain sheath voltage limiters (SVLs) that limit the voltage that appears on the sheath during possible lightning strokes and other transient conditions. A link box is generally required at every splicing vault location. Figure 10 shows a link box.

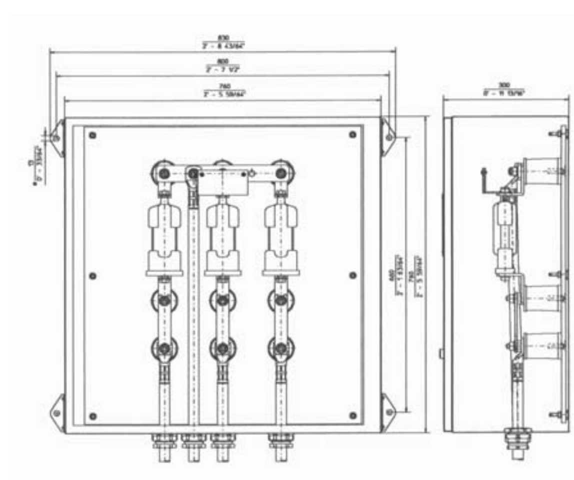


Figure 10. Link box for XLPE cable

Sheath Bonding for XLPE Cables

For single-conductor XLPE cables, the current in the conductor induces a current in the cable's metallic sheath. Depending upon cable positions and sheath material and construction, the sheath current can reach 60 percent or more of the conductor current. These sheath currents generate ohmic losses just as conductor currents would. If these currents are interrupted, the sheath losses are greatly reduced and conductor ampacities improve. However, voltages would be induced in the sheath at values of approximately 50 volts per 1000 amperes per 1000 feet. Although there are no published standards, many utilities limit steady-state sheath voltages to 150 volts or lower. Values up to 500 volts are permitted by some utilities.

Utilities have several methods to deal with sheath currents and voltages, for bonding the sheaths together and for connecting the sheaths to ground. Cross-bonding is by far the most common approach for reducing sheath losses on long XLPE cable systems. The cable sheaths are electrically transposed at splices, typically at intervals of about 1500-2000 feet. Although currents are greatly reduced, voltages are induced in the sheath as described above, so the distance between insulating splices can be limited by allowable sheath voltages.

Each splice has an insulator in its sheath to permit cross-connecting the cable sheaths as shown in Figure 11. Since there is an end-to-end path for fault current, a separate ground continuity conductor is not mandatory – although most utilities provide one as a way to insure a good current path for relaying and fault current flow, and to connect splicing vault hardware to ground.

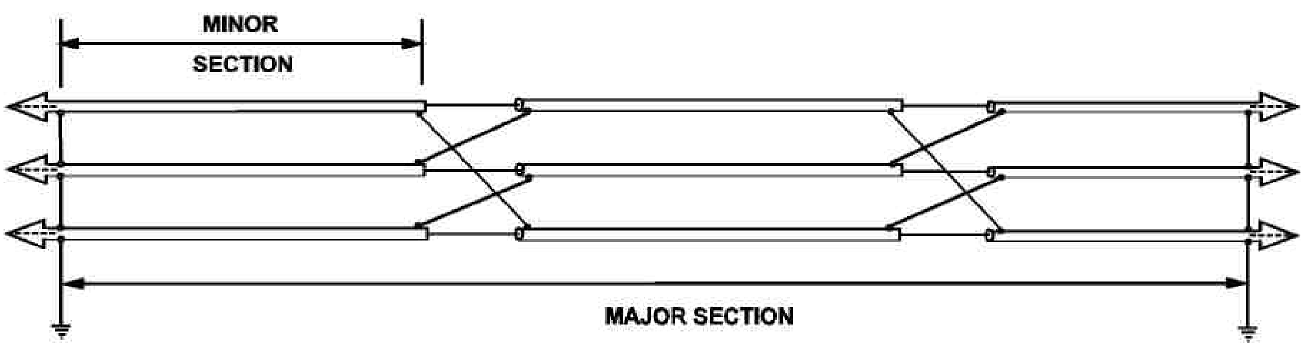


Figure 11. Sheath cross bonding

For example, at a conductor current of 500 amperes per phase (1000 amperes for the two-line system), the induced steady-state sheath voltage for a 2000-ft splicing vault-to-splicing vault section would be about 50 volts. This voltage would be contained within the thick polyethylene jacket that is capable of withstanding transient voltages of more than 10,000 volts. The only places that the sheath voltages can be accessed are in splicing vaults or on termination structures – both are areas where only trained utility personnel are permitted to work. We assumed that a 350-kcmil ground continuity conductor would be installed end-to-end on the line.

Temperature Monitoring

Monitoring cable system temperature is important to insure that cables are not overheated. Changes in earth thermal properties can be significant – e.g. due to soil dryout during long dry periods when cable loadings are high. An increase in soil thermal resistance will cause an increase in cable temperature. Conversely, in many cases monitoring can demonstrate that cables are operating cooler than designed and they can carry additional current because conservative assumptions were made during cable system design. This information will be useful for the Companies to protect their investment – i.e. cable failure due to higher than anticipated temperatures at design loading, as well as if the Companies ever need to increase circuit rating. XLPE cables do not have the thermal mass of HPFF cables, and there is no dielectric fluid to circulate. Hot spots are more likely, therefore temperature monitoring of XLPE cables is more critical than for HPFF cables.

Installing a pair of multimode optical fibers in the cable outer shielding, or even as a separate fiber-optic cable in the ductbank, is becoming common as utilities and optimize cable ampacity capabilities. The optical fiber adds a few dollars a foot to the cable price, but monitoring with a special optical time domain reflectometer (OTDR – optical radar) can provide a temperature profile for the entire length of the cable. Temperature resolution for the monitoring system is one Centigrade degree, and spatial (distance) resolution is one meter.

Most new XLPE projects include a fiber-optic temperature monitoring system.

Other Accessories

Since the XLPE cable system has no dielectric fluid, no pressurizing plant is needed. Cathodic protection is not generally required since the lead sheath is essentially inert, and it is isolated from ground by the thick cable jacket and the thick polyethylene duct. The terminations generally require a monitoring system for the dielectric fluid or SF_6. The monitoring system would be connected to the utility's data acquisition system.

4.4 Reactive Power Requirements

Insulated cables – both HPFF and XLPE – are essentially long capacitors, with the conductor as one electrode and the grounded shield/sheath as the other electrode. They therefore have significant charging currents as the capacitor is charged and discharged at line frequency. The charging current is the source of the reactive VARs discussed below. (VARs equal charging current per conductor, times three conductors, times the line-to-ground voltage, which is 200 kV for a 345-kV line-to-line system.)

For example, 100 amperes per conductor charging current equals

(100A x 3 phases x 200,000V) = 60,000,000 VAR or 60 megaVAR (MVAR)

There are three important considerations for this charging current:

a) <u>System considerations</u>, absorbing the MVARs. Depending upon line length and system electrical parameters at each end of the line, shunt reactors may be required to absorb the MVARs generated by the cable. Load flow and transient studies are needed to determine the required size and location of reactors.

b) <u>Cable rating</u>. Charging currents generate ohmic losses, the same way that real currents do. Charging current is cumulative over each foot of cable. A 345-kV 2500 kcmil HPFF cable has a charging current of about 34.6 amperes per mile, and a 345-kV XLPE cable has a charging current of about 20.8 amperes per mile.

For a ten-mile line at unity power factor, with all the charging current flowing out of one end, a HPFF line would have 34.6 amperes in the first mile, 69.2 amperes in the second mile, and 346 amperes in the tenth mile. An XLPE cable would have 20.8 amperes in the first mile, 41.6 amperes in the second mile, and 208 amperes in the tenth mile. The effect of charging current as a function of length is shown in Table 6.

Table 6
Effect of Charging Current on HPFF and XLPE Cable Systems
HPFF Rating is 1058 A (633 MVA) Each Line
XLPE Rating is 1380 A (825 MVA) Each Line

Line Length, Miles	**Total Charging Current per phase**		**Total MVAR Per Line**		**Allowable Flow-through Per Line, MW At Unity Power Factor**	
	HPFF	XLPE	HPFF	XLPE	HPFF	XLPE
1	34.6	20.8	20.7	12.4	633	825
10	346	208	207	124	598	816
20	692	416	414	248	479	787

Note that charging MVAR are in quadrature with the MW. That is,

$$MVA = \sqrt{\left(MW^2 + MVAR^2\right)}$$

c) Cost of Losses. Charging currents operate at a 100% load factor (they are present any time the line is energized), so the present worth of the cost of their losses can be significant on a long line.

5.0 Installation, Maintenance and Repair

5.1 HPFF Cable Systems

There is one U.S. manufacturer for 345-kV HPFF cable, and there are others overseas. Three U.S. installation contractors have the specialized equipment and trained personnel to install this cable type. General comments on cable installation, maintenance, and repair are given below

5.1.1 Installation

Civil work (pavement removal and restoration, trenching, etc.) is similar to that for other buried utility systems. The 8.625-inch diameter cable pipe would be brought to the site in 40-50 ft lengths and then welded together using special backing rings to insure a smooth profile inside the pipe. The welds would be tested, and corrosion coating restored to the weld area. The trench would be backfilled with a special material with good mechanical stability and excellent thermal properties. A fluidized thermal backfill, FTB™ that resembles a weak mix concrete, is commonly used. A few hundred feet of pipe could be installed per day, depending upon traffic congestion, number of existing utilities, etc. Generally, the street opening times are shorter for HPFF cable pipe installation than for XLPE ductbank installation.

Splicing vaults (typically precast) would be sited approximately at 2400 feet intervals, depending upon the number of dips and bends in the route. Once pipe is installed between splicing vaults, cleaned, and tested (including a 500-psi pressure test to assure integrity), cable would be installed into the pipe by gathering the three cable phases together, and pulling them simultaneously into the pipe using a heavy wire rope and a winch. Long protective end caps would then be placed on the two pipe ends, the pipe section evacuated and then pressurized with 5 – 10 psi dry nitrogen. Splicing can then take place at a later time. When splicing is to begin, a special trailer would be placed over the splicing vault openings. The trailer contains air conditioning equipment to provide low humidity during the splicing operation, ensures cleanliness, and serves as a safe area for personnel, materials, and equipment since the splicing vault is generally under a street. Splicing the three phases, sliding steel sleeves over the splice assembly, welding the sleeves and testing them, would take about 7 days.

At the terminal ends, enclosures would be placed over the cables, cable ends prepared, and the porcelain terminations lowered into place and bolted to special flanges.

During the time of cable installation, splicing, and terminating, the utility or its contractor would install pressurizing plants and other accessories, as well as controls, relays, and alarms, etc.

After all cable is installed end-to-end and terminations are in place, the line would be evacuated, and filled with a high-quality dielectric fluid. The line would be pressurized slowly, and held at about 200 psi. The cables may then be tested with DC voltage, and placed into service.

A typical construction rate in congested city streets would be somewhat greater than a mile a month to trench, install pipe and vaults, backfill, and restore the surface. Cable pulling and splicing can take place at a later time with no need for excavation. It is common to have multiple crews work on different segments of a long underground line to reduce the total number of months to install the underground transmission line.

5.1.2 Maintenance

HPFF cables have been in service for more than 80 years, so maintenance procedures are well established, and utilities have developed detailed Operation and Maintenance manuals. Utility personnel can perform almost all of the routine maintenance, although occasional specialized assistance may be sought from qualified underground cable contractors and manufacturers. maintenance of fluid-handling and corrosion protection systems are most critical. Typical maintenance practices are summarized below:

- Visual inspection of the pressurizing plant monthly. Detailed inspection of the pressuring plant, relief valve calibration, checking relay settings, etc. annually.
- Periodic route inspection to make sure outside contractors are not digging too close to the cable pipes.
- Visual inspection in the substation monthly to look for leaks or cracks in the pothead porcelains, record cathodic protection system voltages and currents, and check the polarization cells if they are used.
- Dielectric fluid sampling to check for dissolved gas analysis; initially every year, then at longer intervals if no problems are found.
- Annual check of the pipe corrosion coating integrity.
- Visual inspection of the splicing vaults for structural integrity every 3-5 years or as conditions warrant.

5.1.3 Repair

The O&M manual directs the utility with steps to take initially if there is a leak or if the line trips.

The following steps are typical if the line develops a leak:

- The leak monitoring system would give an indication of a possible leak.
- Utility crews would perform tests to determine if a leak actually exists. The line may remain in service if the leak is very small, but if the leak is larger the line should be taken out of service and placed on reduced pressure to reduce leak rates.
- The utility would check substation components and perform a route patrol looking for construction by others and looking in cable splicing vaults and adjacent vaults for signs of the dielectric fluid.
- If the leak is small and difficult to find, a firm with special leak-detection equipment would be hired.
- Once the leak is located, repairs can be made – typically by welding a plate over the leaking area, testing the weld integrity (including checking for seepage after the repaired area is re-pressurized), restoring corrosion coating, and testing the coating.
- The line would be placed back in service. The area would be cleaned up – including removing necessary amounts of soil – and backfill restored.

The following steps are typical if the line experiences an electrical failure. The utility typically has one of the three installation contractors perform all steps once the failure location is known.

- The utility would verify that the failure is in the cable system, ground the line, and take other safety precautions.

- The utility or a contractor would use special equipment to determine the general area of the failure, and then other equipment to pinpoint the failure. Most failures have occurred in splice areas, so the location effort would concentrate first in splicing vaults.
- Depending upon the line profile, the dielectric fluid in the pipe would be frozen on one or both sides of the repair area. The crew would dig a pit, place copper tubing and thermal insulation over the pipe, and flow liquid nitrogen through the tubing to freeze the fluid.
- The pipe would be opened and the failure observed. Depending upon the degree of damage, a splice may be re-built, or a short section of cable installed and two new three-phase splices made. Sleeves would be welded over the splices.
- A vacuum pump would be connected to the repaired section to remove moisture and air, and the area would be slowly filled with dielectric fluid by allowing the freeze to thaw.
- The line would be slowly re-pressurized, tested, and placed back in service.

About a month is required to locate the fault, make repairs and restore the line to service.

5.2 XLPE Cable Systems

All of the potential suppliers of 345-kV extruded-dielectric cable are overseas – principally Europe and Japan[2]. However, local technical support has generally been good. U.S. firms would perform the majority of the installation work, with manufacturer's representatives present for critical cable pulling, splicing, and terminating operations. General comments on cable installation are given below:

5.2.1 Installation

Civil work would be similar to those for distribution cables – any experienced firm can perform that work although greater care must be taken to limit duct ovality, avoid too-small bending radii, etc. Generally, even though a contractor specializing in cable systems may be awarded the installation contract, a subcontract for civil work would probably be issued to a local firm familiar with local conditions. The prime contractor would provide a construction supervisor to ensure that the trenching and ductwork is performed properly.

Progression of trenching, duct installation, concrete envelope pouring, and restoration, can be slow – approximately one or two hundred feet a day depending upon allowable work hours, amount of traffic, amount of rock, number of other utilities already in the street, etc. Therefore, on major projects several sections may be installed simultaneously, at different locations along the route, and perhaps by different contractors. XLPE cable can also be directly buried, but the length of trench opening would be significantly longer than that required for a duct system – two thousand feet versus two hundred feet. This project does not propose to directly bury the XLPE cables beneath roadways.

Precast splicing vaults would probably be installed, although field-poured splicing vaults may be required at some locations. The number and location of splicing vaults would be determined by pulling tension calculations which account for the cable size and weight, and the line plan and profile. For very high conductor currents, the allowable sheath voltages could limit the splicing vault spacing.

[2] A U.S. manufacturer produces XLPE cable up to 138 kV, and has recently provided 230-kV cable . At some point we expect this manufacturer to extend its capabilities to 345 kV.

Once a number of contiguous splicing vaults and duct sections are installed, the cable contractor would begin pulling and splicing cable. There are several U.S. installers that have the equipment to pull the cables. The manufacturer would provide a factory engineer to oversee the entire job. In addition, the manufacturer is expected to provide skilled personnel to make splices and terminations, as is done on most high-voltage extruded-dielectric transmission cable installations in this country.

After the splicing and terminating is completed for a line segment, an acceptance test would be performed by energizing the line at rated voltage, with no load, for 24 or 48 hours – although variable-frequency tests are being developed that will permit testing the cable system at voltages higher than its designed operating voltage. Note that failure rates are small; the few failures that do occur generally are due to cable damage or poor workmanship, and occur soon after the line is energized.

A typical progression rate for trenching, duct and vault installation, backfilling, and restoring the surface is less than one mile per month, excluding the cable-pulling and splicing which can take place at a later time without need for excavation. However, having multiple crews work at different segments of a long underground line can reduce the total number of months to install the underground transmission line.

5.2.2 Maintenance

The manufacturer, engineer, and owner should establish formal O&M procedures for the line, and trained utility personnel would be expected to perform the routine procedures. Several U.S. and Canadian contractors are available to assist as needed. An extruded-dielectric cable requires less maintenance than a HPFF cable. Typical maintenance practices are summarized below:

- Visual inspection of the cable route periodically to make sure outside contractors are not digging too close to the transmission cables.
- Visual inspection of the cable potheads monthly to look for cracked porcelain, leakage of dielectric fluid, etc.
- Conducting jacket integrity test every few years or as conditions warrant. This would identify jacket damage from dig-in or other causes, and it requires checking all of the connections in the link boxes.
- At the time the jacket integrity test is conducted, utility personnel would visually inspect splicing vault for structural integrity.

5.2.3 Repair

The O&M manual directs the utility on what steps to take initially if a cable circuit trips.

Assistance from the manufacturer's engineers and qualified installation contractors is needed to repair a failed cable. The fact that the manufacturer may be a day or two away may be a concern. However, the manufacturers that have provided the majority of U.S. transmission-voltage extruded-dielectric cables (NK (now Pirelli), Sagem, and Pirelli) presently have experienced staff in this country, and they have established longstanding relationships with installers. They should be available to assist the utility with the initial steps involved in fault verification, location, and preparation for repair.

Even for a 115-kV XLPE cable system where there is long utility experience, it typically takes a few days to switch out the circuit, locate the fault (including excavation if needed), determine the extent and possible cause of the failure, and determine the appropriate repair steps. By the time local support is arranged, and repair cable and splices brought to the site from the utility spare-parts location, an installation engineer and splicing crew can be on site from Europe or Japan. Total outage time to make repairs following a cable system failure can range from several days for a simple pothead failure, to several (4 – 6) weeks or even longer if a cable section must be replaced between two splicing vaults and replacement splices made.

Note that the entire cable route must be accessible by truck for patrolling and possible staging of personnel and equipment for repairs. This is not a problem for city street installations, but could create difficulties for off-road installations such as rights-of-way where wetlands, steep rock ledges, and other obstacles must be considered.

6.0 115-kV CABLES

In addition to the 345-kV cable evaluation described in earlier sections of this report, The Companies requested PDC to evaluate the cable requirements for placing a section of 115-kV line underground, for a distance of about 0.8 miles through city streets. This line would have a summer normal rating of approximately 1695 amperes (337 MVA). A similar 115-kV XLPE cable is also being evaluated for a 3.6-mile section from Norwalk Junction to Norwalk Substation as identified in Volume 1, Sections I.2 and I.3.

6.1 115-kV Cable System Types

Historically, the majority of the 115-kV transmission cable installations in the United States have used pipe-type cables. The pipe can be pressurized to 200 psi with a dielectric fluid, to give the same type of high-pressure fluid-filled (HPFF) cable that is considered for 345-kV applications. At 115 kV, the pipe could be pressurized to 200 psi with dry nitrogen gas to give a high-pressure gas-filled (HPGF) cable system. This reduces the potential environmental impact if there were a pipe leak. (The HPGF system is only used up to 138 kV; the nitrogen gas does not provide enough electrical strength to the paper insulation for 345-kV operation).

Extruded-dielectric, XLPE-insulated cables have become the U.S. (and worldwide) standard within the last ten years at voltages through 138 kV. There is a U.S. manufacturer that can supply 115-kV XLPE cable. However, the majority of the XLPE cable manufacturers continue to be located overseas.

Two U.S. manufacturers can provide 115-kV ethylene-propylene rubber (EPR cable) – which is very similar to the XLPE cable but uses a rubber insulation that is more flexible and resistant to electrical discharges and moisture.

The reliability of 115-kV extruded-dielectric cables is considered just as good as that for 115-kV HPFF or HPGF pipe-type cables. There is significantly more experience in this country and overseas with cable and accessories for this voltage than for 345-kV XLPE cables.

Our analysis assumes that the 115-kV cables would have XLPE insulation since this is the most common insulation type used for 115-kV extruded-dielectric cables in the United States. An EPR cable would be acceptable although the conductor size requirement might be greater than sizes commercially available. If the 115-kV cable is adopted by the CSC, the Companies should review the advantages and disadvantages of the three cable insulations (pipe-type, XLPE, and EPR) for the specific application.

Figure 12 shows a 115-kV XLPE cable with a relatively thin insulation wall of 590 mils (0.590 inches). This cable is similar to that for the proposed route and in the alternate route.

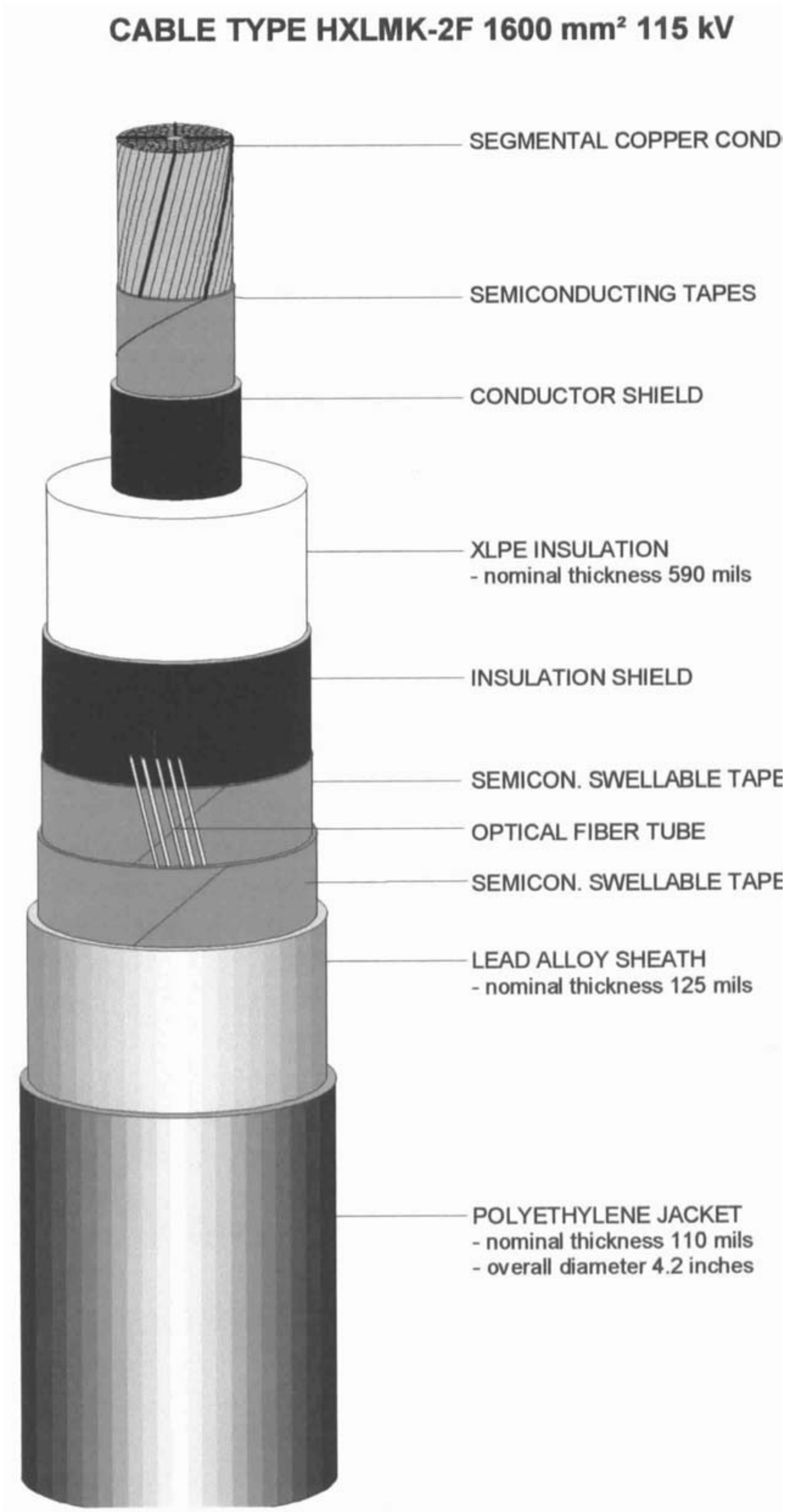


Figure 12. Typical 115-kV XLPE cable. The code at the top of the figure is the product number from Sagem, the manufacturer that provided this drawing, and includes the conductor size in metric units, 1600 mm^2.

6.2 Cable Requirements, Assumed Installation Conditions

The conditions used for ampacity calculations are summarized in Table 7.

Table 7
Assumed Cable Operating and Installation Conditions
115-kV XLPE Cables

Voltage	115 kV
Daily Load Factor	0.75 per unit
Conductor	3000 kcmil compact segmental copper
Insulation thickness	0.7 inches
Sheath	0.125 inches lead
Jacket	0.125 inches low density polyethylene
Approximate overall diameter	4.2 inches
Approximate weight	21 lb/ft
Sheath bonding	Cross bonding (See Section 6.4)
Trench cross-section	See Figure 13
Soil thermal resistivity	90 C°-cm/watt
Concrete thermal resistivity	55 C°-cm/watt
Ambient earth temperature, summertime	25°C

Notes:

1. The “full-wall” insulation thickness in Association of Edison Illuminating Co. specifications is 0.800 inches. However, most utilities design to a lower wall thickness – recognizing that the “full-wall” is very conservative. We specified 0.700 inches as a reasonable insulation thickness.
2. We show a lead sheath, which is generally considered the best material. However, several alternate constructions are available and should provide satisfactory service. EPR is often supplied without a metallic sheath since the insulation is more moisture resistant.
3. Soil thermal resistivity is an assumed “average soil.”

The trench cross-section for these cables is shown in Figure 13.

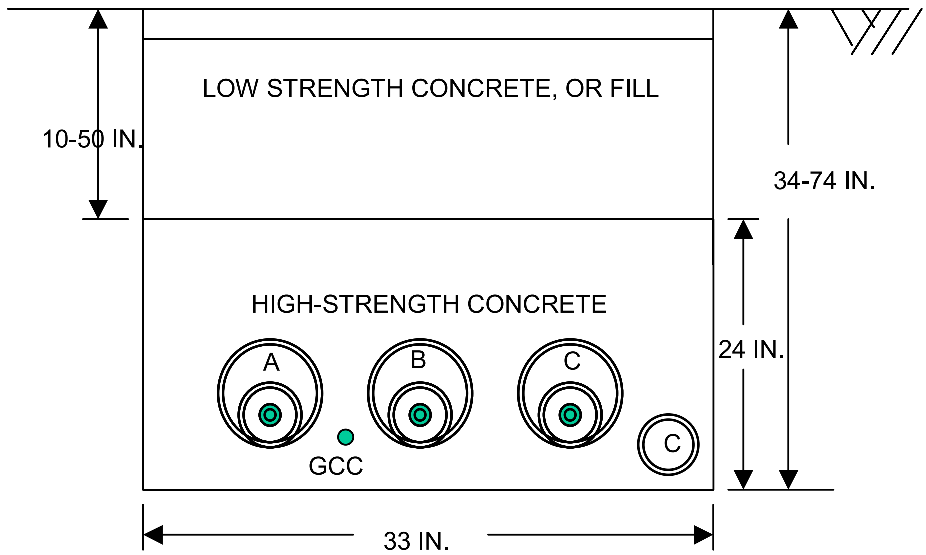


Figure 13. Assumed trench cross-section showing Ground Continuity Conductor (GCC) and communications duct (C)

6.3 Calculated Ampacities and Power Transfer

PDC calculated that a 3000-kcmil compact segmental copper-conductor 115-kV cable would be able to carry 1695 amperes at design conditions. Power transfer at 115 kV would be 337 MVA. Reactive power for a 1-mile length would be approximately 1.4 MVAR, so there would be negligible effect on real-power transfer. Manufacturers of EPR-insulated cables do not currently have the capability to supply this large a conductor construction.

6.4 Accessories

For the 0.8-mile underground line, it may be possible to install the line with just one splice per phase near the center, for an average section length of 2100 feet – depending upon the number of bends and dips along the route. However, to be conservative we assumed there would be two splices per phase, giving an average section length of 1480 feet. Cross-bonding, as described in Section 4.3.2 , would then be used. Sheath voltage would be about 75 volts for a 1000-ampere current, if the 1480-ft section length were used.

The splicing vault size would be approximately 22 feet long, 7 feet wide, and 7 feet high. A nominal six-inch duct size would be used; the next smaller duct size, four inches, is too small for the cable.

Six terminations (potheads) would be required with three each installed on transition structures at each end of the cable section. Figure 14 shows a typical transition structure with terminations installed.

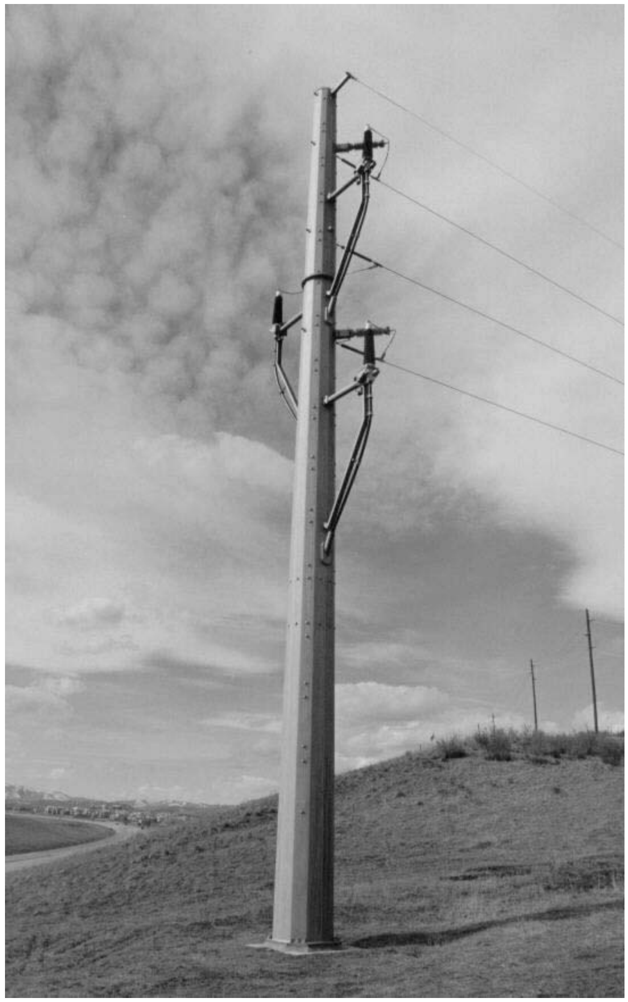


Figure 14. Typical transition structure for a single 115-kV XLPE cable line

Link boxes, sheath surge diverters, ground continuity conductor, temperature monitoring system, and other accessories would be very similar to those used for a 345-kV XLPE cable system. Because the line only generates 1.4 MVAR for an 0.8 mile length, shunt reactors would not be needed.

6.5 Reliability

XLPE cables operating at 115-kV have proven to be very reliable. Early problems with splices and terminations have been resolved by the cable manufacturers. Nevertheless, there is the chance of a dig-in or other failure, such as one associated with overheating from an adjacent ductbank. Replacing a single-phase cable section between splicing vaults and splicing-in the new piece of cable would take seven to ten days. A termination could be replaced in two or three days. In all cases, the time estimates assume that the point of failure is easily established and that the Companies have adequate spare parts on hand.

There are three options for maintaining power transfer while repairs are being made:

- Supply the power over alternate transmission paths.
- Provide a fourth conductor the full length, with splices and terminations that could quickly be connected to replace a failed phase.
- Install a redundant line, with the cable in each line sized slightly smaller than 3000 kcmil. One line would be able to carry the full 1695-ampere current at an emergency operating temperature for the ten days it might take to get the failed line back into service.

Detailed design studies would include evaluating each of these options based upon the Companies' requirements, route accessibility, etc.

7.0 UNDERGROUND CABLES – SYSTEM EFFECTS

The electrical characteristics of underground cable systems are significantly different from those for overhead lines. Major differences are:

7.1 Cable Capacitance

Cable capacitance is significantly larger than that for overhead lines. The large capacitance of an EHV cable system has the following effects:

- The charging current required to charge and discharge the capacitance at line frequency creates I^2R heating, reducing the allowable power transfer in the cable.
- The passage of charging current through the series inductance of other transmission system components causes a series voltage rise that could result in excessive system voltages.
- If the utility system cannot provide the VARs associated with the charging current, shunt reactors may be required.
- System restoration may be difficult because of the energy required to charge the large capacitance after a cable has been out of service.
- The much higher stored energy associated with the cable capacitance results in greater duties on circuit breakers, surge arresters, and other substation components.

7.2 Cable Inductance

Cable inductance is significantly lower than that for overhead lines. This lower inductance has several effects:

- Fault current levels are generally higher.
- Voltage regulation may be more difficult.
- Distribution of power flows among system elements is strongly influenced by inductive reactance – power flows on cables are greater when connected in parallel with overhead facilities of equal size

7.3 Cable Rating

Underground cables generally have lower continuous ratings than overhead lines. The mutual heating from the proximity of the three phases and the thermal insulating effect of the earth impede heat transfer versus the direct conductor-to-air heat transfer for an overhead line. However, the short-term emergency rating of a cable can exceed that of the overhead line because of the cable system's and nearby earth's large mass that can absorb heat during short term emergency periods.

8.0 Multiple Short Underground Sections

Report Sections 1 though 7 address underground cable circuits which terminate at substations. This section addresses the concept of installing one or more short segments of underground cable within an overhead section of transmission line. The term “porpoising” has been employed to describe this unusual type of transmission line construction. A transition station is required whenever an underground cable segment interconnects to an overhead section of transmission line. Such transition stations typically require a fenced-in area approximately 1-4 acres in size. Within the transition station would be a deadend structure, pothead stands, potheads and surge arresters, circuit breakers, shunt reactors that resemble EHV transformers, and a control enclosure. The protective relaying systems and System Control and Data Acquisition (SCADA) equipment, battery systems, etc. would reside inside the control enclosure. HPFF cables would also require pressurizing plants. In addition, a reliable electric distribution supply is needed for the pumps, alarms, and controls. At remote locations, where there may be only a single distribution supply available, the transition must be equipped with an emergency generator capable of operating for many days should the distribution supply experience an interruption.

The size, complexity, and cost of the transition station increases significantly when system conditions require each three-phase cable segment to be independent. To maintain independence, circuit breakers must be installed within the transition station for each cable segment along with visible breaks and appropriate grounding locations required for worker safety. To accommodate three independent parallel underground cable segments anywhere between Beseck and East Devon Substation as well as on the 345-kV overhead transmission lines that terminate at Beseck Substation, the size of the transition station would be appreciably larger.

Because of the high cost of the transition stations, the per-foot cost for a short underground section of cable is significantly higher than that for a longer line. Multiple transition stations have several other potential drawbacks:

- The reliability of HPFF and modern-generation XLPE cables is good; of the few problems that have occurred, almost all have been in terminations or splices. Adding more terminations or splices would reduce the reliability of the cable system.
- The porcelain insulators would be targets for vandals. Breaking the insulators could cause electrical failure of the cable system, and could result in burning of the HPFF cable’s dielectric fluid. Some utilities place rock shields around the potheads. These rock shields require maintenance, and are considered unsightly.
- Roadways must be maintained for utility personnel to have access to the transition stations.
- Many people find the transition stations less attractive than poles or towers for overhead lines.

Multiple underground sections can also cause operating problems:

- Special relaying may be required to determine if the cause of a line trip is in the underground section of the transmission line. Overhead lines experience self-clearing faults (lightning, tree branches), so utilities typically have automatic re-closing on the line. Underground cable faults are permanent, therefore reclosing is not usually permitted on a cable fault.

- Difficulties with Line Carrier Relaying - Multiple short-length underground transmission line segments create significant problems for power systems that employ carrier signals on the transmission line for relaying purposes. The characteristic impedance of transmission cables is at least ten times lower than that of overhead lines; this difference results in reflections of carrier signals at each overhead to underground transition. Consequently, a single "porpoise" can effectively disrupt line carrier relaying.
- Power System Transients - Switching a transmission line causes transient oscillations, or "voltage ringing." The ringing of overhead transmission lines is characteristically at a sufficiently high frequency where transformers and lines inductances attenuate this ringing before it affects the customers' facilities. The higher shunt capacitance of underground transmission lines can result in transient oscillations which appear at a much lower frequency that can penetrate farther into the system. These transient overvoltages can potentially be magnified in the lower-voltage transmission or distribution systems. This can damage or interfere with utility customer equipment and can cause damage to utility equipment which could results in customer outages.
- Constructing multiple short underground line segments results in a complex system where the dominant capacitance of the underground cable are interposed between the sections of overhead line which are dominantly inductive. As a result, complex oscillations could result, having multiple frequencies. These may have greater potential for interaction with the system and its customers. Voltage transients on the line itself may also be magnified, making the design of the system insulation and overvoltage protection more difficult.
- System Restoration - Locating faults in underground transmission lines is much more time consuming than on overhead lines. In most cases, cable fault location specialists and instrumentation must be brought in to accurately locate the fault. The exact fault location must then be determined by testing with other instruments and possibly by multiple excavations. If there are multiple short underground line segments, this will significantly increase fault location time compared to a single long overhead or underground line.
- Ferranti Voltage Rise - Current supplied to a capacitive load (i.e. cable shunt capacitance) through a series inductance (i.e. overhead line reactance) causes a voltage rise at the capacitive load. If underground line segments are added in the middle of an otherwise overhead transmission line then additional equipment (shunt reactors) may be necessary to prevent overvoltage conditions during line energization or light load conditions.

Each of these items is important and must be incorporated in the design and operation of the combination overhead and underground transmission line. Proper system planning is critical in this design process and must not be ignored.

APPENDIX A

HYDRAULIC and PRESSURIZING PLANT REQUIREMENTS FOR POSSIBLE 345-kV HPFF CABLE CIRCUITS

INTRODUCTION:

The hydraulic design and pressurizing plant sizing / placement are critical parts of a high-pressure fluid-filled cable system evaluation, to provide reliable operation under all loading and contingency conditions. Four sets of requirements were evaluated:

Fluid volume changes – to account for expansion and contraction with load changes and with seasonal ambient earth temperature changes.
Pump capacity – to make sure the pumps have sufficient capacity to provide the maximum fluid demand.
Stop-joints – to isolate the line into hydraulic sections for maintenance/repair or in the event of a major leak.
Leak Detection and Location – to detect and locate a fluid leak in the unlikely event a leak occurs.

A typical trench cross-section for the cable system is shown in Figure A-1. We assumed the fluid return pipe is filled with dielectric fluid. It is not necessary to fill that pipe until the utility decides to circulate the fluid, but the system must still be sized for that eventuality.

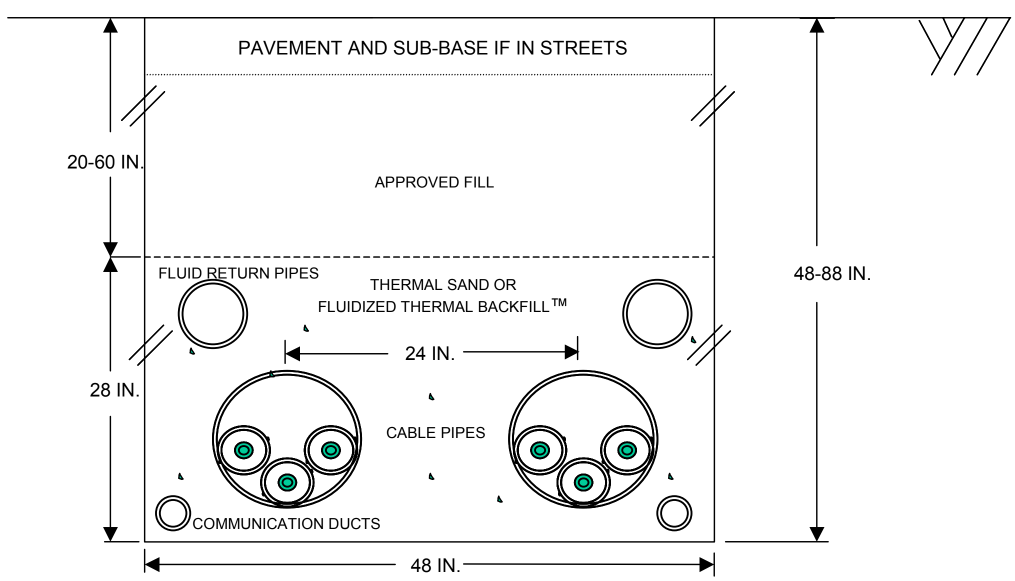


Figure A-1. Typical trench cross section

VOLUME CHANGES AND TANK SIZE

The dielectric fluid filling a HPFF cable pipe increases and decreases in volume due to changes in line loading: the conductor heats with increased power flows , the cable system expands and dielectric fluid is forced into reservoir tanks in the pressurizing plants. The conductor cools as power flows decrease, fluid pressure decreases and pumps are called upon to pull fluid from the reservoir tanks and pump it into the pipes to maintain the required pressure on the cables.

In addition, the fluid volume of the cable system changes with seasonal changes in ambient earth temperature – e.g. from a 10^{o}C wintertime temperature to a 25^{o}C summertime temperature.

The maximum possible volume changes occur between the wintertime, when the cable is de-energized, and the summertime when the cable is operating at its long-term emergency rating.

The recommended design practice is to calculate the fluid volume when all system components are at wintertime ambient of 10^{o}C (the estimated minimum temperature at average burial depth) then calculate the fluid volume when each component is at its calculated temperature when the line has been at its long-term emergency loading, for summertime maximum ambient earth temperature of 25^{o}C. The fluid volume forced into the tank is a positive amount due to conductor size expansion, insulation size expansion, and fluid expansion, all due to their respective temperature changes. Expansion of the cable pipe diameter with higher temperatures provides a small reduction in the amount of fluid forced into the tank.

This volume accounts for a portion of the required tank volume. The tank volume is determined by three components:

- The volume change due to fluid expansion and contraction as described above.

- A “buffer” amount which provides additional capacity in case the calculations do not account for all conditions, (e.g. an especially cold winter with low ambient earth temperature) and which provides additional fluid so the tank does not run dry too quickly if there is a fluid leak along the pipe length. This amount is typically a few thousand gallons.

- A volume above the fluid that is pressurized with dry nitrogen to 3 – 10 psig. This nitrogen assures that the dielectric fluid is not exposed to oxygen or moisture. The nitrogen pressure may drop to 3 psi when the fluid level is low (cold wintertime conditions) and may rise to 10 psi when the fluid level is high (hot summertime conditions with heavy loads).

For the potential 8.1 mile East Devon to Singer lines, we calculated the total fluid volume for two cable pipes to be 137,000 gallons and two fluid return pipes to be 86,000 gallons. The maximum volume change from a cold ambient of 10^{o}C to maximum emergency temperature would be about 15,000 gallons. If there were one reservoir tank, the volume would need to be about 22,000 gallons.

For the potential 15.5-mile Singer – Norwalk lines, we calculated the total fluid volume for two cable pipes to be 262,000 gallons and two fluid return pipes to be 164,000 gallons. The maximum volume change from a cold ambient of 10^{o}C to maximum emergency temperature would be about 29,000 gallons. If there were one reservoir tank, the volume would need to be about 38,000 gallons.

As noted in the following section, it is recommended that more than one tank be installed for each line, and each tank would then have a smaller volume.

NUMBER OF PLANTS, TANK SIZE

Maintaining a minimum 180-250 psig fluid pressure throughout the cable line is critical. If pressure were lost, the electrical strength of the insulation system would be reduced, and electrical failure could result. Therefore, most utilities place a pressurization plant at each cable terminal. This allows pressure to be maintained even if there were a catastrophic failure of one plant. It is possible to have one plant serve as a backup for multiple cable circuits that go from one station to two other stations, as shown in Figure A-2.

As noted above, typical installations have a pressurizing plant at each end of the cable. This should be adequate for any length HPFF cable line less than about 25 miles. (We know of no lines where intermediate plants are required.) If a line were longer than about 25 miles, detailed hydraulic calculations would be required to verify that no intermediate plant would be required.

A detailed hydraulic study would also be required to account for segments of long, deep cable depths such as at directional drill locations where the annual ambient earth temperature change is negligible, or long lengths on bridges where ambient air temperature changes are greater than for below-ground sections.

Approximate tank sizes for the proposed Middletown – Norwalk Project are shown in Figure A-2. Detailed design may result in different sizings for the individual tanks. Sizing and locations can also change based upon available room in the various substations.

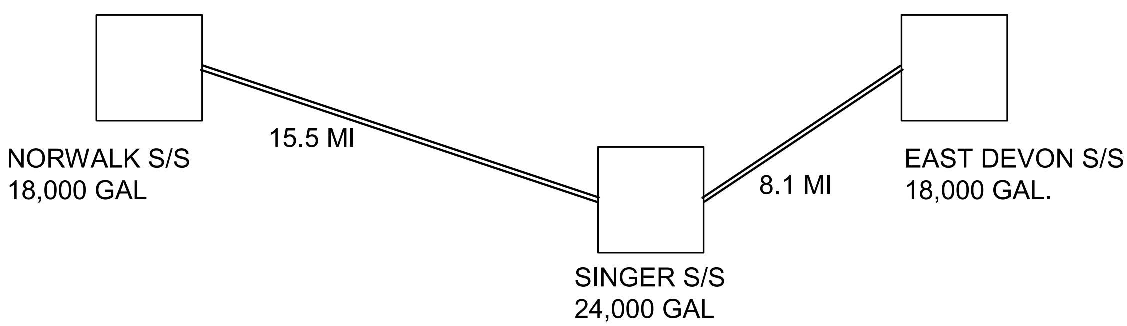


Figure A-2. Possible tank placement, sizing

Most pressurizing plants are in the substations or transition stations, but it is feasible to place them at other locations along the line if there is not room in the station. Reliable power supplies, alarm and control connections, etc. would be required at these locations.

PUMP CAPACITY

The pressurizing pumps must be sized to feed the maximum fluid demand – which is conservatively sized by assuming the lines suddenly lose all load after they have been operating at their long-term emergency rating for an extended period. Each pressurization plant has a primary and a backup pump which can provide fluid. Therefore, if standard 5 or 7.5 gal/min pumps are provided, the total available capacity is 10 or 15 gal/min, much greater than the line would require.

Some utilities would use larger pressurizing pumps, e.g. 10 gal/min, and run them continually down one feeder and back its companion, or down the fluid return pipe and back a cable pipe. This reduces the effects of any localized hot spots. Since fluid return lines are being considered, the Companies would have three options to mitigate the derating effects of hot spots from adjacent heating sources, e.g. a distribution ductbank crossings:

- Circulate fluid up one cable pipe and back the other cable pipe.
- Install oversize reservoir tanks, and shuttle fluid back and forth between two plants – this would be desirable if one line were out of service.
- Fill the return lines with fluid, and circulate between the cable pipe and the return line.

STOP JOINTS

Utilities install special joints to isolate the pipe into hydraulic sections for maintenance or repair, and to reduce the amount of fluid that might escape the pipe in the unlikely event of a large leak.

Either “semi-stop” or full-stop” joints may be used. Both types are part of electrical splices. The semi-stop joints have sleeves that are clamped over each cable and are sealed in stainless steel plates. They permit a minor fluid passage – less than a cup an hour – hence the name semi-stop. A full-stop joint has an epoxy splice and sealing plate that can withstand higher differential pressures and permits no fluid passage. The full-stop joints are larger and are more expensive, and are sometimes used at each side of a major water crossing.

Note that these stop features must be bypassed during normal cable operation, so that no sections of cable are starved for dielectric fluid. The bypass valves are closed as required after the line is taken out of service. Manual valves are most common and present the least chance of inadvertent operation, but electrically-operated valves could be used if required.

There is no industry standard for stop joint placement. For maintenance / repair of cable systems, the dielectric fluid can be frozen to hold the volume of fluid uphill of the freeze by placing coils around the pipe and passing liquid nitrogen through the coils. These freezes can withstand a differential pressure of 100 psi; therefore, if the line has significant elevation changes, the utility might have stop joints installed to limit maximum pressure to 60 psig to provide a factor of safety. This corresponds to an elevation change of about 160 feet.

Utilities might also want to install stop joints along the length of a line to provide isolation in the event of a major leak. This is not normally done except for water crossings.

LEAK DETECTION AND LOCATION

Although the incidence of an HPFF cable insulating fluid leak is small, there is always a chance of a leak, due to dig-in, corrosion, or – very uncommonly – an electrical failure.

Leak Detection

Pressurizing plants almost always have two levels of leak detection built-in:

> **Fluid level alarms** are placed on the reservoir tank. If the fluid level in the tank falls below a pre-determined level, the resulting alarm alerts utility personnel to check for possible fluid loss in the cable or fluid return pipes.
>
> **Frequent pump operation alarms** are commonly employed. If the pressurizing pumps operate more frequently than historical levels, e.g. every four hours at the most, and they begin operating every three hours, this could be an early indication of a small leak.

In addition, pressurizing plant suppliers offer more sophisticated systems that may provide an earlier indication of a potential leak. Sensitive flow meters provide accurate indications of flow into and out of the reservoir tank. If there is a cumulative flow out of the tank over the period of a day, a leak might exist. An alarm would be sent to the utility and the utility would then dispatch personnel to investigate for a possible leak. As a further level of sophistication, the line loading can be monitored, ambient earth temperature monitored, and a few locations along the cable pipe monitored using thermocouples. A computer in the pressurizing plant calculates the expected fluid volume changes based upon these monitored parameters, and initiates an alarm if the variation between measured and calculated volume changes is greater than the calculated flow of the model.

A few manufacturers offer leak detection / location cables that may be placed in the trench along with the cable pipes. If there is a leak, the cables would indicate the presence of the leak, and measurements from the ends can give the approximate leak location. These systems are typically used for buried petroleum storage tanks, and have not yet been applied to cable pipes because of concern that trace amounts of petroleum products (e.g. from abandoned gas stations or other sources) might create false alarms.

Leak Location

If the utility does suspect a fluid leak, testing is performed on the cable or return pipe to verify the integrity of the cable and return pipe (there have been many false indications of leaks because the line loading is uncharacteristically low, causing cooling and fluid contraction). If these tests indicate a leak is present, the utility has several options for locating the leak.

If the leak detection / location cable technology were employed, it should be able to detect the presence of a leak and its approximate location. Note that this approach is presently used principally for buried storage tanks, and has not been applied to cable pipes – especially for lengths as long as those considered for the East Devon to Singer and Singer to Norwalk cables.

The first step is to physically inspect terminations, pressurizing plants, splicing vaults, etc. for the presence of the leaked fluid. Adjacent vaults (telephone, sewer, etc.) would be checked, as well.

If the leak is not located, then the brute-force method is to de-energize the underground cable circuit, close stop joints and isolate to the section between stop joints (or between a terminal and a stop joint). The utility would freeze the fluid in the middle of that section, determine which half has the leak, freeze in the middle of that section, etc. until the leak is isolated to a few hundred feet. Small diameter holes would be carefully bored near the cable pipes along the alignment, and the soil removed from the bore would be inspected for the presence of dielectric fluid.

Other methods such as flow direction indicators placed into joint casings, have been developed to speed the leak location process, and new approaches are being investigated by the utility industry.

The most successful method for pinpointing a leak is to inject a small quantity of a tracer gas, known as a perfluorocarbon tracer (PFT), into the dielectric liquid and use a sophisticated gas chromatograph to determine the presence of the tracer. The PFT does not occur naturally, so its presence is a positive indication of a leak. The PFT could be inserted into the fluid when the cable system is installed, so it would immediately leave the pipe if there were a leak some time later. However, since leaks are so uncommon, the utility would probably inject the PFT only when a leak is verified. The dielectric liquid would be circulated to spread the PFT so it can exit the pipe at the leak. The chromatograph can be taken along the feeder route to detect the presence of the PFT. On a 15-mile underground cable circuit, the utility would probably use a different technique such as freezing the fluid, to narrow the search to a mile or so before applying the PFT.

Singer Substation

Site Selection Study

Prepared by:

The United Illuminating Company
157 Church Street
New Haven, CT 06506

The Connecticut Light and Power Company
107 Selden Street
Berlin, CT 06037

SEPTEMBER, 2003

Table of Contents

Section		Page
Executive Summary		2
Part I	Introduction	3
Part II	Background	4
Part III	Discussion	5
Part IV	Cost Estimates	22
Part V	Conclusion and Recommendation	25

Appendices:

A. B&V Singer Substation GIS Options

B. Singer Substation Layouts and Oneline

C. Aerial Photos of Sites

D. Site Analysis Sheet and Cost Estimates

E. B&V Singer Substation Site Study

F. Letter from the City Of Bridgeport

Executive Summary

This study was conducted to identify, evaluate, and recommend a substation site for the proposed Singer Substation in Bridgeport. Singer Substation is a 345 kV, 4 bay, breaker and a half scheme substation. The purpose of the substation is to interconnect the 345KV loop proposed in the Southwest Connecticut Electric Reliability Study, Volume 1, dated December 2002, and published by ISO New England. Further, the substation will connect the local generation in Bridgeport to the 345KV network in order to relieve the fault current conditions at our Pequonnock Substation and the 115KV network.

There were several alternative methods studied. Because of land availability, Gas Insulated Substation technology was selected. The study determined that a site with a land mass of 2-3 acres would be necessary to accommodate Singer Substation. Six viable sites were identified out of the eleven sites studied. Several of the smaller sites were evaluated for possible use for substation auxiliary equipment locations should that be necessary.

The study recommends Site 1 as the prime site. This site is located at 280 Main St. Bridgeport. It is owned by PSEG Power CT and is an empty warehouse. The site was selected because of proximity to the 345 kV system and existing generation and because it has the least impact. The site is zoned heavy industrial and has the lowest interconnection cost. This recommendation of Site #1 is supported by The City of Bridgeport, Office of Planning and Economic Development.

Introduction

In accordance with the Southwest Connecticut Reliability Study, Volume 1, dated December 2002, the transmission system in southwest Connecticut requires reinforcement. This study identified the need for a 345kV substation in Bridgeport that will interconnect the 345kV "loop" and the local Bridgeport generation. The removal of generation from the 115KV network and reconnecting it to the 345KV loop will relieve the high fault current conditions at Pequonnock Substation and the 115KV network. The 345KV loop will increase the power transfer into the Southwest Connecticut region.

Singer Substation is to be located in Bridgeport at or near the Bridgeport Harbor Station/Bridgeport Energy/Pequonnock Substation area. This area is located on the eastern portion of the south end neighborhood. This area is characterized by mixed use properties. These properties are dominated by The University of Bridgeport and Seaside Park to the south. To the east is heavy industrial, dominated by Bridgeport Harbor Station and Bridgeport Energy generating plants. On the north side of the railroad tracks is the Coty's Bluefish Stadium and Sports Complex. A large printing company, L P MacAdams, is located one block to the north. The remainder of the neighborhood is old multi family dwellings, two small churches, and the old Read's warehouse on Broad St. The easternmost portion of this area is clearly heavy industrial, which is where we began our search for a suitable site for Singer Substation.

On July 16, 2003 the siting of this substation was discussed with the City of Bridgeport, Office of Planning and Economic Development. The city planners generally supported the project and indicated that they would support siting the substation east of Main St. They felt that any development of this kind west of Main St. would have an adverse impact to the South End neighborhood. The City forwarded a letter dated August 5, 2003 confirming this position with regard to Singer Substation (See Appendix F)

Since there will be no distribution facilities associated with this substation, the search for sites centered around finding a large enough site as close as possible to the Pequonnock Substation and the generating plants. The initial investigation identified properties that met the needs for the substation, regardless of their availability and current use. Additionally, the study identifies a number of smaller sites that can be utilized in conjunction with a larger site which together would provide a large enough parcel to accommodate the proposed Singer Substation. This study will identify all sites considered for Singer Substation. It will also consider the cost of land, cost to interconnect, cost of construction and cost of site preparation. The site selection study will prioritize the sites and will recommend a site to acquire for the proposed substation.

Estimates prepared for this Site Selection Study are to be used for comparisons of the sites within the confines of this study and should not be used for construction or budgetary purposes. These estimates were prepared without benefit of detailed engineering or bidding.

Background

The Southwest Connecticut Reliability Study identified the need for a 345kV Substation in Bridgeport. Singer Substation would interconnect the 345kV loop, extending from Middletown to Norwalk with the local generation at Bridgeport. A report was prepared by Black and Veatch setting forth a variety of configurations, pros and cons with each configuration, relative costs and space requirements (See Appendix A). There were several one line configuration options to select from. After reviewing this report and consulting with Transmission Planners, a 4 bay breaker and a half scheme was selected. At 345kV a conventional Air Insulated Substation (AIS) of this arrangement would require approximately a 6-8 acre building site, due to the required clearances and spacing at 345KV. There are no available open plots of land of this size in the immediate vicinity of the Pequonnock/BE/BHS complex and none of the identified sites would meet this requirement. Based upon these issues, the use of AIS technology was rejected.

The next step was to investigate Gas Insulated Substation (GIS) technology. This technology is used in situations where space, airborne contamination, arc free switching, or aesthetics is a prime design consideration. In the case of Singer Substation both space and esthetics must be considered due to the urban location of the substation. Having reviewed a number of different layouts for a 4 bay breaker and a half scheme UI determined that the best site would be between 2 and 3 acres in size. Properties of this size are present in the area of Pequonnock/BE/BHS. Considering this information, UI selected the use of GIS Technology for Singer Substation.

With GIS technology there are many options with respect to the design/arrangement of the substation site. The best layouts would be selected based upon the shape of the lot, its surroundings, and location relative to the Pequonnock/BE/BHS complex. A generic layout was developed that could be applied to all sites for the purposes of determining their suitability for use. Utilizing this layout we identified 6 buildable sites in the general location of the Pequonnock/BE/BHS Complex. Although a total of 11 sites were identified, 5 sites were of insufficient size to be utilized for the substation without significant additional construction efforts (i.e. multilevel buildings, equipment under buildings, etc.). These sites remained in the study to be available for individual pieces of equipment, possibly to be used in conjunction with another site if required. Cost estimates were then prepared for the generic layout. Appendix B depicts layouts for sites 1, 7, 8, and 10. Although they are discussed in this report, generic layouts for sites 6 and 11 were not generated. Site 6 is owned by the Bridgeport Housing Authority, who has plans in place and approved for the construction of a 25-unit apartment complex. As such it is not available. The 11 acre size of site 11 makes a layout moot at this stage of project development, since the site will accommodate virtually any layout proposed.

UI estimated the cost of running the transmission lines from a common point to the respective sites. These estimates included the 115kV lines from Pequonnock Substation and the Bridgeport Energy generating facility, as well as the eastbound and westbound sections of the 345kV loop. These estimates, based upon location of the site, became one of the cost criteria used as a basis for comparison from site to site. Other factors that contribute to cost differentials include: the length of an architectural wall, the length of sidewalk, and site preparation costs including demolition of existing buildings and structures and foundations. Individual descriptions of each site, along with its pros and cons, are included in the discussion section of this report. The site analysis, substation estimate, and cost differentials are noted in the following section and on the tabular sheet located in Appendix D.

Discussion

In the course of site investigations for Singer Substation, a total of 11 sites were identified   Five of these sites were deemed to have insufficient land mass to accommodate the proposed substation. It was felt that these smaller sites could be used in conjunction with a larger site to locate some of the equipment necessary for a 345kV interconnection. Therefore, these smaller sites remained in the study in the event that they could be utilized. The following is a discussion of these 5 sites. Please refer to Appendix C for aerial photographs of each site.

Site Numbers 2, 3,4,5,9

Site 2: Site 2 is a 1.046 acre site abutting the railroad right-of-way. It is a narrow parcel that could be utilized for installation of Auto Transformers. The 345kV would need to be GIS technology due to the width of the site, as opposed to the 80 foot width required for extra high voltage (EHV) clearances and spacing with the required buffer and fence. The 115kV could be open air because of its lower clearance and spacing requirements. This site is presently owned by PSEG Power CT and contains a small warehouse. This site is located within the coastal zone.

Pros:

- Close to Pequonnock Substation.
- Adjacent to Site 5.
- Minimal impact to the surrounding community.

Cons:

- The site must be used in conjunction with another site.
- The site is on the “outside” of a bad railroad curve. A derailed train could impact the site.
- The site abuts a CDOT right of way and an access road to the Bridgeport to Long Island ferry terminal.
- The existing warehouse would need to be demolished.

<u>Site 3:</u> Site 3 is a very small parcel located on the southern end of Pequonnock Substation. The parcel itself is only 0.127 acres and could not be utilized for anything except for a single transformer location. With this site, the 115kV could be extended from Pequonnock Substation. The 345kV would have to be installed utilizing GIL technology due to the lack of room for EHV clearances and spacing. This site is owned by PSEG Power CT and contains another small warehouse. This site is located within the coastal zone.

<u>Pros:</u>

- Close to Pequonnock Substation
- Close to Site 5
- Minimal impact to neighborhood

<u>Cons:</u>

- Site must be used in conjunction with another site
- The existing warehouse would need to be demolished
- Would need to acquire an easement for the 345kV underground exit from the site.
- Specialized construction methods required to avoid creating settlement problems at Pequonnock Substation.

<u>Site 4:</u> Site 4 is a small parcel (0.244 acres) located just North of Pequonnock Substation. This site is owned by UI. However, this site is also too small for anything except the installation of Auto Transformers. As with Site 2, the 115kV taps could be air insulated. The 345kV would need to be GIL technology due to inadequate space to accommodate EHV clearances. This site is located within the coastal zone.

<u>Pros:</u>

- Site is owned by UI.
- Site is immediately adjacent to Pequonnock Substation.
- No demolition of existing buildings or structures on site is required.
- Easy 115kV connections.
- Minimal impact to neighborhood.

<u>Cons:</u>

- Site must be used in conjunction with another site.
- Site is next to water, requiring higher foundations be built and transformers could be subject to driving surf during storms.
- Development of this area leaves no room for further expansion of Pequonnock Substation.
- An easement would be required for the underground 345kV exit from the site.
- Specialized construction methods required to avoid creating settlement problems at Pequonnock Substation.

Site 5: Site 5 is a 1.607 acre parcel owned by PSEG Power CT. It is located on PSEG property which is bounded by Singer Avenue, Railroad Court and the Bridgeport Energy (BE) Switching Station. This was the first site that was considered because of its location between BE and Pequonnock as it would also be located adjacent to the 345kV loop. The 115KV transmission line that ties BE to Pequonnock Substation runs through the site. Interconnection costs for this site would be minimal. Due to the size of the site, GIS technology would have to be used for all 345kV connections. Use of this site would also require either a multi-level building with transformers underneath or the utilization of one of the smaller sites for auto transformer locations. Due to the existing owner's future plans for this property, and their reluctance to sell the lot, this site was rejected. PSEG recommended three other sites for consideration. These are sites were included and are identified in this study as Sites 1, 2, and 8. Site 5 is located within the coastal zone.

Pros:

- The site is located in close proximity to existing transmission that would minimize interconnection costs.
- This is a clear site; no demolition of existing structures is required.
- The site is zoned industrial and adjacent to a generating facility
- No special screening for noise or esthetics is anticipated.
- Easy street access to any portion of the site.

Cons:

- The Site is slightly smaller than required. It could be modified to allow for construction of the substation, but this would require a multi-story building with equipment underneath or the utilization of a second, smaller site for equipment.
- All 345KV equipment connections must be gas connections this will eliminate the prospect of a shared system spare transformer
- Due to space constraints, 3 phase transformers may need to be used, which would require UI to maintain a system spare at a separate location.
- The owner, PSEG Power CT, has future plans for the site.
- The Bridgeport Harbor Station property would need to be subdivided to define the Singer Substation lot boundaries.
- There would be very limited future expansion possibilities once the site is developed for Singer Substation.

Site 9: This site lies directly across Singer Avenue from Site 5. The site is bounded by Singer Avenue, Whiting Street, Main Street and Keifer Street and lies within the coastal zone. It is approximately 1.724 acres and may have multiple owners. The site houses at least 4 businesses, one of which is a large 6-7 story warehouse operated by P.J. Reynolds Moving Co. Other businesses include a liquor store and a car repair shop. The site alone is too small to accommodate the substation without specialized construction or utilization of an additional, smaller site. Due to the number of businesses, there would be significant demolition and relocation costs associated with moving the businesses and leveling the entire block. In consideration of all of these factors, this site was rejected from further consideration as a viable location for Singer Substation.

Site Numbers 1, 6, 7,8,10, & 11

The remainder of this section will provide a discussion on each viable site remaining. All of the remaining sites have sufficient land mass to construct the proposed Singer Substation utilizing GIS technology. The 345kV loop will enter and exit the substation site underground. Sites which are adjacent to Bridgeport Energy will interconnect the 115kV from BE and Pequonnock Substation via overhead entry from the power plant side of the sites. Sites which are not adjacent to Bridgeport Energy will interconnect the 115kV and 345kV via underground cables. See Appendices B and C for layouts and aerial photographs of each site.

Site 1

Description: Site 1 is located at 280 Main Street. This site is bounded by Main Street, Whiting Street, and Atlantic Street. The rear of the property abuts Bridgeport Energy (BE) Power Plant. This site is industrial zoned and is occupied by an empty warehouse. The site is presently owned by PSEG Power CT. The lot size is 2.339 acres and is adequate to construct Singer Substation and provide for modest future expansion. Residential properties are located along Atlantic Street and Main Street, across from the site. There are commercial properties located along Whiting Street, including a large warehouse, liquor store and car repair shop (Please reference Site 9 above.)

Site Development: Because of residences along Main and Atlantic Streets, and the commercial establishments along Whiting Street, screening for noise abatement, aesthetics and security will be considered and integrated into the substation design along these three street fronts. Additionally, sidewalks will need to be provided, as required. The property line that abuts BE can be secured by a standard 14 ft. chain link fence. The building fascia that will abut Main Street will be designed to provide additional screening of the substation from the neighborhood and for noise abatement. The 345kV loop will enter and exit the Site underground as will the 115KVgeneration interconnection. This site is located in a coastal zone.

Pros:

- This site is of adequate size to accommodate the substation.
- The site is located within an industrial zone, no zone change is required.
- The site abuts Bridgeport Energy, allowing for easy connections for BE and Pequonnock Substation.
- Compared to other viable sites examined, this Site is has less impact to near by residential and commercial properties.
- This site has the lowest overall installed costs.
- This site provides room for an additional future expansion.
- The site was originally recommended by the owner as a possible site for the substation.
- The selection of this site is supported by The City of Bridgeport.

Cons:

- Demolition of warehouse will be required.
- The site is owned by PSEG Power CT. Owner has been reluctant to sell property since its withdrawal of an 18.4 application at the ISO for increased generation.
- The site is adjacent to residential properties.

Estimated Cost: The estimated cost of development, including the transmission interconnections is approximately $37.5 million

Site 6

Description: Site 6 is located at 375 Main Street. It is a 2.206 acre site bounded by Whiting Street, Railroad Court, Main Street, and Broad Street. This site is presently an empty lot with residential zoning. UI was informed that this site is presently owned by the Bridgeport Housing Authority. Plans are in place and all approvals have been obtained for the construction of a 25 unit apartment complex and the property was not for sale. This status of this property was reconfirmed at an informal town meeting with Bridgeport held on April 17, 2003. As a result of these discussions, this site has been rejected for further consideration for Singer Substation. No further analysis was undertaken.

Site 7

Description: Site 7 is a block located at 350 Lafayette Street. It is a 3.058 acre site bounded by Lafayette Street, Atlantic Street, Broad Street, and Whiting Street. The property has a 2 story masonry building that formally served as the Warnaco Company executive offices. The bulk of this Site (2.764 Acres) is currently owned by Turner's Faith Church and is currently used primarily as a parking lot. Representatives from the Church have indicated their intent to construct a new church building on the property and have rebuffed all further attempts to discuss this Site as a possible location for the substation. The remainder of the Site has 3 multi-family dwellings located at the corner of Broad and Atlantic Streets, which are fully occupied. No attempt has been made to contact the owner(s) of these properties. Zoning at the site is entirely residential. This site is located in the coastal zone.

Site Development: This site is surrounded by residential housing. If selected, the site would require special screening for noise abatement, aesthetics, and security on all 4 sides. Access to the substation is planned from along Lafayette Street. A free standing architectural wall would surround the site, and sidewalks and planting buffers would be installed along all four sides. The 345kV and the 115kV lines would enter and exit the site underground, within the streets. Site access is obtainable from all sides of the site, however; road widths on Whiting Street could restrict a 55 foot turning radius.

Pros:

- The site is large enough to support construction of Singer Substation with additional room for modest future expansion.
- Minimal demolition or existing structures is required.

Cons:

- The site requires purchase and relocation of 3 multi-family dwellings.
- The site is located within a residential neighborhood.
- The site requires a zoning change for use as a substation.
- The site requires architectural walls, side walks and other treatments on all four sides of the property.
- The owner has refused to sell the property to UI.
- The 115kV connections to the Site must be from underground.
- This site has the second highest development costs.

Estimated Cost: The estimated cost of development, including the transmission interconnection cost, is approximately $43 million.


BH JULIAN
ENTERPRISES
SPACE AVAILABLE
860-442-5100
BROKERS PROTECTED

Site 8

Description: This site is located at 182 Main Street. It is a 2.825 acre property located within an area designated as a "multi use" zone. The site is bounded by Main Street, Russell Street, Atlantic Street and Henry Street. The site is presently owned by PSEG Power CT. A small portion of the property is presently occupied by a two-family home. The site is located within the coastal zone.

Site Development: This site is located on the opposite side of Atlantic Street from Site 1. The typical screening for noise abatement, aesthetics, and security would be required on 3 sides of the Site. Special screening in the form of an architectural wall would need to be installed on 3 sides of the site. Site access is obtainable from either Atlantic Street or Henry Street. Overhead 115kV could be utilized. Right of way would need to be acquired across both the PSEG and BE properties and the overhead transmission lines would need to be extended from the BE switch yard to Site 8, crossing Atlantic Street. For the purposes of this study, we have assumed that underground transmission lines will be extended from BE and Pequonnock Substations along city streets.

Pros:

- The Site is large enough to accommodate the substation.
- The Site is located adjacent to an industrial use property.
- No demolition would be required.
- The Site provides room for additional future expansion of the substation.
- This Site was originally recommended by the owner as a possible site for the substation.

Cons:

- The site is presently owned by PSEG Power CT. They have been reluctant to sell the property since the withdrawal of their 18.4 application for additional generation.
- The site is adjacent to residential properties along Main and Henry Streets.
- Easements are required to get the 115kV overhead transmission lines to the site.
- The site is located an additional block away from the proposed route of the 345kV loop.
- Zoning change is required for substation use.

Estimated Cost: The estimated cost of development including transmission interconnection costs is $39 million.

Site 10

Description: Site 10 is a 5.29 acre site, which is the combination of 2 properties. One parcel has a street address of 325 Lafayette Street. The second parcel has an address listed as 350 Myrtle Avenue. The site is bisected by an abandoned portion of Warner Street. The entire site is formerly owned by the Warnaco Company, a clothing manufacturer. The site is primarily covered with 3 and 4 story textile factory buildings that were built between 1880 and 1910. The buildings are constructed of heavy timber and brick. These buildings are listed on the national historic register. Recently the owner was able to convert the mutli-use zone on the parcel at 325 Lafayette St. to residential zone. His plans for this parcel are to renovate the interior and construct 140 apartment units. This site is not within the coastal zone.

Site Development: This site is surrounded by residential neighborhoods. The size of the site is more than sufficient to support the substation construction and future expansion. The substation could be constructed on either of 2 existing parcels. The 325 Lafayette Street parcel contains 2.54 acres of buildable land and the parcel located at 350 Myrtle Avenue contains about 2.33 acres of buildable land. There is a permanent utility easement bisecting the property with an area of 0.42 acres. Either parcel would require screening for noise abatement, aesthetics and security around all four sides of the substation. Primary site access would be from either Myrtle Avenue or Lafayette Street, depending on which parcel was used. Sidewalks and planting strips would also need to be included into the final design. The 115kV transmission lines would need to enter either parcel underground (understreet) from Pequonnock Substation and Bridgeport Energy. The 345kV lines would exit either parcel underground.

Pros:

- The site is large enough to accommodate the substation and additional future expansion.
- The unused portion of the site, following installation of the substation, could be subdivided and sold or utilized in some other fashion.

Cons:

- The site is the farthest location from Pequonnock Substation and Bridgeport Energy of all possible sites considered.
- Underground transmission is required for the 115kV.
- The site has adjacent residential properties on all four sides.
- Screening, sidewalks and planting strips are required on all sides of the site.
- Zoning change has occurred for the residential development of 140 apartments on the 325 Lafayette Street parcel.
- The site is partially zoned residential and partially designated as “mixed use.”
- Zoning change is required for substation use.
- Highest overall interconnection cost of all sites considered due to the distance from BE and Pequonnock Substation.

- This site has a higher land cost, as offered by the present owner.
- This site has the highest demolition cost.
- Redevelopment of a portion of the site, to construct residences, has already begun.

Estimated Cost: The estimated cost of development, including transmission interconnection costs, is $45.3 million

Appendix “A”

Black & Veatch Report

“Singer Substation GIS Configuration Options”

Dated: December 13, 2002

SINGER SUBSTATION
GIS CONFIGURATION OPTIONS

B&V is presently studying the feasibility of installing a new six position, 345kV substation near the existing UI Pequonnock substation. The following document provides a brief summary of B&V's study to date and serves as the discussion point to determine which interconnection option should be developed and recommended for installation.

B&V's study to date has included the preliminary review of four substation configuration options for the interconnection of the 345kV and 115kV transmission grids. The four substation configuration options include: Single Breaker – Double Bus, Ring Bus, Breaker-and-One-Half, & Double Breaker – Double Bus. Open-air bus designs and GIS bus designs were both reviewed for each configuration. The cost and physical space requirements associated with using single-phase transformers and three-phase transformers were also reviewed for each configuration. A Radial Bus configuration was considered but due to the critical nature of this substation the low reliability offered by this configuration was deemed unacceptable. Therefore the Radial Bus design was not pursued. The following descriptions for each bus configuration shall provide a basic understanding of the configurations reviewed including their space requirements, advantages/disadvantages, flexibility, and relative cost.

Single Breaker – Double Bus

The Single Breaker – Double Bus substation configuration consists of two main buses connected together through a bus tie circuit breaker (breaker is N.O.). Each circuit has one circuit breaker and can be connected to either bus through disconnect switches. This configuration allows all circuits to be connected to one bus in case of an outage on the other bus. Switching of a circuit from one bus to the other is not automatic. The Single Breaker – Double Bus configuration provides slightly better reliability and flexibility over a radial bus due to the fact that different circuits can be connected to different buses. The Single Breaker - Double Bus configuration is generally applied in locations where system reliability is not as critical. It is also the least commonly used configuration in the U.S.A.

A preliminary one-line diagram (SK1), a GIS substation plan arrangement sketch using three-phase transformers (SK1A), and a GIS substation plan arrangement sketch using single-phase transformers (SK1B) of the new Singer Substation utilizing a Single Breaker – Double Bus configuration can be found in Attachment A.

Single Breaker - Double Bus substations have the following advantages and disadvantages when compared to other configurations:

Advantages:

- Slightly increased reliability over a simple Radial Bus.
- Slightly increased flexibility of operation over a simple Radial Bus.
- Easy to expand.

Disadvantages:

- Increased cost over a simple radial bus.
- Increased complexity of protective relaying over a simple radial bus.
- Switching of bus protection current transformer secondary circuits or installation of a "HYBRID" bus protective relay package is required. The "HYBRID" bus protective relay package will simulate the required switching of current transformer secondary circuits internal to the relay electronics.
- Line circuit breaker maintenance requires a line outage.
- Bus fault can separate loads from sources.

Approximate Substation Sizes:

- Open-Air Substation Arrangement: 355' x 815'
- GIS Substation Arrangement (3-phase XFMRs): 175' x 320'
- GIS Substation Arrangement (1-phase XFMRs): 210' x 310'

Budgetary GIS Substation (EPC) Costs:
The following EPC costs do not include the cost for the supply and installation of the reactors, if required. However, each of the following budgetary GIS substation EPC costs do include the cost associated with the supply and installation of a spare transformer.

- GIS Substation Arrangement (3-phase XFMRs): $21,965,500.00
- GIS Substation Arrangement (1-phase XFMRs): $24,468,900.00

Ring Bus

The Ring Bus configuration consists of numerous bus sections, with each section sourcing one circuit. In some applications Owner's have paired a transmission line and a transformer on one ring position, however this is not recommended. Ring Bus substations are highly reliable and flexible to operate. In this configuration, only one position is removed from service for a circuit or bus fault. The circuit breakers on each end of the faulted bus section are opened. The failure of a breaker to operate for a line or bus fault will cause two circuits and two bus sections to be removed from service. The Ring Bus configuration allows for any circuit breaker to be removed from service for maintenance without an outage on any circuit. Line disconnect switches are often installed to allow a circuit to be removed from service and the ring to remain intact. Since the line disconnect switch is not capable of breaking load, the two circuit breakers sourcing the circuit are opened, the line disconnect switch is opened and then the two circuit breakers are closed.

Normal industry practice limits the recommended size of a Ring Bus to a maximum of eight circuits. It is recommended that sources of generation or redundant circuits are not terminated on adjacent positions of the Ring Bus. This will prevent a failed circuit breaker from removing two sources of generation or two feeds to the same load from service.

The Ring Bus configuration is generally applied in substations from 69kV through 500kV and in locations where high system reliability is a requirement.

A preliminary one-line diagram (SK2), a GIS substation plan arrangement sketch using three-phase transformers (SK2A), and a GIS substation plan arrangement sketch using single-phase transformers (SK2B) of the new Singer Substation utilizing a Ring Bus configuration can be found in Attachment A.

Ring Bus substations have the following advantages and disadvantages when compared to other configurations:

Advantages:

- High reliability when compared to Radial or Single Breaker – Double Bus configurations.
- Flexible operation.
- Lower cost when compared to Breaker-and-One-Half or Double Breaker – Double Bus.
- Any breaker can be removed from service for maintenance without an associated circuit outage.
- Initial design can allow for future expansion to breaker-and-one-half configuration.

Disadvantages:

- More complex protective relaying and control system than Radial or Single Breaker – Double Bus configurations.
- Failed breaker during fault causes outage of one additional circuit.
- The ring bus can be opened in two or more locations resulting in possible system flow problems.

Approximate Substation Sizes:

- Open-Air Substation Arrangement: 290' x 490'
- GIS Substation Arrangement (3-phase XFMRs): 185' x 320'
- GIS Substation Arrangement (1-phase XFMRs): 210' x 330'

Budgetary GIS Substation (EPC) Costs:

The following EPC costs do not include the cost for the supply and installation of the reactors, if required. However, each of the following budgetary GIS substation EPC costs do include the cost associated with the supply and installation of a spare transformer.

- GIS Substation Arrangement (3-phase XFMRs): $20,436,600.00
- GIS Substation Arrangement (1-phase XFMRs): $22,940,000.00

Breaker-and-One-Half

The Breaker-and-One-Half configuration consists of two main buses. Connected between the buses are three circuit breakers and between each two circuit breakers is a circuit. In this configuration, each circuit has a dedicated circuit breaker and shares a circuit breaker with the adjacent circuit. Therefore, there are one-and-one-half breakers per circuit. Breaker-and-One-Half substations are very reliable and are very flexible to operate. In this configuration, only one circuit is removed from service for a fault, the faulted circuit. A bus fault requires no circuits be removed from service. The failure of a circuit breaker between a main bus and a circuit to operate for a fault will require only the circuit and the main bus adjacent to the failed circuit breaker be removed from service. The failure of a circuit breaker between two circuits to operate for a fault will require the two adjacent circuits to the failed circuit breaker be removed from service. This configuration allows any circuit breaker to be removed from service for maintenance without an outage on any circuit. Line disconnect switches are often applied to allow a circuit to be removed from service and all circuit breakers to remain energized. This operation is similar to the ring bus. Since the line disconnect switch is not capable of breaking load, the two circuit breakers adjacent to the circuit are opened, the line disconnect switch is opened and the circuit breakers are closed.

Similar to the Ring Bus, it is recommended that sources of generation or redundant circuits not be located in a Breaker-and-One-Half substation such that they are separated by only one circuit breaker. This will prevent a failed breaker from removing two sources of generation or two feeds to the same load from service.

The Breaker-and-One-Half configuration is generally applied in substations from 115kV through EHV voltages. Because of its high reliability, it is often applied at major generation facilities and at locations where system reliability is critical.

A preliminary one-line diagram (SK3), a GIS substation plan arrangement sketch using three-phase transformers (SK3A), and a GIS substation plan arrangement sketch using single-phase transformers (SK3B) of the new Singer Substation utilizing a Breaker-and-One-Half configuration can be found in Attachment A.

Breaker-and-One-Half substations have the following advantages and disadvantages when compared to other configurations:

Advantages:

- Very high reliability.
- Very flexible operation.
- Any breaker can be removed from service for maintenance without an associated circuit outage.
- Easy to expand.

Disadvantages:

- Large land area required for air insulated.
- High cost when compared to a Radial, Single Breaker – Double Bus, or Ring Bus configurations.
- Complex protective relaying and control.
- A failed breaker during a fault (line or generator) can cause the loss of an additional circuit (line or generator).

Approximate Substation Sizes:

- Open-Air Substation Arrangement: 330' x 610'
- GIS Substation Arrangement (3-phase XFMRs): 185' x 350'
- GIS Substation Arrangement (1-phase XFMRs): 210' x 310'

Budgetary GIS Substation (EPC) Costs:

The following EPC costs do not include the cost for the supply and installation of the reactors, if required. However, each of the following budgetary GIS substation EPC costs do include the cost associated with the supply and installation of a spare transformer.

- GIS Substation Arrangement (3-phase XFMRs): $26,074,100.00
- GIS Substation Arrangement (1-phase XFMRs): $28,577,500.00

Double Breaker – Double Bus

The Double Breaker - Double Bus configuration consists of two main buses. Connected between the buses are two circuit breakers and between the circuit breakers, a circuit. In this configuration, each circuit has two dedicated circuit breakers. Double Breaker - Double Bus substations are the most reliable and the most flexible to operate. They require no separation of sources of generation or redundant circuits as they are automatically separated. In this configuration, only one circuit is removed from service for a fault, the faulted circuit. Similar to the Breaker-and-One-Half configuration, a bus fault requires no circuits be removed from service. The failure of a circuit breaker to operate for a line fault will require only the faulted circuit and the main bus adjacent to the failed circuit breaker to be removed from service. Similarly, the failure of a circuit breaker to operate for a bus fault will require only the faulted bus and the circuit adjacent to the failed circuit breaker to be removed from service. This configuration allows any circuit breaker to be removed from service for maintenance without an outage on any circuit. Line disconnect switches are often applied to allow a circuit to be removed from service and all circuit breakers to remain energized. Since the line disconnect switch is not capable of breaking load, the two circuit breakers adjacent to the circuit are opened, the line disconnect switch is opened and the circuit breakers are closed.

The Double Breaker - Double Bus configuration is generally applied in substations from 230 kV through EHV voltages, at nuclear generating facilities, at major generation facilities, and at locations where system reliability is extremely critical.

A preliminary one-line diagram (SK4), a GIS substation plan arrangement sketch using three-phase transformers (SK4A), and a GIS substation plan arrangement sketch using single-phase transformers (SK4B) of the new Singer Substation utilizing a Double Breaker – Double Bus configuration can be found in Attachment A.

Double Breaker - Double Bus substations have the following advantages and disadvantages when compared to other configurations:

Advantages:
- Highest level of reliability.
- Most flexible operation.
- Any breaker can be removed from service for maintenance without an associated circuit outage.
- Easy to expand.
- A failed breaker for a circuit fault (line or generator) will not affect any other circuit.

Disadvantages:
- Very high cost when compared to other bus configurations.
- Large land area required for air insulated.
- Complex protective relaying and control (similar to Breaker-and-One-Half).

Approximate Substation Sizes:
- Open-Air Substation Arrangement: 385' x 815'
- GIS Substation Arrangement (3-phase XFMRs): 220' x 340'
- GIS Substation Arrangement (1-phase XFMRs): 215' x 320'

Budgetary GIS Substation (EPC) Costs:
The following EPC costs do not include the cost for the supply and installation of the reactors, if required. However, each of the following budgetary GIS substation EPC costs do include the cost associated with the supply and installation of a spare transformer.
- GIS Substation Arrangement (3-phase XFMRs): $30,299,000.00
- GIS Substation Arrangement (1-phase XFMRs): $32,802,300.00

CONCLUSION

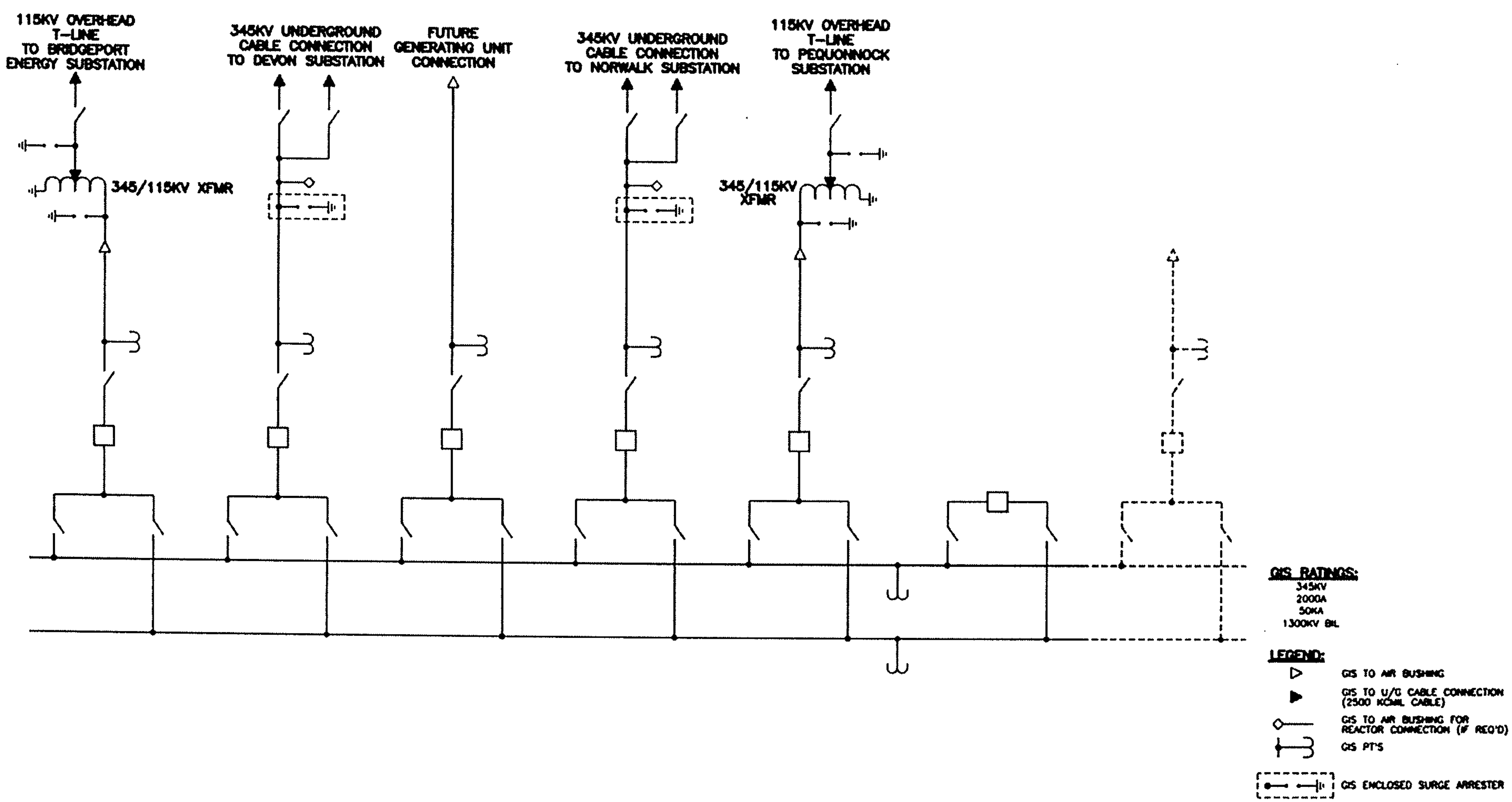
We conclude the following concerning the four options presented.

- An open-air substation arrangement for any of the four options presented is not a feasible solution. None of the 5 proposed properties are large enough to accommodate even the smallest footprint of the four proposed configuration options.
- Preliminary layouts indicate that all four GIS substation arrangement options discussed (Single Breaker – Double Bus, Ring Bus, Breaker-and-One-Half, & Double Breaker – Double Bus) could be located on the Proposed Site, Alternate #1 Site, and Alternate #2 Site. Please note that more detailed equipment information would be required to confirm actual layouts.
- The Alternate #3 site and Alternate #4 site properties are not large enough to accommodate any of the GIS substation options proposed.
- The approximate maximum height of the building housing the GIS equipment would be 50'.
- If the Proposed Site, Alternate Site 1, or Alternate Site 2 are chosen, additional study needs to be completed to determine the routing of the 115kV lines from the new Singer substation to the Bridgeport Energy substation and the Pequonnock Substation. Routing of the lines and access to these sites may be limited.
- Because of the probable routing of the two 115kV transmission lines into the Singer Substation, the future 345kV circuit will need to be connected via a underground cable circuit directly to the GIS or through an open air termination.

In review of the four options presented above, along with the available property parcels identified for the installation of the new Singer Substation, B&V recommends that a Breaker-and-One-Half substation be installed on the parcel of property labeled as the Proposed Singer 345kV Substation. Although the Breaker-and-One-Half option is not the lowest cost alternative, B&V believes that this substation arrangement option provides UI with the necessary level of reliability and flexible operation that is required on the 345kV transmission system at this location.

ATTACHMENT A

Substation Configuration Options – One-Line & Arrangement Drawings

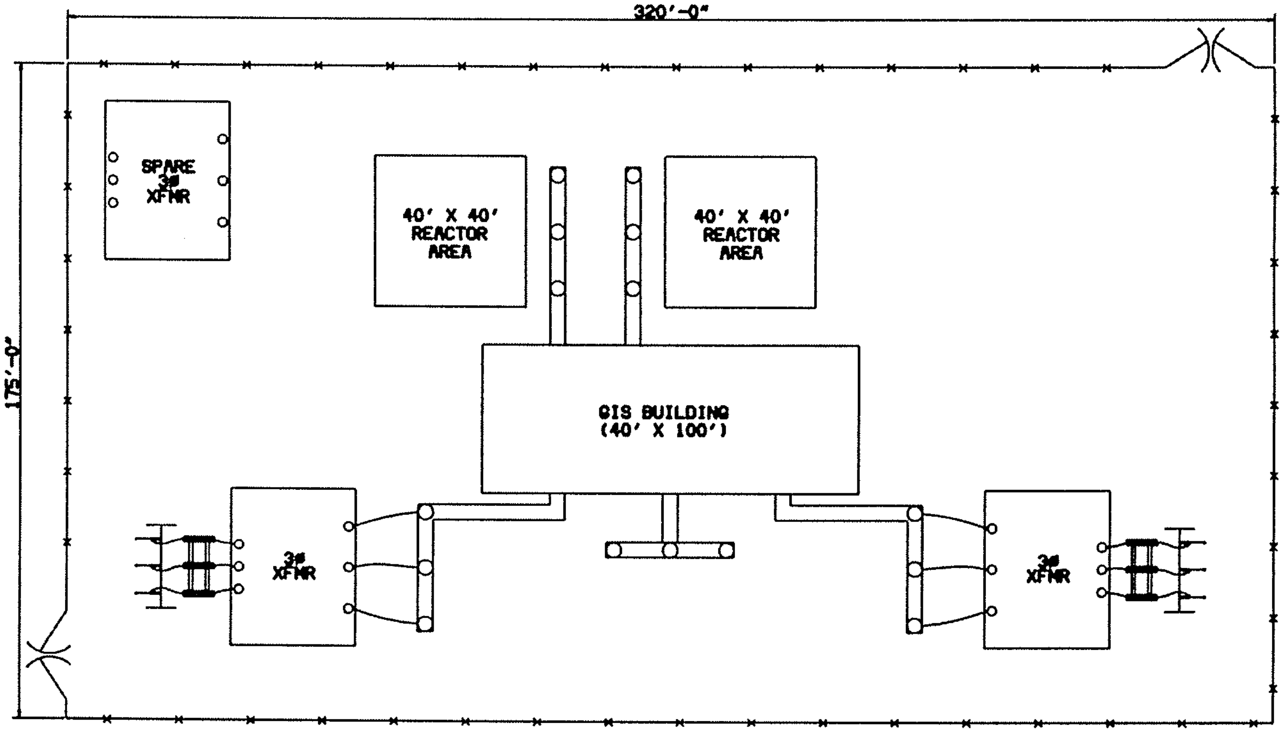


NOT TO BE USED FOR CONSTRUCTION

BLACK & VEATCH CORPORATION	SINGER SUBSTATION	133193-SK1
	345KV SINGLE BREAKER – DOUBLE BUS	A

A — CLIENT REVIEW

REVISIONS AND RECORD OF ISSUE



NOT TO BE USED
FOR CONSTRUCTION

BLACK & VEATCH CORPORATION

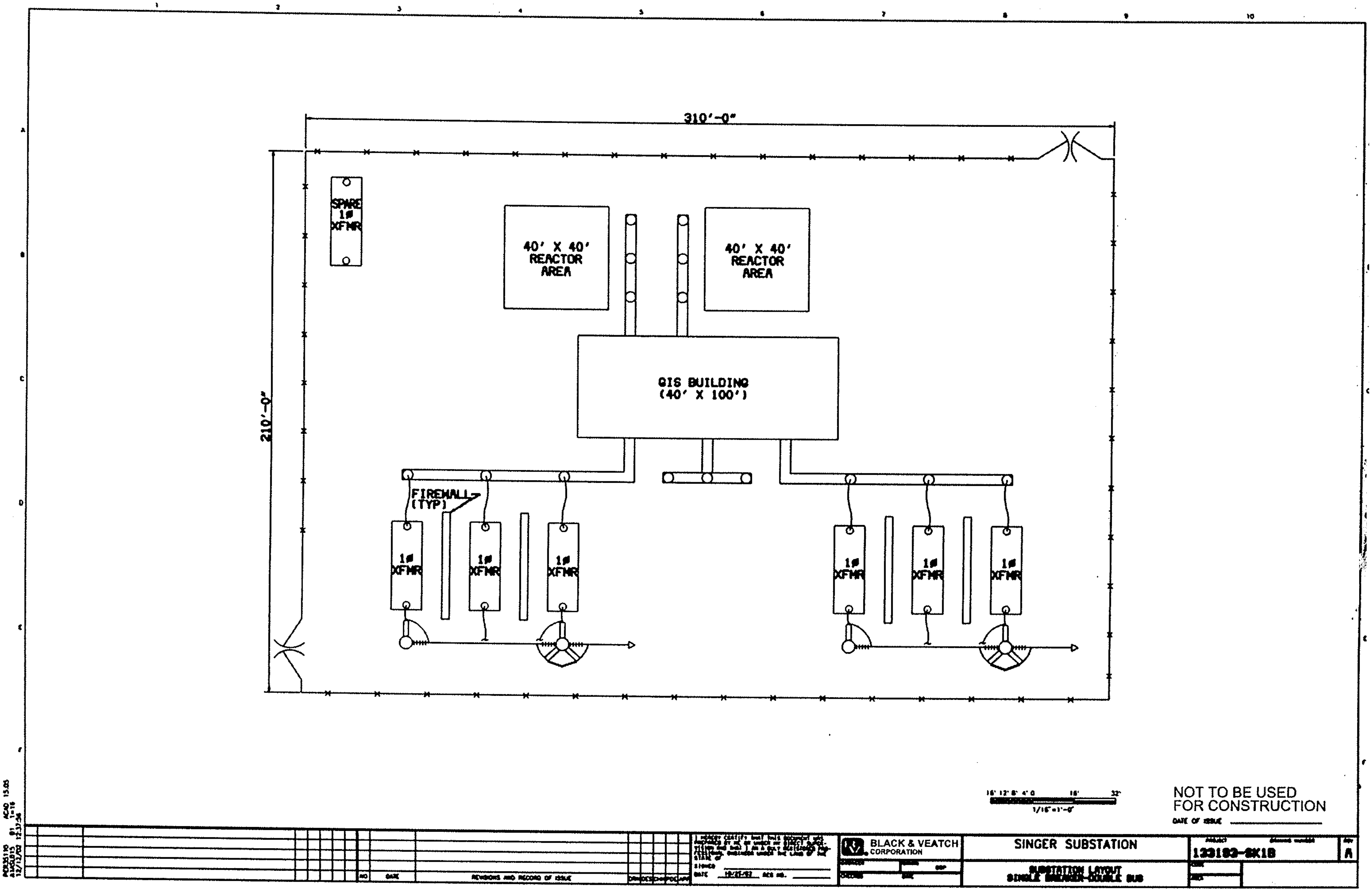
SINGER SUBSTATION

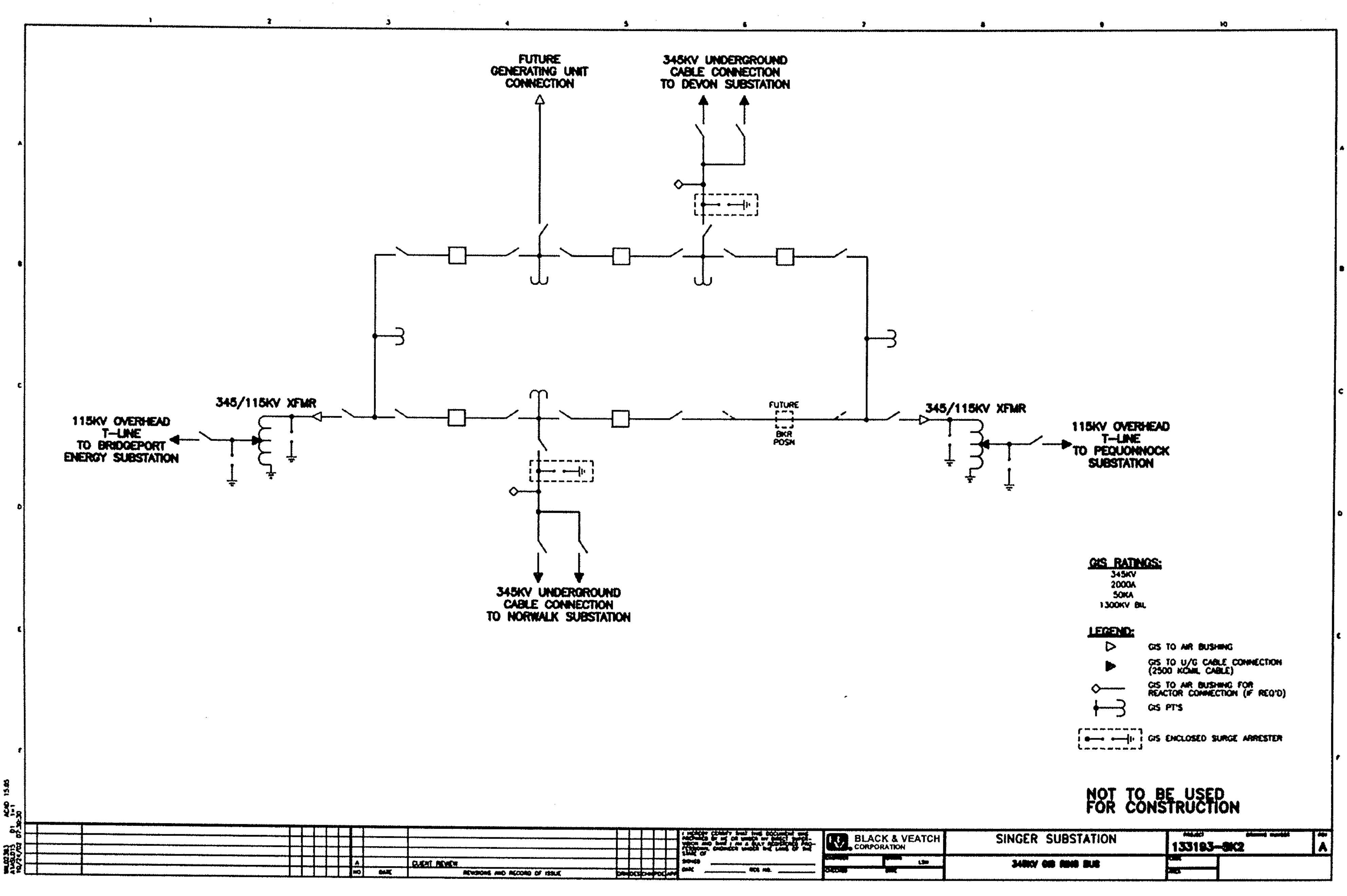
SUBSTATION LAYOUT
SINGLE BREAKER-DOUBLE BUS

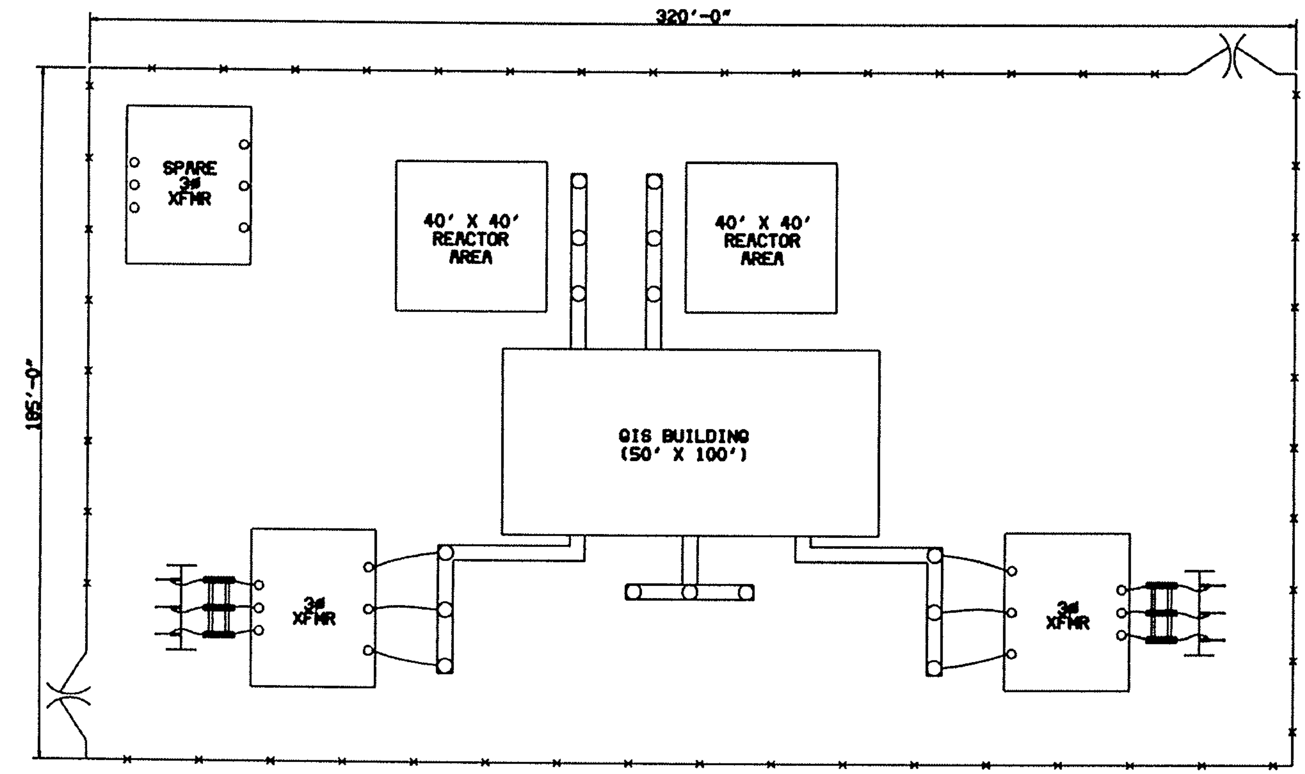
123183-SK1A

A

REVISIONS AND RECORD OF ISSUE


310'-0"
210'-0"
SPARE 1ø XFMR
40' X 40' REACTOR AREA
40' X 40' REACTOR AREA
GIS BUILDING (40' X 100')
FIREWALL (TYP)
1ø XFMR
1ø XFMR
1ø XFMR
1ø XFMR
1ø XFMR
1ø XFMR
1/16"=1'-0"
NOT TO BE USED FOR CONSTRUCTION
DATE OF ISSUE
BLACK & VEATCH CORPORATION
SINGER SUBSTATION
SUBSTATION LAYOUT SINGLE BREAKER-DOUBLE BUS
133183-SK1B
A
REVISIONS AND RECORD OF ISSUE


FUTURE
GENERATING UNIT
CONNECTION
345KV UNDERGROUND
CABLE CONNECTION
TO DEVON SUBSTATION
345/115KV XFMR
115KV OVERHEAD
T-LINE
TO BRIDGEPORT
ENERGY SUBSTATION
FUTURE
BKR
POSN
345/115KV XFMR
115KV OVERHEAD
T-LINE
TO PEQUONNOCK
SUBSTATION
345KV UNDERGROUND
CABLE CONNECTION
TO NORWALK SUBSTATION
GIS RATINGS:
345KV
2000A
50KA
1300KV BIL
LEGEND:
GIS TO AIR BUSHING
GIS TO U/G CABLE CONNECTION
(2500 KCMIL CABLE)
GIS TO AIR BUSHING FOR
REACTOR CONNECTION (IF REQ'D)
GIS PT'S
GIS ENCLOSED SURGE ARRESTER
NOT TO BE USED
FOR CONSTRUCTION
A
CLIENT REVIEW
NO
DATE
REVISIONS AND RECORD OF ISSUE
BLACK & VEATCH
CORPORATION
SINGER SUBSTATION
345KV GIS RING BUS
133193-SK2
A



NOT TO BE USED
FOR CONSTRUCTION

DATE OF ISSUE

BLACK & VEATCH CORPORATION

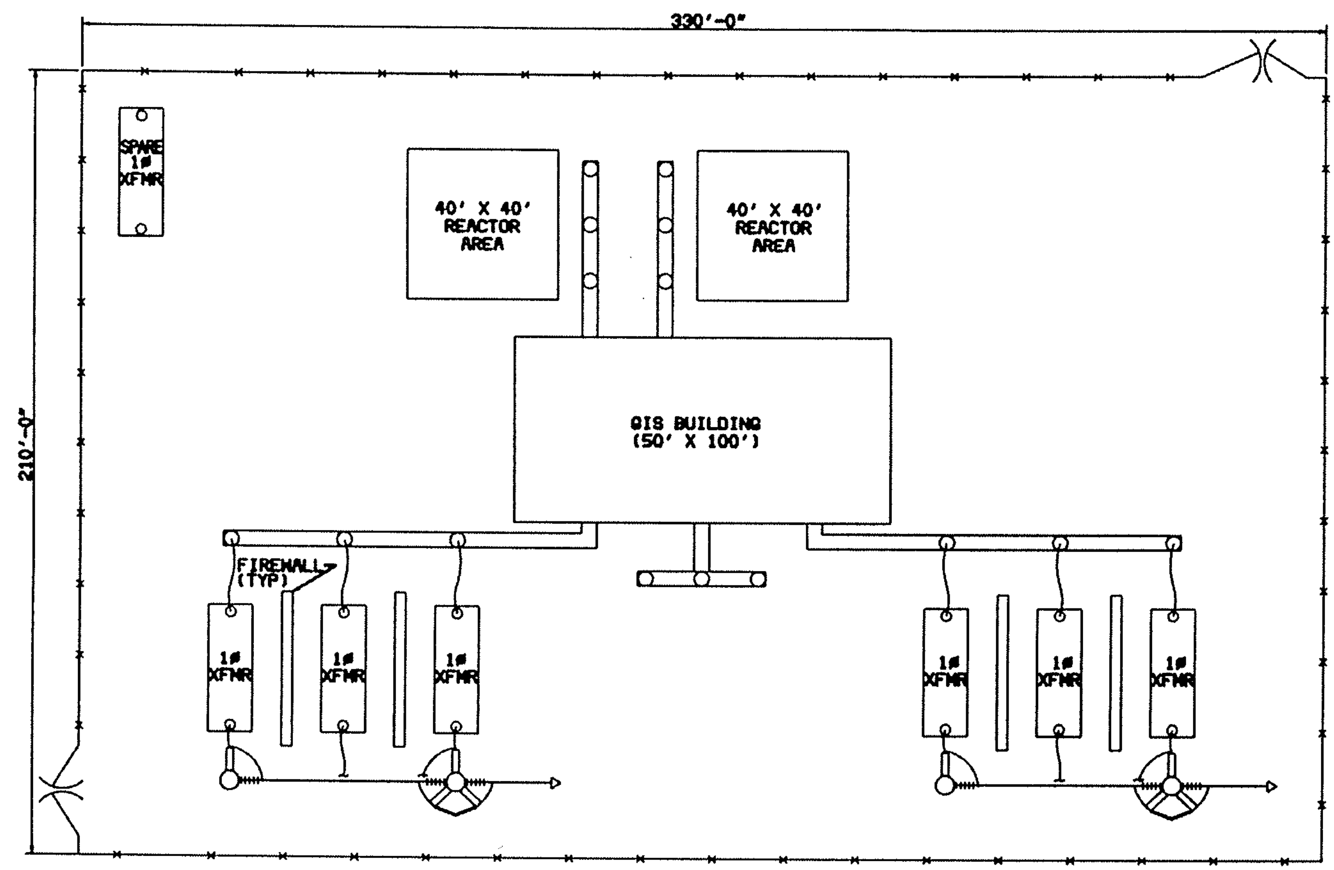
SINGER SUBSTATION

SUBSTATION LAYOUT
RING BUS

123183-SK2A

A

NO | DATE | REVISIONS AND RECORD OF ISSUE



1/16" = 1'-0"

NOT TO BE USED
FOR CONSTRUCTION

DATE OF ISSUE

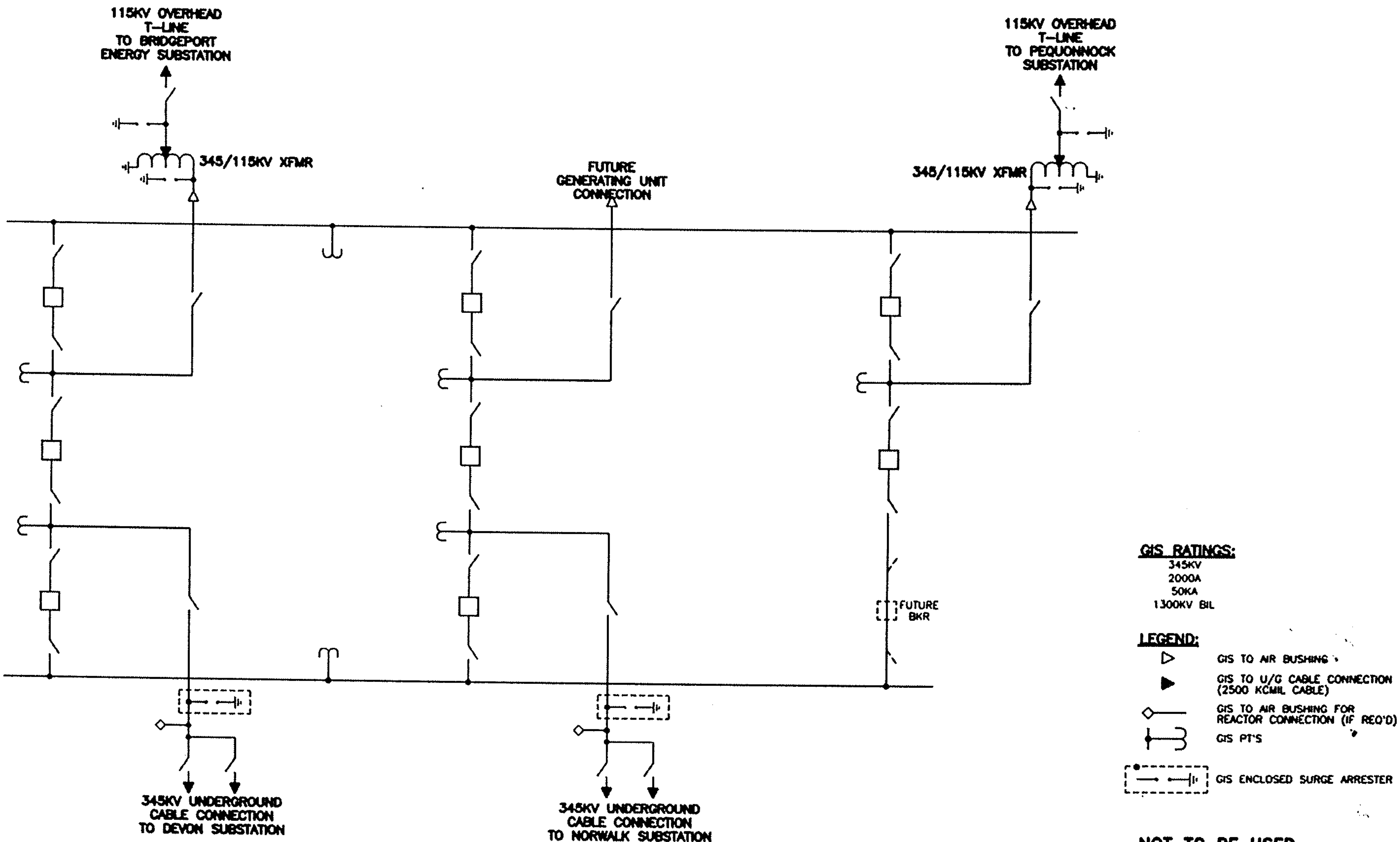
BLACK & VEATCH CORPORATION

SINGER SUBSTATION

SUBSTATION LAYOUT
RING BUS

123183-SK2B

A



NOT TO BE USED FOR CONSTRUCTION

BLACK & VEATCH CORPORATION

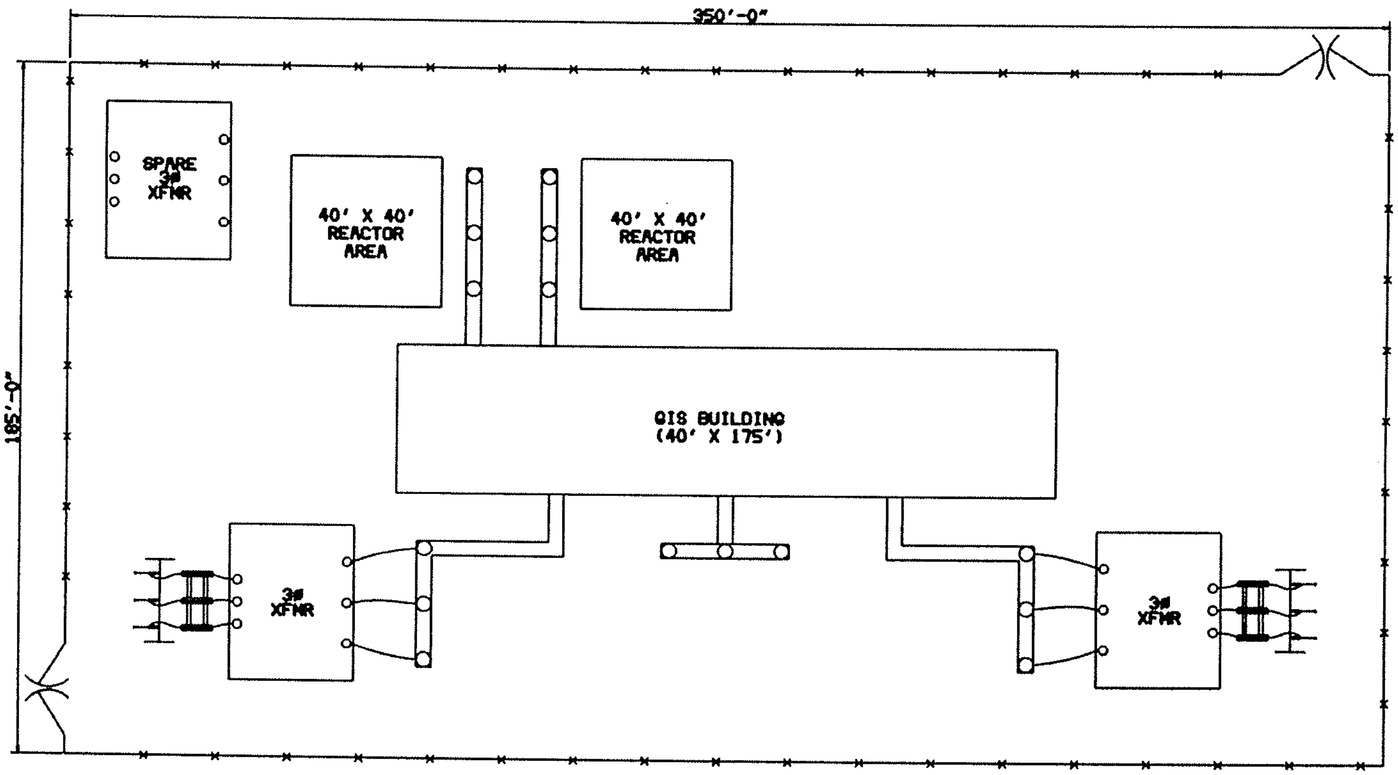
SINGER SUBSTATION

345KV GIS BREAKER-AND-A-HALF

133193-SK3

A

NO	DATE	REVISIONS AND RECORD OF ISSUE
A		CLIENT REVIEW



NOT TO BE USED FOR CONSTRUCTION

DATE OF ISSUE

1/16" = 1'-0"

BLACK & VEATCH CORPORATION

SINGER SUBSTATION

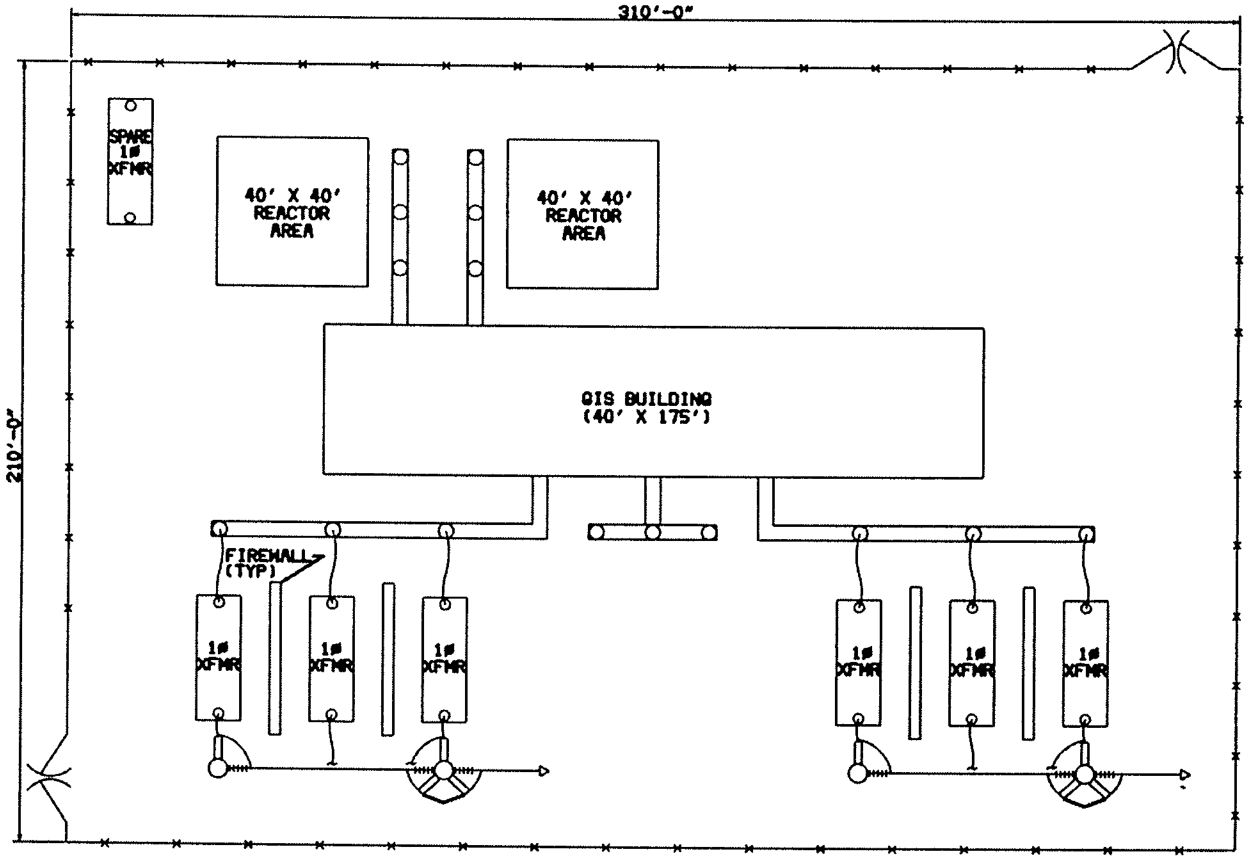
SUBSTATION LAYOUT BREAKER-AND-ONE-HALF

133183-SK3A

A

DATE 10/25/02

REVISIONS AND RECORD OF ISSUE

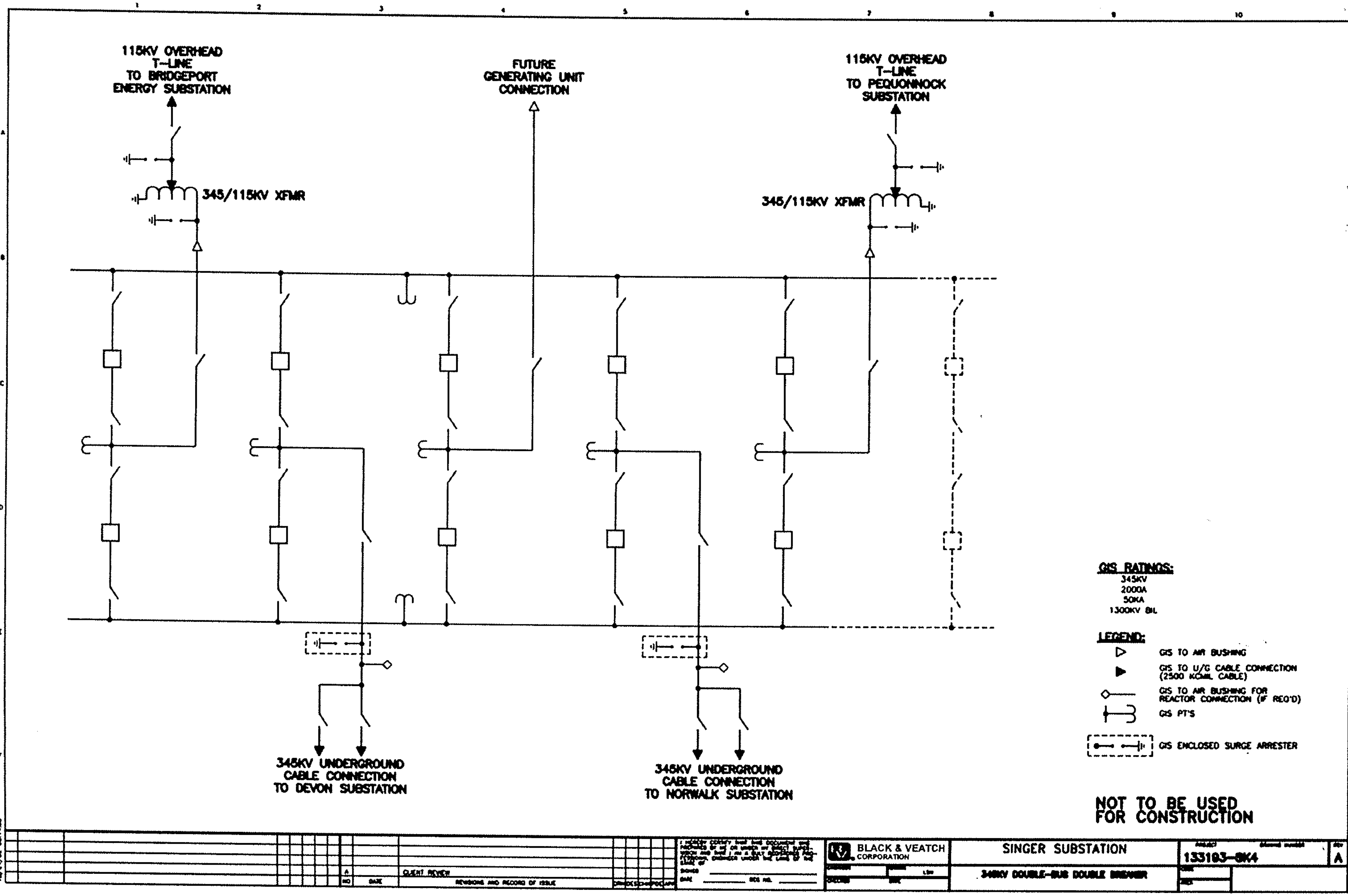


NOT TO BE USED FOR CONSTRUCTION

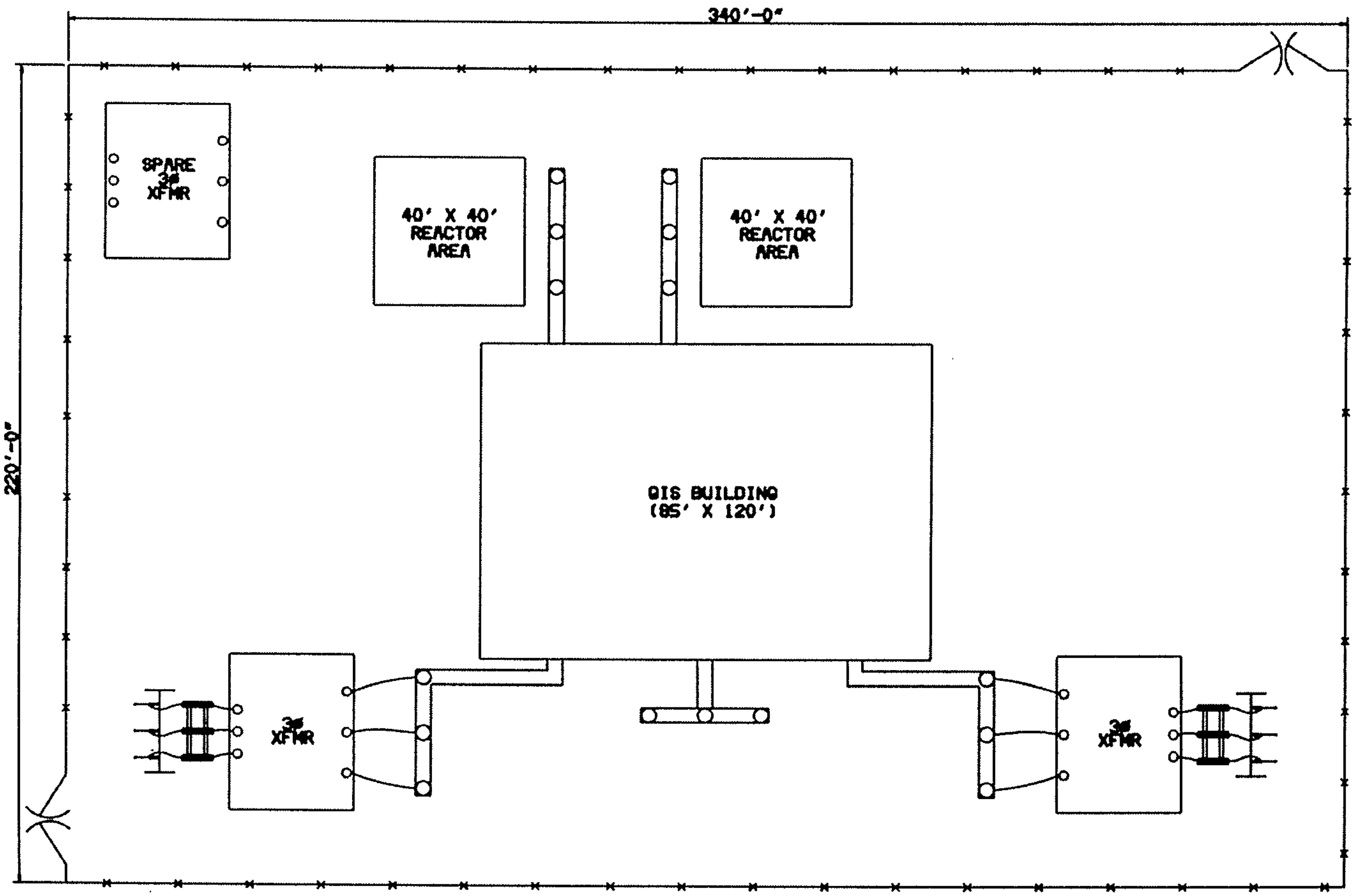
DATE OF ISSUE

BLACK & VEATCH CORPORATION	SINGER SUBSTATION	133183-SK3B	A
	SUBSTATION LAYOUT BREAKER-AND-ONE-HALF		

REVISIONS AND RECORD OF ISSUE



115KV OVERHEAD
T-LINE
TO BRIDGEPORT
ENERGY SUBSTATION
345/115KV XFMR
FUTURE
GENERATING UNIT
CONNECTION
115KV OVERHEAD
T-LINE
TO PEQUONNOCK
SUBSTATION
345/115KV XFMR
345KV UNDERGROUND
CABLE CONNECTION
TO DEVON SUBSTATION
345KV UNDERGROUND
CABLE CONNECTION
TO NORWALK SUBSTATION
GIS RATINGS:
345KV
2000A
50KA
1300KV BIL
LEGEND:
GIS TO AIR BUSHING
GIS TO U/G CABLE CONNECTION
(2500 KCMIL CABLE)
GIS TO AIR BUSHING FOR
REACTOR CONNECTION (IF REQ'D)
GIS PT'S
GIS ENCLOSED SURGE ARRESTER
NOT TO BE USED
FOR CONSTRUCTION
CLIENT REVIEW
REVISIONS AND RECORD OF ISSUE
BLACK & VEATCH
CORPORATION
SINGER SUBSTATION
A



NOT TO BE USED
FOR CONSTRUCTION

BLACK & VEATCH CORPORATION

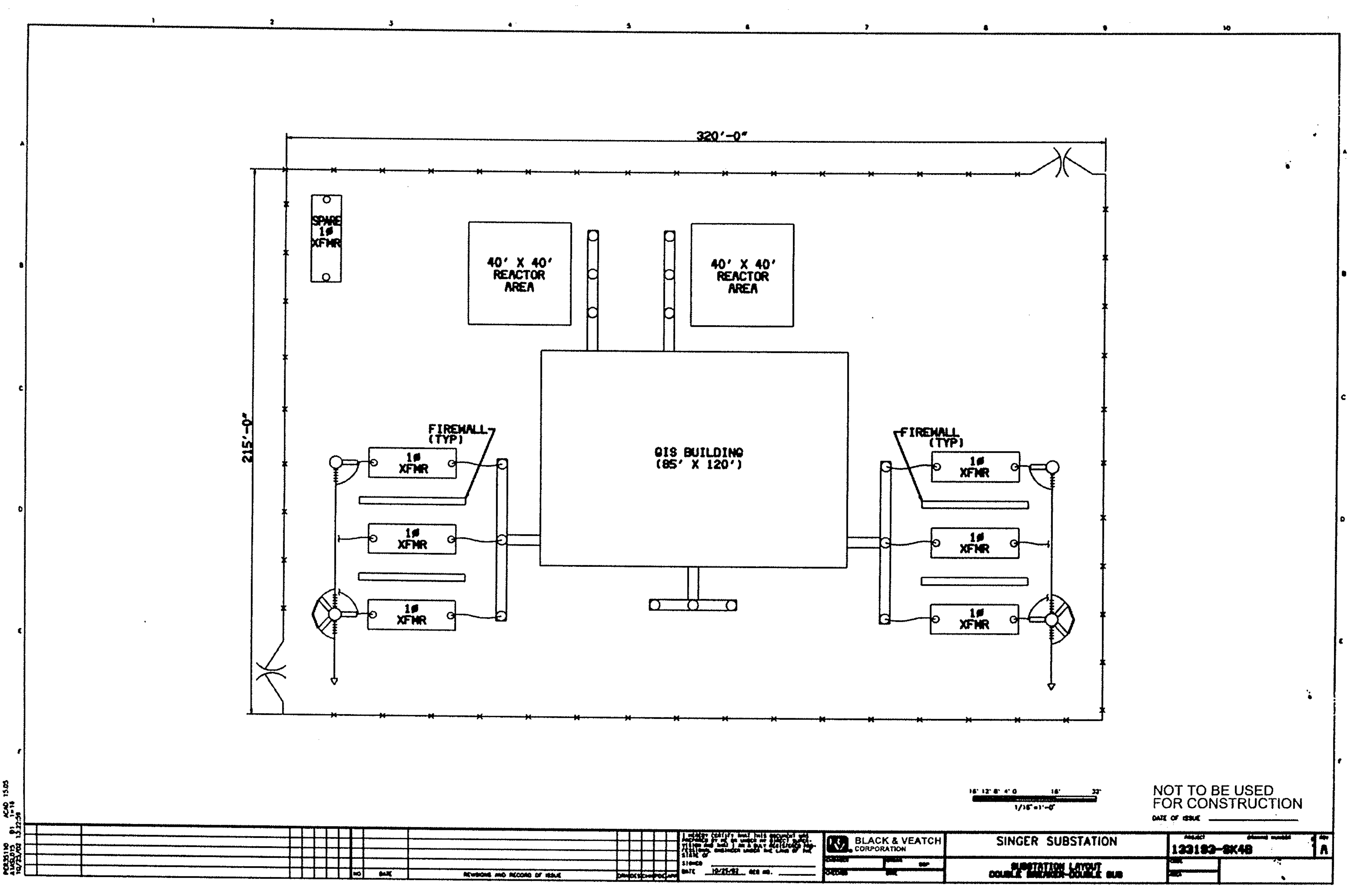
SINGER SUBSTATION

SUBSTATION LAYOUT
DOUBLE BREAKER-DOUBLE BUS

133183-SK4A

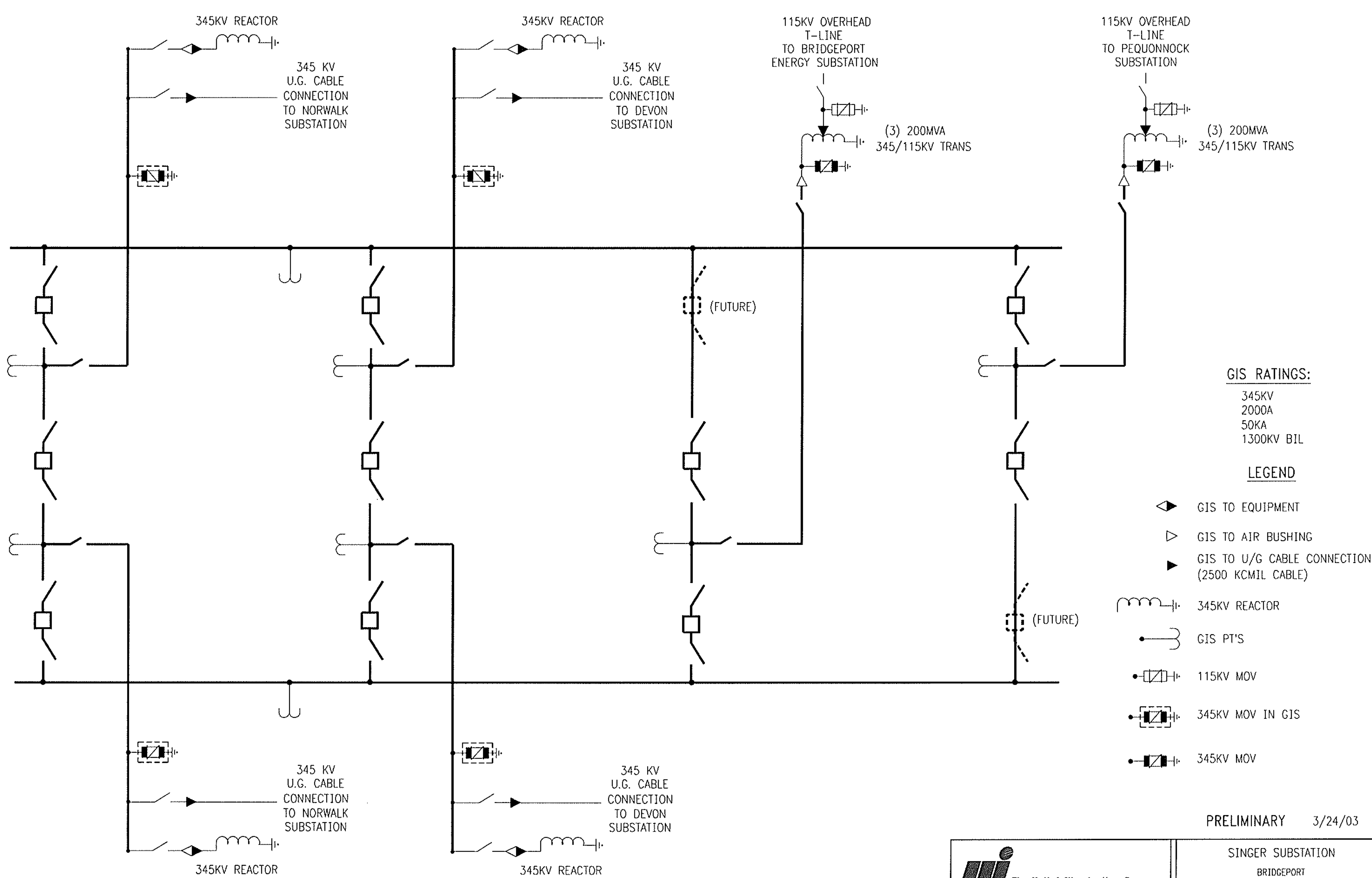
A

DATE 10/25/02


320'-0"
215'-0"
SPARE 1Ø XFMR
40' X 40' REACTOR AREA
40' X 40' REACTOR AREA
GIS BUILDING (85' X 120')
FIREWALL (TYP)
FIREWALL (TYP)
1Ø XFMR
1Ø XFMR
1Ø XFMR
1Ø XFMR
1Ø XFMR
1Ø XFMR
1/16"=1'-0"
NOT TO BE USED FOR CONSTRUCTION
DATE OF ISSUE
REVISIONS AND RECORD OF ISSUE
BLACK & VEATCH CORPORATION
SINGER SUBSTATION
SUBSTATION LAYOUT
DOUBLE BREAKER-DOUBLE BUS
133183-SK48
A

Appendix “B”

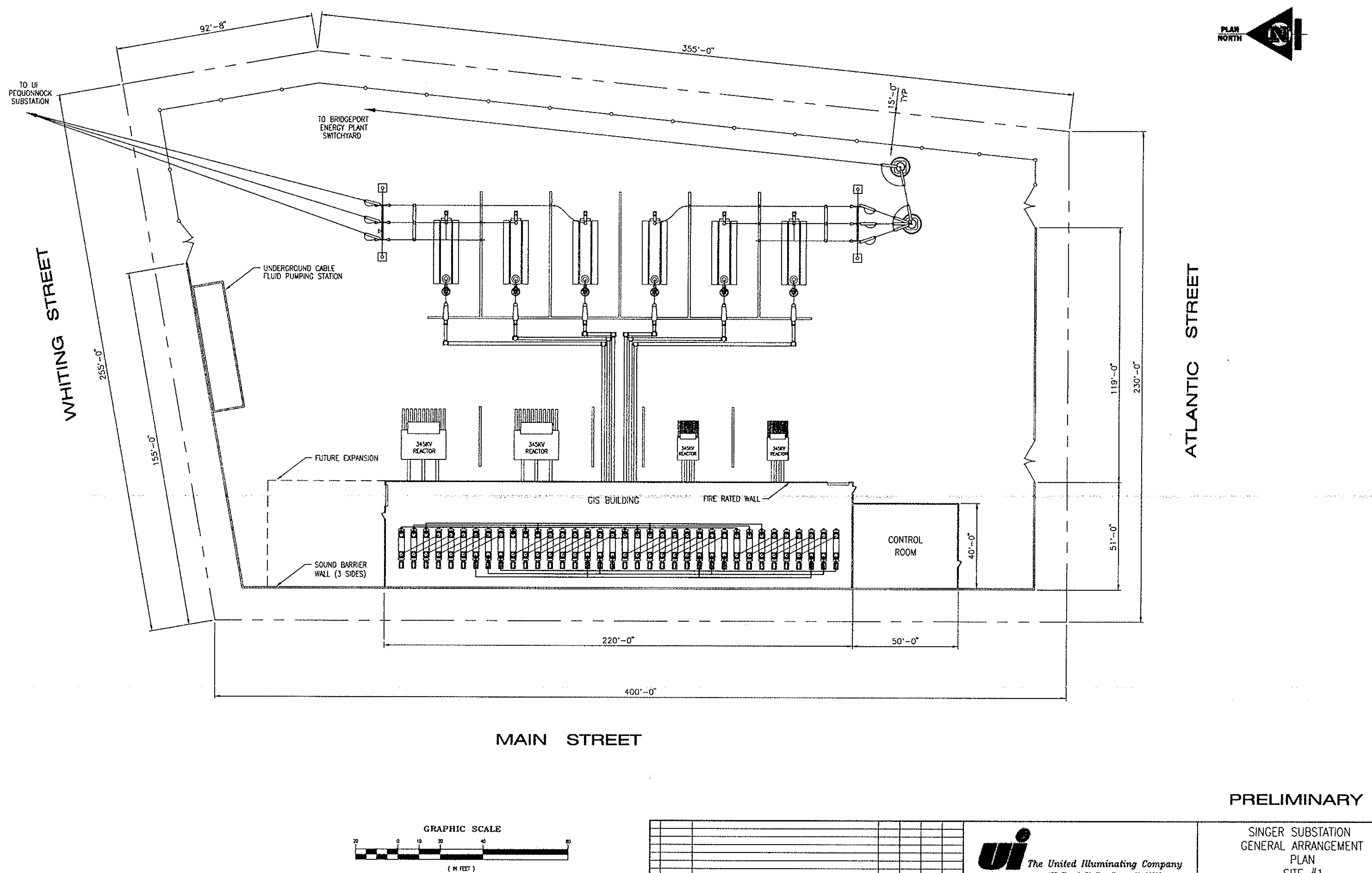
Singer Substation Layouts and Oneline for Site # 1, 7, 8, and 10



PRELIMINARY 3/24/03

The United Illuminating Company
157 Church St. New Haven, CT 06506

Drawn By GS	Engineering Appvl.	SINGER SUBSTATION BRIDGEPORT ONE LINE DIAGRAM	
Checked By RA	Operations Appvl.	Date 11/06/2002 Scale: NONE	Drawing Number 25251-100



PRELIMINARY

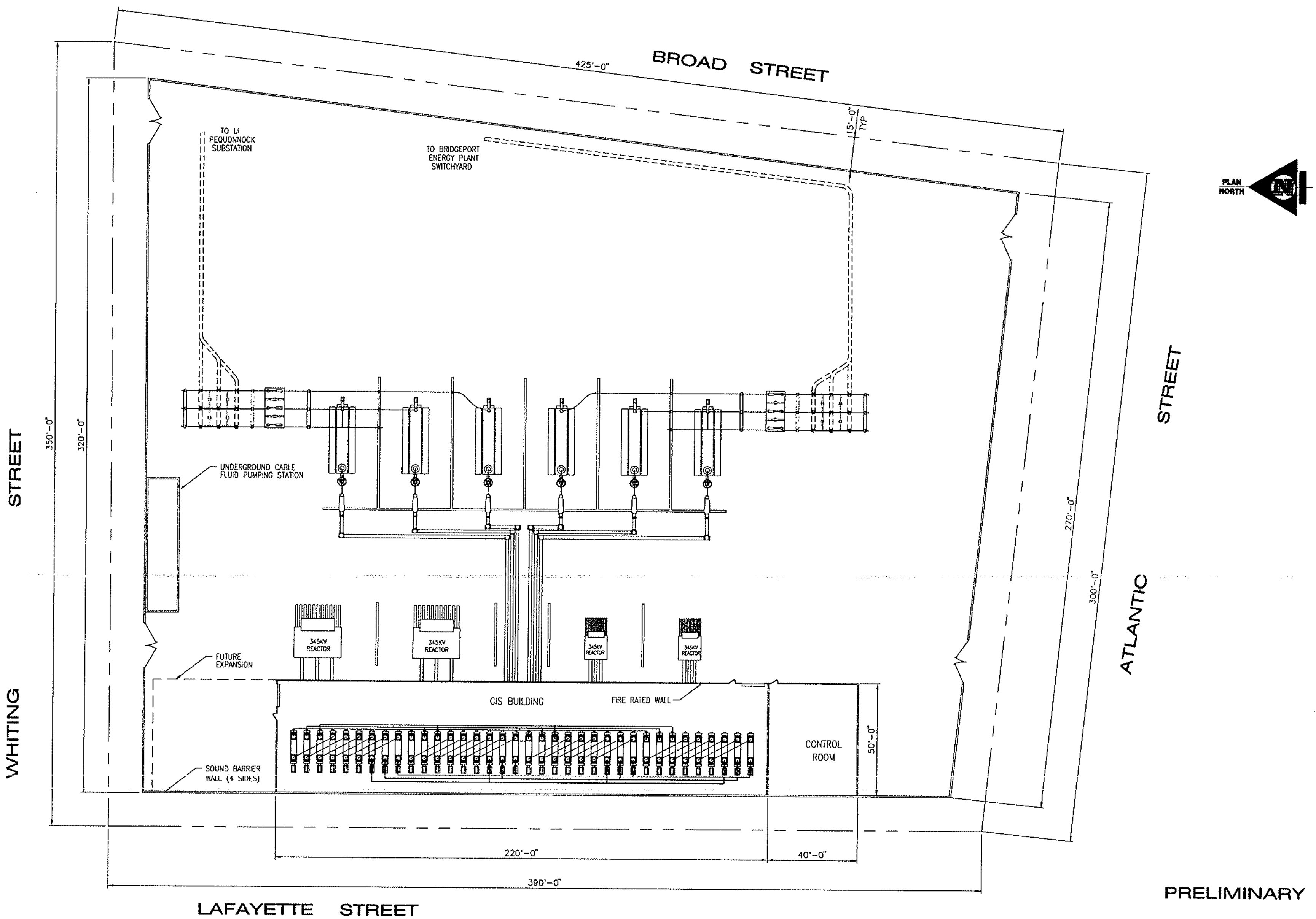
No	Date	Revision	By	Chkd.	Engr.	Supv.

The United Illuminating Company
157 Church St. New Haven, Ct. 06506

Drawn | Date | Scale: 1"=20'-0"
Chkd. | Design Engr. RSA | Design Supv. RSA

SINGER SUBSTATION
GENERAL ARRANGEMENT
PLAN
SITE #1

CAD FILE NAME	SEQUENCE No.	DRAWING NUMBER
	063534	SP-1



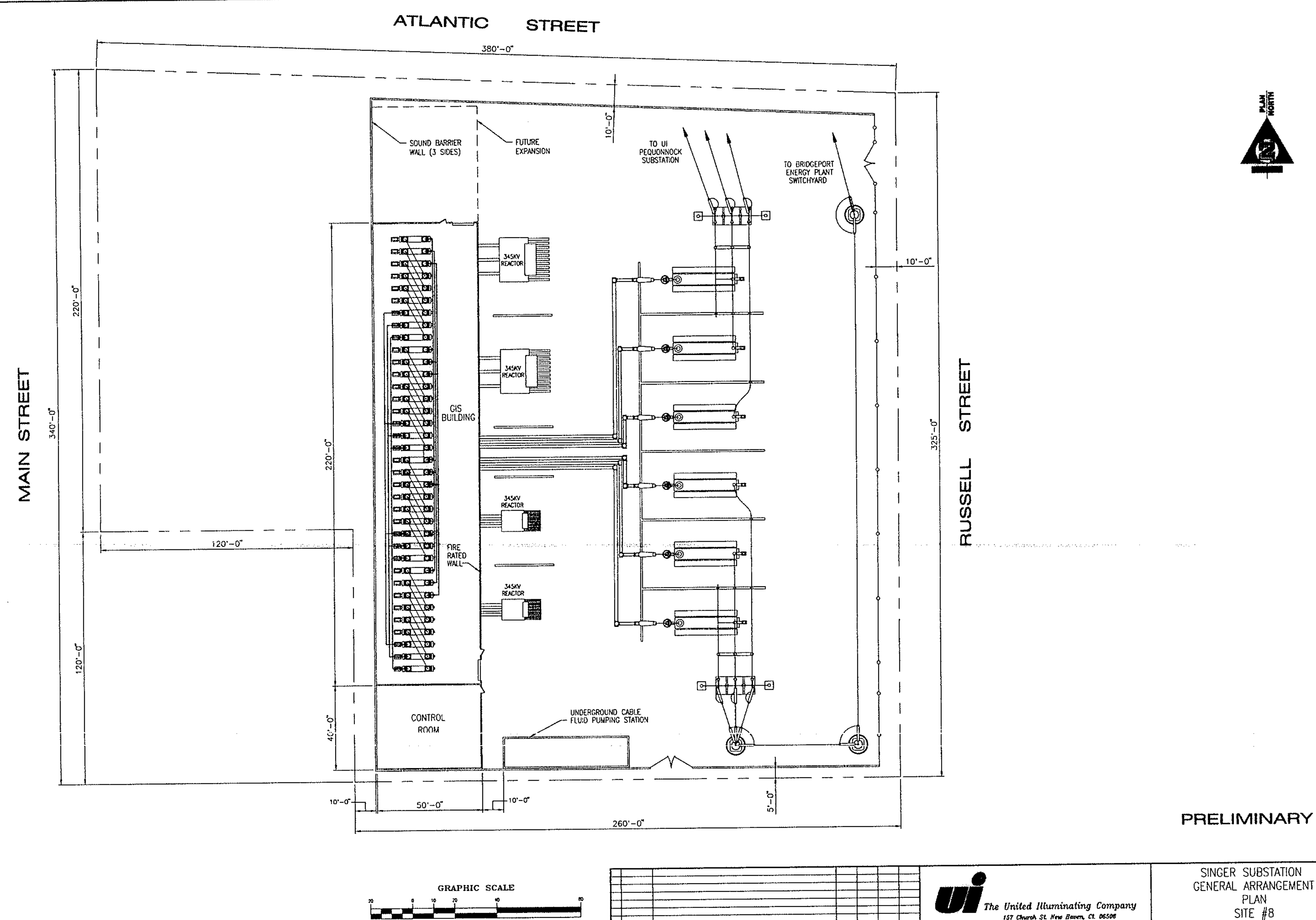
No	Date	Revision	By	Chkd.	Engr.	Supv.

The United Illuminating Company
157 Church St. New Haven, Ct. 06506

Drawn | Date | Scale: 1"=20'-0"
Chkd. | Design Engr. RSA | Design Supv. RSA

SINGER SUBSTATION
GENERAL ARRANGEMENT
PLAN
SITE #7

CAD FILE NAME | SEQUENCE No. 063534 | DRAWING NUMBER SP-7



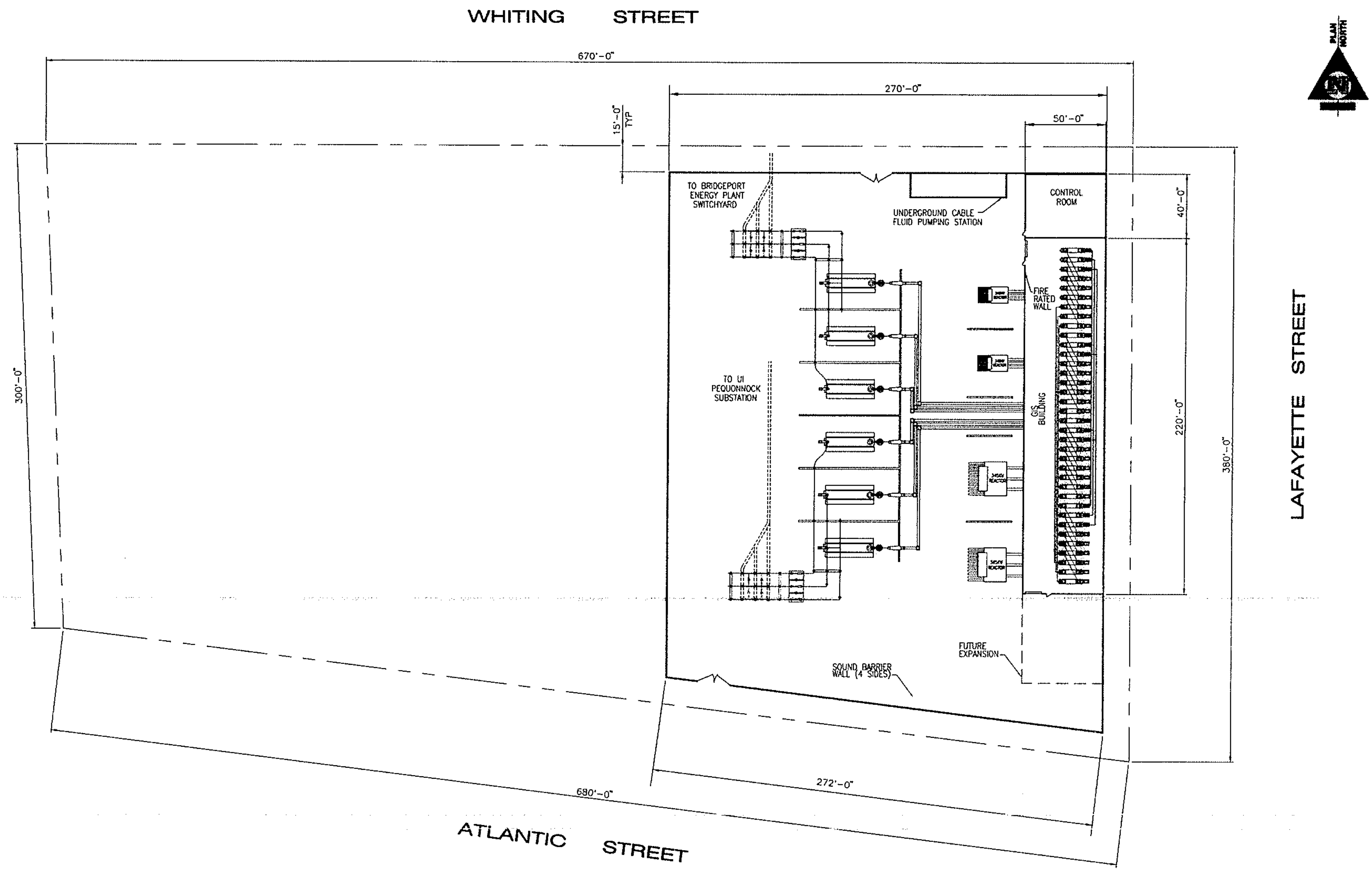
No	Date	Revision	By	Chkd.	Engr.	Supv.

The United Illuminating Company
157 Church St. New Haven, Ct. 06506

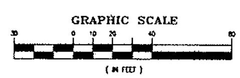
Drawn
Chkd.
Date
Design Engr. RSA
Scale: 1"=20'-0"
Design Supv. RSA

SINGER SUBSTATION
GENERAL ARRANGEMENT
PLAN
SITE #8

CAD FILE NAME
SEQUENCE No. 063534
DRAWING NUMBER SP-8



PRELIMINARY



No	Date	Revision	By	Chkd.	Engr.	Supv.

The United Illuminating Company
157 Church St. New Haven, Ct. 06506

Drawn	Date	Scale: 1"=30'-0"
Chkd.	Design Engr. RSA	Design Supv. RSA

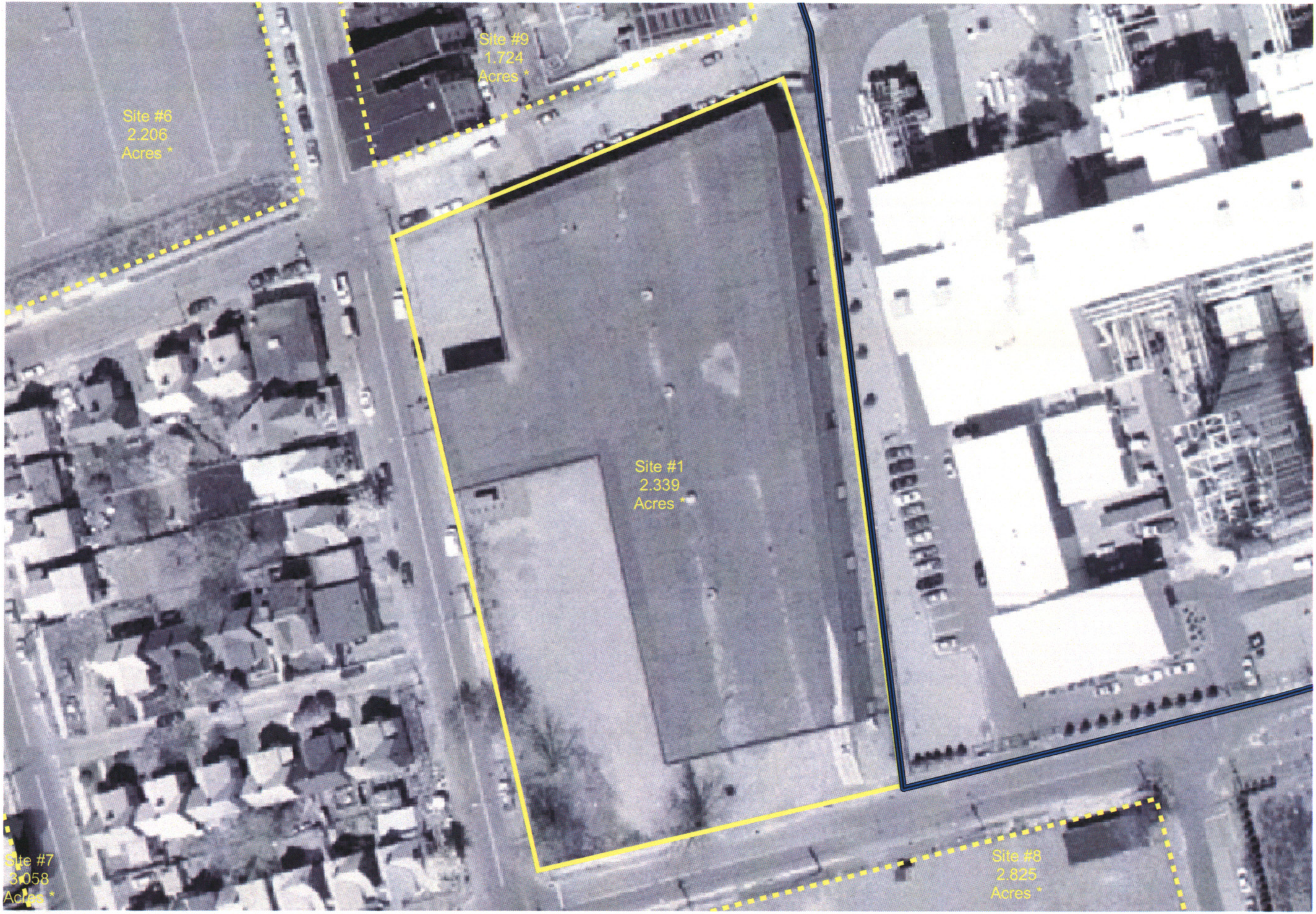
SINGER SUBSTATION
GENERAL ARRANGEMENT
PLAN
SITE #10

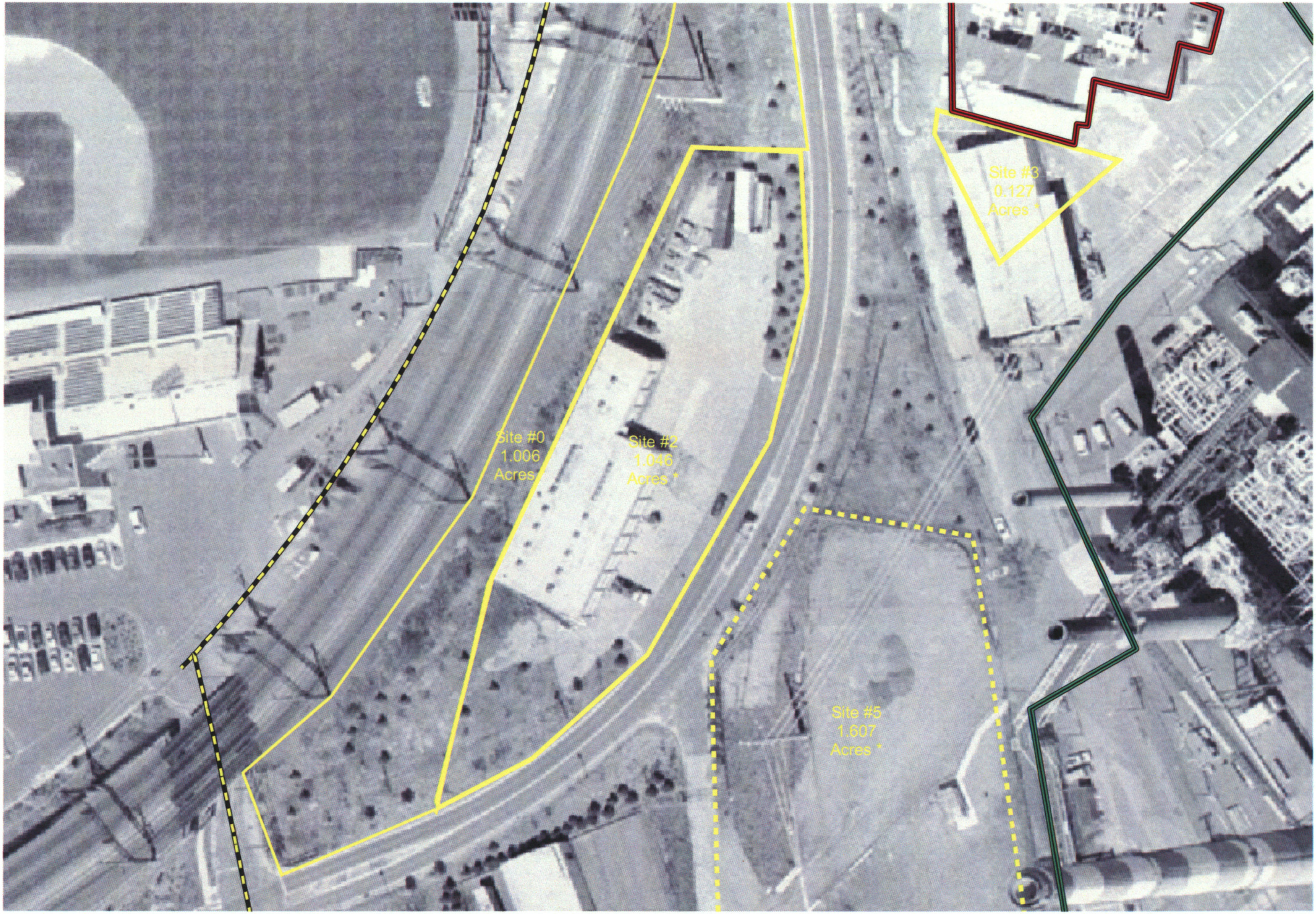
CAD FILE NAME	SEQUENCE No.	DRAWING NUMBER
	063534	SP-10

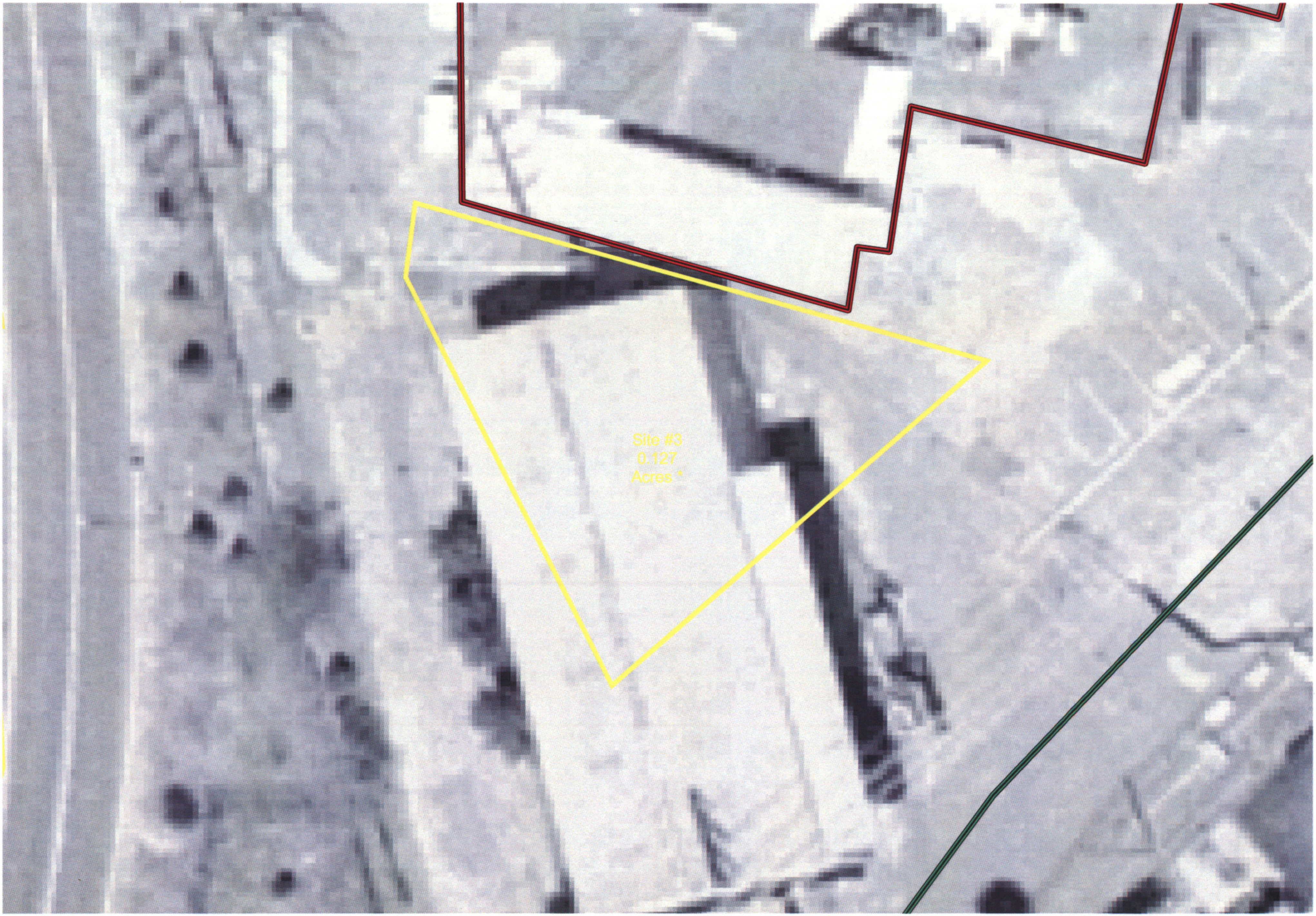
Appendix “C”

Aerial Photos of Individual Sites

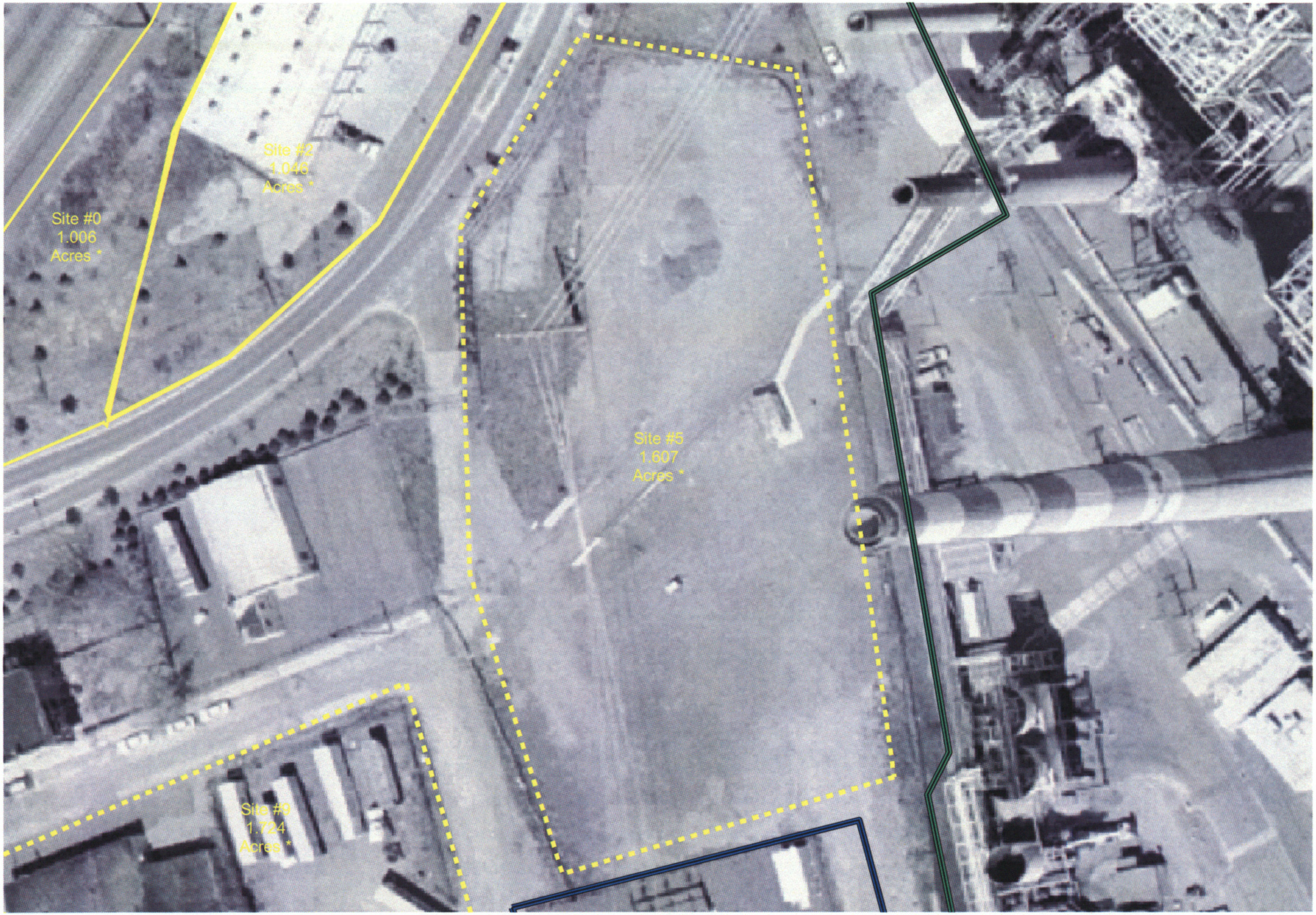
Singer Substation Site Location

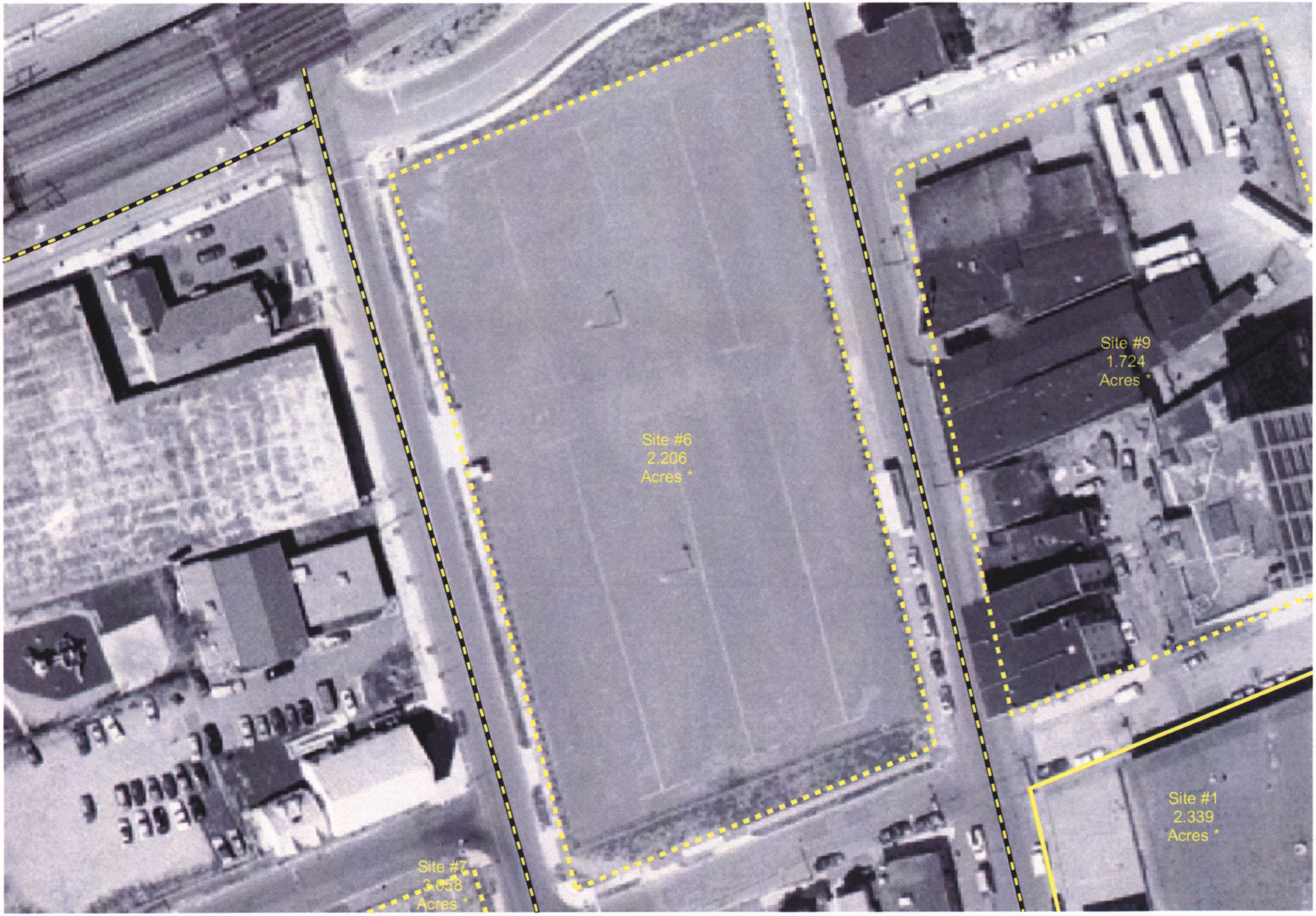

Site #6
2.206
Acres *
Site #9
1.724
Acres *
Site #1
2.339
Acres *
Site #7
3.058
Acres *
Site #8
2.825
Acres *


Site #0
1.006
Acres
Site #2
1.046
Acres *
Site #3
0.127
Acres *
Site #5
1.607
Acres *


Site #3
0.127
Acres ±

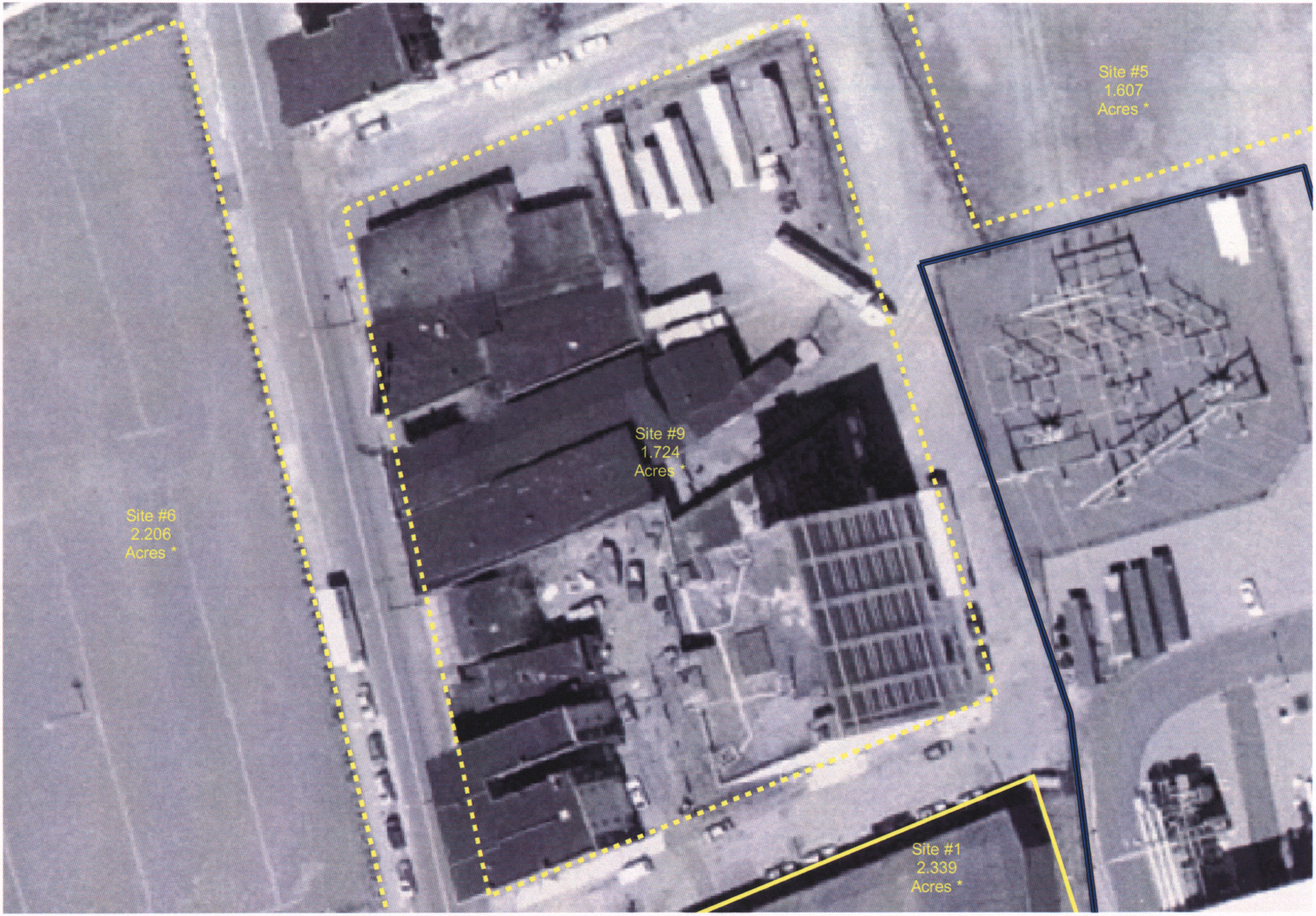

Site #4
0.244
Acres *

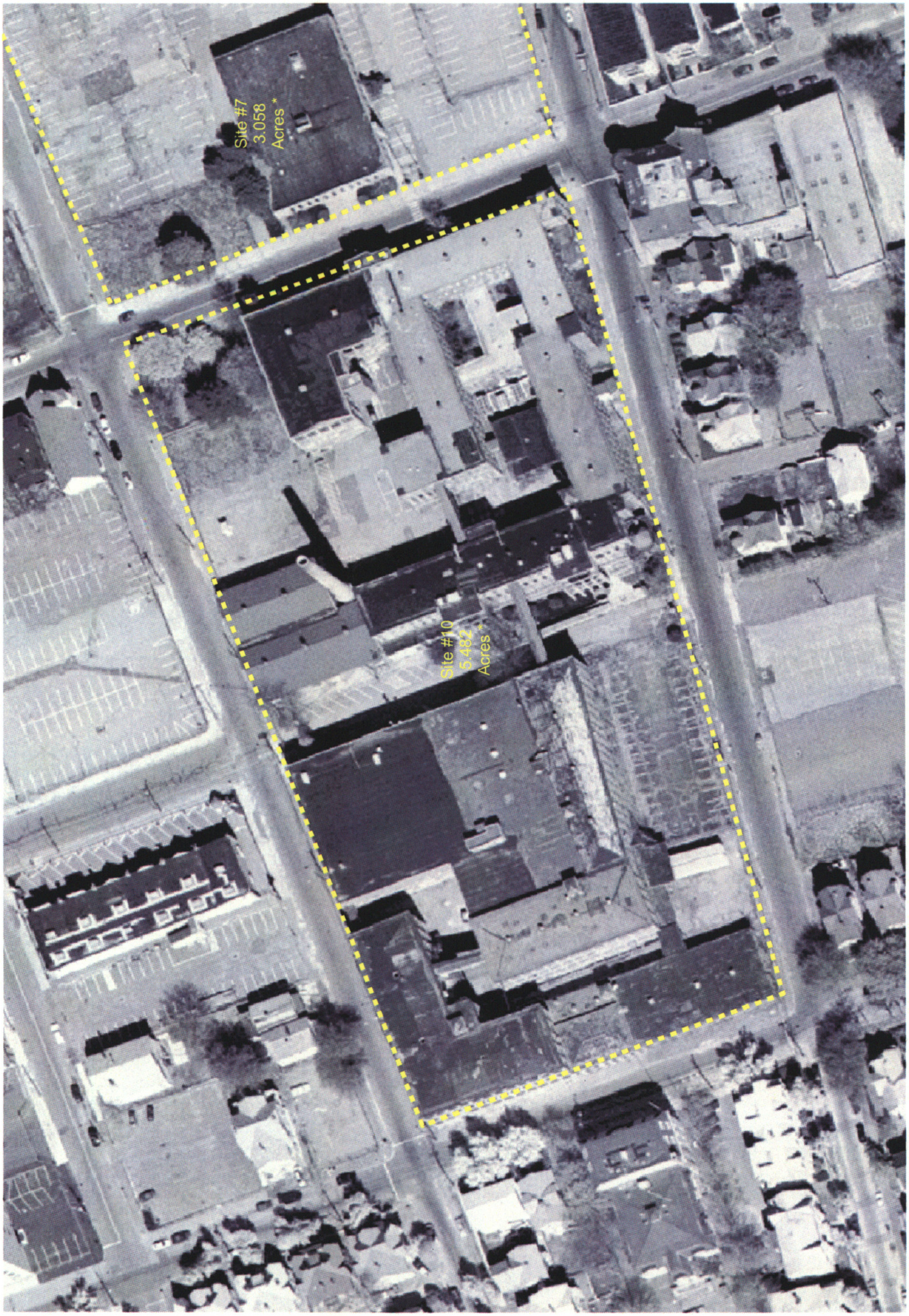

Site #0
1.006
Acres *
Site #2
1.046
Acres *
Site #5
1.607
Acres *
Site #9
1.724
Acres *


Site #9
1.724
Acres *
Site #6
2.206
Acres *
Site #1
2.339
Acres *
Site #7
3.058
Acres *


Site #6
Acres *
Site #7
3.058
Acres *


Site #1
2.339
Acres *
Site #8
2.825
Acres *


Site #5
1.607
Acres *
Site #9
1.724
Acres *
Site #1
2.339
Acres *
Site #6
2.206
Acres *


Site #7
3.058
Acres *
Site #10
5.482
Acres *


Site #1
2.339
Acres *
ATLANTIC ST
Site #8
2.825
Acres *
Legend
<all other values>
ID
UI Co. Pequonnock Substation
PSE & G Bridgeport Harbor Station
Bridgeport Energy
pequg
115kv
Singer Substation Site Location
UI - Graphics Dept.
June 2003
* - Acreage is approximate

Appendix "D"

Singer Substation

Site analysis sheet and Cost Estimates

Site #	Site Size (Acres)	Owner	Planned Use By Owner	Advantages	Dis-advantages	Estimated Cost of Property	Estimated Cost of 115kV Work (See Note 1)	Estimated Cost of 345kV UG (See Note 2)	115 kV TXM ROW Acquisition Required	UI Site Selection Rating	Comments
Note 1: OH cost based on $1.5M per circuit mile. UG cost basec 115KV UG cost estimates are based upon $4.6M per mile.											
Note 2: UG cost estimates are costs from common fixed points along the proposed route into each substation site, and an estimated cost per mile of $5.2M.											
1	2.339	PSEG	Possible Warehouse consolidation.	1) Adequate Size of Parcel 2) Adjacent to Generation Facility (Bridgeport Energy) 3) Industrial Zoning 4) Easier 115kV interconnection 5) Least amount of screening required 6) Suggested Site by owner Oct 2002	1) Owner is reluctant to sell since retraction of 18.4 applications 2) Close proximity to a Gas pipeline 3) Neighborhood will require special screening	$1,500,000	$250,000	$2,000,000	Yes	1	UI's First choice for construction of 345 kV substation
2	1.046	PSEG	Unknown	1) Close to current 115kv Substation (Pequonnock) 2) Close to Bridgeport Energy 115 kV Line 3) Easier 115kV interconnection	1) Inadequate Size 2) Potential significant Insulator contamination due to RR proximity	$300000*	N/A	N/A	N/A	N/A	Parcel may have use as an auxillary site
3	0.127	PSEG	Warehouse (Existing)	1) Close to current 115kv Substation (Pequonnock) 2) Close to Bridgeport Energy Line 3) Easier 115kV interconnection 4) No Neighbors	1) Inadequate Size of Parcel	$250000*	N/A	N/A	N/A	N/A	Parcel may have use as an auxillary site
4	0.244	UI	Substation Expansion	1) Close to existing Pequonnock Substation 2)No Neighbors 3) "Possible" declaratory ruling	1) Inadequate Size of Parcel 2) Too Close to LI Sound	N/A	N/A	N/A	N/A	N/A	Parcel may have use as an auxillary site
5	1.607	PSEG	Future Generating Station Expansion for Pollution Control	1) Adjacent to Bridgeport Energy 2) Minimal 115kV construction required 3) No Residential Neighbors	1) Planned Use by Owner 2) Must acquire TXM and ROW from Bridgeport Energy 3) Size of property extremely tight for proposed 345kV substation 4) Possible extended outages for Bridgeport Energy during construction 5) Tight Size of property would dictate complicated construction 6) Limited experience with required engineering solutions 7) Neighborhood may require special screening	$1,000,000	$50,000	$100,000	Yes	4	May Require use of site 3 for Auto TXF's to 115kV Substation. May require converting Bridgeport Energy to 345kV. Possible multi-story substation. Owner has future use. Future expansion would not be possible.
6	2.206	BPT Housing	Affordable Housing	1) Adequate size of property 2) Presently Vacant Site 3) Easier Construction Sequence	1) Planned Use by Owner for low/moderate income housing 2) Must acquire TXM and ROW from Bridgeport Energy 3) Close to residential might have special zoning requirements 4) City has made the parcel not for sale 5) Neighborhood may require special screening	Not available	$300,000	$1,000,000	Yes	N/A	We have been told through our Attorney that the Housing Authority will not make this land available. This was Later confirmed on 4/17 at the Informal Mtg with the Mayor.
7	3.058	Faith Temple Church	Church Construction	1) Adequate size of property 2) Mostly Vacant lot 3) Easier construction sequence	1) Difficult 115kV underground Construction 2) Close to residential housing 3) Close to University of Bridgeport 4) Possible UG 115kv interconnection required 5) Owner is reluctant to sell 6) Must acquire TXM and ROW from Bridgeport Energy 7) Neighborhood will require special screening and sidewalks 8) Must acquire 3 multi family homes at c/o Broad & Atlantic Sts. 9) Need zoning change from residential to heavy industrial for	$1,200,000*	$2,600,000	$1,700,000	Yes	5	Peq to Site#7=2000ft, BE to site #7=950 ft.
8	2.825	PSEG	Future Generating Station Expansion	1) Adequate Size of Property 2) Mostly Vacant 3) Easier Construction on Site	1) Property has a residential building occupying one corner of the site 2) More Difficult UG construction (Crossing HP Gas pipeline) 3) Special screening is required 4) Must acquire TXM and ROW from Bridgeport Energy	$525,000	$1,600,000	$3,000,000	Yes	2	Need to acquire private TXM ROW across BE/BHS property for Txm entry.
9	1.724	Multiple	Unknown	1) Size Appears Adequate 2) Easier construction sequence	1) A Large amount of Demolition required 2) Must acquire TXM and ROW from Bridgeport Energy 3) Neighborhood may require special screening 4) Site is too small for the Substation without special construction 5) Need to relocate at least 4 Businesses including P.J. Reynolds Moving Co.	Site Rejected	$100,000	$1,300,000	Yes	N/A	Numerous property owners would be affected by demolition and taking of property
10	5.29	Spencer Blackstone	Residential Apartments	1) Size more than adequate 2) Surplus Land after Completion 3) Entire Lot is on the Market	1) Land cost 4,000,000= $756,000 or $17/Sq Ft. 2) Zoning change has been obtained by owner to residential. 3) Construction has begun on residential Apartments 4) Highest cost to connect due to distance from BE& Peq 5) Largest screening wall required surrounded by residential establishments 6) Need UG 115KV Transmission from BE and Peq. 7) Abuts UB property 8) Need to get zone change to Heavy Industrial for substation Use 9) Large amount of demolition req'd. 75% of site covered in 4 story Bldgs.	$4,000,000	$4,375,000	$2,000,000	no	6	Peq to Site#10= 3000ft , BE to site #10= 2000 ft
11	11	Remington Property	Corporate Offices and Manufacturing	1) Site is more than adequate 2) Surplus Land can be sold to help defray costs 3) Small residential exposure one line borders LI sound and another borders Loco Pl. and industrial	1) Site is located approximately 1/3 of a mile from desired interconnection 2) Overhead 115kV highly unlikely 3) Underground construction from Pequonnock, Bridgeport Energy and Railroad Avenue. 4) High interconnection costs. 5) Relocation of existing business currently ... rty. 6) Demolition costs.	$4,458,000	$2,800,000	$3,548,000	No		Land would be split with Port Authority

Singer Substation Differential Cost Analysis							
Site #	**115KV**	**345KV**	**Substation**	**Land**	**Demolition**	**Total**	
1	$250,000	$2,000,000	$33,440,000	$1,500,000	$250,000	$37,440,000	$0
7	$2,600,000	$1,700,000	$34,440,000	$4,000,000	$250,000	$42,990,000	$5,550,000
8	$2,887,500	$1,100,000	$33,940,000	$725,000	$0	$38,652,500	$1,212,500
10	$4,375,000	$2,000,000	$33,440,000	$4,000,000	$1,500,000	$45,315,000	$7,875,000
11	$2,800,000	3,548,000	$33,440,000	$4,458,000	$1,000,000	$45,246,000	$7,806,000

Singer Substation Preliminary Cost Estimate				
Item	Description	Unit Cost	# Req'd	Total
1	Bldg & Foundations	lot	lot	$ 2,500,000.00
2	Shunt Reactors- 75MVAR	$1,200,000.00	2	$ 2,400,000.00
3	Shunt Reactors 150MVAR	$1,500,000.00	2	$ 3,000,000.00
4	115/345KV Auto Txfrs.	$1,340,000.00	6	$ 8,040,000.00
5	GIS Equipment	$15,000,000.00	1	$15,000,000.00
7	Station Service & Grounding	$500,000.00	1	$500,000.00
8	Relaying & Control	$2,000,000.00	1	$2,000,000.00
		Totals		$33,440,000.00

Appendix "E"

Black & Veatch Report

Singer Substation Site Selection Report.

UNITED ILLUMINATING

SINGER SUBSTATION SITE SELECTION STUDY

REVISION 1

Date: June 24, 2003

Revision 1 = Added Site #11 to the Study.

UNITED ILLUMINATING

SINGER SUBSTATION SITE SELECTION STUDY

This substation site selection study report identifies and evaluates possible sites for the construction of the new UI 345kV Singer GIS Substation in the Bridgeport, CT area. Based on the detailed evaluation of the preferred sites, the report recommends the one site most suitable for locating the substation. This evaluation includes proposed substation arrangements (including future expansion capability), transmission line routings (overhead & underground), and estimated costs for each proposed site determined to be feasible for construction of the Singer Substation.

UI has identified 11 potential properties in the Bridgeport, CT area as potential sites for the new Singer Substation. This document provides a brief summary of the feasibility of constructing the new Singer Substation on each of the 11 potential sites. The 11 potential site locations are identified on the POTENTIAL SINGER SUBSTATION SITES drawing (Drawing # SP-0A) included in Attachment A.

Preliminary Site Evaluation

In a preliminary evaluation of the potential site locations for the Singer Substation, site locations 2, 3, 4, 5, 6, & 9 were determined to have undesirable characteristics for the placement of the 345kV Singer GIS Substation. A summary of the undesirable characteristics for these sites is provided in the following descriptions.

Site #2

Site #2 is narrow plot of land, consisting of approximately 1.05 acres, located between Railroad Court Street and the railroad tracks. The site would allow for adequate access to both the 345kV underground cable circuits and the 115kV overhead transmission line circuits. The size of the site however is not sufficient to support the complete footprint of the new Singer Substation. Site #2 is only large enough to support the 345kV GIS building and the 345kV shunt reactors. The 345/115kV power transformers and interconnection to the 115kV transmission lines would have to be located on another site. Locating the power transformers and 115kV transmission line interconnections on another site introduces additional issues/concerns associated with protective relaying, control, and operation & maintenance. These issues/concerns can be avoided by constructing the complete facility on a single site. In addition, Site #2 presently contains an existing structure that would have to be removed prior to constructing anything on the site. Because of these issues/concerns, Site #2 was determined to be a non-preferred site and no further development or evaluation was performed for this site.

Site #3

Site #3 is a small triangular shaped plot of land, consisting of approximately 0.13 acres, located on the South end of the existing UI Pequonnock Substation. The size of the site is not sufficient to support the new Singer Substation. Site #3 is only large enough to locate one of the 345/115kV transformer banks associated with the interconnection of the 115KV lines to the Singer Substation. Similar to Site #2, locating one power transformer bank and one 115kV transmission line interconnection on another site introduces additional issues/concerns associated with protective relaying, control, and operation & maintenance. These issues/concerns can be avoided by constructing the complete facility on a single site. In addition, Site #3 presently contains an existing structure that would have to be removed prior to constructing anything on the site. Because of these issues/concerns, Site #3 was determined to be a non-preferred site and no further development or evaluation was performed for this site.

Site #4

Site #4 is a small triangular shaped plot of land, consisting of approximately 0.24 acres, located on the North end of the existing UI Pequonnock Substation. The size of the site is not sufficient to support the new Singer Substation. Site #4 is only large enough to locate one of the 345/115kV transformer banks associated with the interconnection of the 115KV lines to the Singer Substation. Similar to Site #2, locating one power transformer bank and one 115kV transmission line interconnection on another site introduces additional issues/concerns associated with protective relaying, control, and operation & maintenance. These issues/concerns can be avoided by constructing the complete facility on a single site. In addition, Site #4 is located in an area in which access to the 115kV transmission line corridor would be difficult. Because of these issues/concerns, Site #4 was determined to be a non-preferred site and no further development or evaluation was performed for this site.

Site #5

Site #5 is a plot of land, consisting of approximately 1.61 acres, located on the West side of the PSE&G Bridgeport Harbor Power Station. The site would allow for adequate access to both the 345kV underground cable circuits and the 115kV overhead transmission line circuits. The size and layout of Site #5 is sufficient to support the initial footprint of the new Singer Substation if three-phase power transformers were used. The preferred Singer Substation layout utilizes single-phase power transformers. If Site #5 were chosen, future expansion of the Singer Substation would be limited. While developing this study, UI was informed by PSE&G that Site #5 would not be an available site because of PSE&G's plans to use this site for future expansion of the existing PSE&G Bridgeport Harbor Power Station. Therefore, no further development or evaluation was performed for this site.

Site #6

Site #6 is a plot of land, consisting of approximately 2.21 acres, located South of Railroad Court Street and East of Broad Street. The site would allow for adequate access to both the 345kV underground cable circuits and the 115kV overhead transmission line circuits. The size and layout of Site #6 is sufficient to support the complete footprint of the new Singer Substation. While developing this study, UI was informed that Site #6 would not be an available site because of existing plans to build a residential housing complex on the site. Therefore, no further development or evaluation was performed for this site.

Site #9

Site #9 is a plot of land, consisting of approximately 1.76 acres, located North of Whiting Street and East of Main Street. The site would allow for adequate access to both the 345kV underground cable circuits and the 115kV overhead transmission line circuits. The size and layout of Site #9 is sufficient to support the initial footprint of the new Singer Substation. The future expansion of the Singer Substation on Site #9 would be very limited due to the size of the site and the requirement to maintain a 'buffer zone' between the street and substation fence. While developing this study, UI determined that to develop Site #9 they would be responsible for relocating four (4) businesses and a warehouse that presently reside on this site. In addition, Site #9 presently contains numerous existing structures that would have to be removed prior to constructing anything on the site. Because of these issues/concerns, Site #9 was determined to be a non-preferred site and no further development or evaluation was performed for this site.

In light of the foregoing, site locations 2, 3, 4, 5, 6, & 9 were not included in the following detailed evaluation.

Detailed Site Evaluation

Site #1

Site #1 is a plot of land, consisting of approximately 2.34 acres, located on the West side of the Bridgeport Energy Corporation Power Station. The size and layout of Site #1 is sufficient to support the complete footprint of the new Singer Substation. Sufficient area exists on the site to allow for future expansion of the 345kV GIS substation. The site allows for adequate access of both the 345kV underground cable circuits and the 115kV overhead transmission line circuits. A drawing (Drawing SP-1A) showing the preliminary routing of the 345kV underground cable circuits and 115kV overhead line circuits to the Singer Substation located on Site #1 can be found in Attachment A. A preliminary one-line diagram (Drawing OLD-1&8) and a preliminary GIS substation plan arrangement drawing (Drawing SP-1) can also be found in Attachment A. Specific concerns relating to Site #1 are the presence of a large warehouse building that would have to be removed prior to constructing anything on the site and the need for walls along three sides of the site to shield the substation from the local residential area.

Site #1 has the following advantages and disadvantages when compared to other sites:

Advantages:
- Lowest estimated installed cost.
- Size of site is sufficient for complete footprint including future expansion.
- Provides flexibility of an overhead connection for the two 115kV transmission line circuits.
- Provides the simplest route selection for the two 115kV overhead lines.
- Requires the second smallest amount of perimeter wall to shield the substation from local residential areas.

Disadvantages:
- Smallest of the preferred sites.
- Contains a large warehouse building that must be removed prior to start of construction.
- Future transmission circuits into the site will need to be underground cable circuits.

Approximate Site #1 Size: 2.34 Acres

Budgetary Singer Substation (EPC) Site Cost – Site #1: $47,713,084.00
A summary breakdown of the total Site #1 EPC estimated costs can be found in Table 1. A cost differential comparison of EPC costs between the potential sites can be found in Table 2.

Site #7

Site #7 is a plot of land, consisting of approximately 3.06 acres, located South of Whiting Street and West of Broad Street. The size and layout of Site #7 is sufficient to support the complete footprint of the new Singer Substation. Sufficient area exists on the site to allow for future expansion of the 345kV GIS substation. The site also allows for adequate access of the 345kV underground cable circuits to the GIS Building. It is not believed that sufficient aerial R-O-W can be obtained to route the 115kV overhead transmission line circuits to Site #7. Therefore, the 115kV interconnections have been revised to 115kV underground cable circuit connections for this site. A drawing (Drawing SP-7A) showing the preliminary routing of the 345kV underground cable circuits and 115kV underground cable circuits to the Singer Substation located on Site #7 can be found in Attachment A. A preliminary one-line diagram (Drawing OLD-7&10) and a preliminary GIS substation plan arrangement drawing (Drawing SP-7) can also be found in Attachment A. Specific concerns relating to Site #7 are the presence of a few small buildings that would have to be removed prior to constructing anything on the site and the need for walls around the entire perimeter of the site to shield the substation from the local residential area.

Site #7 has the following advantages and disadvantages when compared to other sites:

Advantages:
- Size of site is sufficient for complete footprint including future expansion.
- Site has the lowest estimated OH & UG R-O-W cost.

Disadvantages:
- Third highest estimated installed cost.
- Third highest site real estate cost.
- Due to lack of sufficient aerial R-O-W, the 115kV interconnections have been revised to 115kV underground cable circuit connections for this site.
- Contains a few small buildings that must be removed prior to start of construction.
- Requires the largest amount of perimeter wall to shield the substation from local residential areas.

Approximate Site #7 Size: 3.06 Acres

Budgetary Singer Substation (EPC) Site Cost – Site #7: $53,228,893.00
A summary breakdown of the total Site #7 EPC estimated costs can be found in Table 1. A cost differential comparison of EPC costs between the potential sites can be found in Table 2.

<u>Site #8</u>

Site #8 is a plot of land, consisting of approximately 2.83 acres, located near the Southwest corner of the Bridgeport Energy Corporation Power Station. The size and layout of Site #8 is sufficient to support the complete footprint of the new Singer Substation. Sufficient area exists on the site to allow for future expansion of the 345kV GIS substation. The site allows for adequate access of both the 345kV underground cable circuits and the 115kV overhead transmission line circuits. A drawing (Drawing SP-8A) showing the preliminary routing of the 345kV underground cable circuits and 115kV overhead line circuits to the Singer Substation located on Site #8 can be found in Attachment A. A preliminary one-line diagram (Drawing OLD-1&8) and a preliminary GIS substation plan arrangement drawing (Drawing SP-8) can also be found in Attachment A. Specific concerns relating to Site #8 are the presence of a historical building in the Southwest corner of the property that cannot be removed or disturbed and the need for walls along three sides of the site to shield the substation from the local residential area.

Site #8 has the following advantages and disadvantages when compared to other sites:

Advantages:
- Second lowest estimated installed cost.
- No existing buildings on the site requiring removal.
- Size of site is sufficient for complete footprint including future expansion.
- Provides flexibility of an overhead connection for the two 115kV transmission line circuits.
- Requires the third smallest amount of perimeter walls to shield the substation from local residential areas.

Disadvantages:
- Second smallest of the preferred sites.
- Presence of a historical building in the Southwest corner of the property that cannot be removed or disturbed.
- Future transmission circuits into the site will need to be underground cable circuits.

Approximate Site #8 Size: 2.83 Acres

Budgetary Singer Substation (EPC) Site Cost – Site #8: $49,669,194.00
A summary breakdown of the total Site #8 EPC estimated costs can be found in Table 1. A cost differential comparison of EPC costs between the potential sites can be found in Table 2.

Site #10

Site #10 is a plot of land, consisting of approximately 5.29 acres, located South of Whiting Street and West of Lafayette Street. The size and layout of Site #10 is sufficient to support the complete footprint of the new Singer Substation. Sufficient area exists on the site to allow for future expansion of the 345kV GIS substation. The preliminary arrangement of the Singer Substation (including future expansion) would only use the Eastern half of Site #10, thus allowing other development on the other half. The site also allows for adequate access of the 345kV underground cable circuits to the GIS Building. It is not believed that sufficient aerial R-O-W can be obtained to route the 115kV overhead transmission line circuits to Site #10. Therefore, the 115kV interconnections have been revised to 115kV underground cable circuit connections for this site. A drawing (Drawing SP-10A) showing the preliminary routing of the 345kV underground cable circuits and 115kV underground cable circuits to the Singer Substation located on Site #10 can be found in Attachment A. A preliminary one-line diagram (Drawing OLD-7&10) and a preliminary GIS substation plan arrangement drawing (Drawing SP-10) can also be found in Attachment A. Specific concerns relating to Site #10 are the presence of numerous large factory/warehouse buildings that would have to be removed prior to constructing anything on the site and the need for external walls around the entire perimeter of the site to shield the substation from the local residential area.

Site #10 has the following advantages and disadvantages when compared to other sites:

Advantages:
- Second largest available site.
- Size of site is sufficient for complete footprint including future expansion.
- Site has the second lowest estimated OH & UG R-O-W cost.

Disadvantages:
- Second highest estimated installed cost.
- Second highest site real estate cost.
- Due to lack of sufficient aerial R-O-W, the 115kV interconnections have been revised to 115kV underground cable circuit connections for this site.
- Contains a numerous buildings/structures that must be removed prior to start of construction.
- Requires the second largest amount of perimeter wall to shield the substation from local residential areas.

Approximate Site #10 Size: 5.29 Acres

Budgetary Singer Substation (EPC) Site Cost – Site #10: $59,072,270.00
A summary breakdown of the total Site #10 EPC estimated costs can be found in Table 1. A cost differential comparison of EPC costs between the potential sites can be found in Table 2.

Site #11

Site #11 is a plot of land, consisting of approximately 11 acres, located South of Henry Street and East of Main Street. The size and layout of Site #11 is sufficient to support the complete footprint of the new Singer Substation. Sufficient area exists on the site to allow for future expansion of the 345kV GIS substation. The preliminary arrangement of the Singer Substation (including future expansion) would only use the Northern portion of Site #11, thus allowing other development on the Southern portion of the site. The site also allows for adequate access of the

345kV underground cable circuits to the GIS Building. It is not believed that sufficient aerial R-O-W can be obtained to route the 115kV overhead transmission line circuits to Site #11. Therefore, the 115kV interconnections have been revised to 115kV underground cable circuit connections for this site. A drawing (Drawing SP-11A) showing the preliminary routing of the 345kV underground cable circuits and 115kV underground cable circuits to the Singer Substation located on Site #11 can be found in Attachment A. A preliminary one-line diagram (Drawing OLD-7&10) and a preliminary GIS substation plan arrangement drawing (Drawing SP-11) can also be found in Attachment A. Specific concerns relating to Site #11 are the presence of numerous large factory/warehouse buildings that would have to be removed prior to constructing anything on the site and the need for external walls on the West side of the site to shield the substation from the local residential area.

Site #11 has the following advantages and disadvantages when compared to other sites:

Advantages:

- Largest available site.
- Size of site is sufficient for complete footprint including future expansion.
- Requires the least amount of perimeter wall to shield the substation from local residential areas.

Disadvantages:

- Highest estimated installed cost.
- Highest site real estate & UG R-O-W cost.
- Due to lack of sufficient aerial R-O-W, the 115kV interconnections have been revised to 115kV underground cable circuit connections for this site.
- Contains a numerous buildings/structures that must be removed prior to start of construction.

Approximate Site #11 Size: 11 Acres

Budgetary Singer Substation (EPC) Site Cost – Site #11: $63,522,950.00
A summary breakdown of the total Site #11 EPC estimated costs can be found in Table 1. A cost differential comparison of EPC costs between the potential sites can be found in Table 2.

CONCLUSION

We conclude the following in regards to the 11 potential sites identified for the installation of the Singer Substation.

- Site locations 2, 3, 4, 5, 6, & 9 were determined to have undesirable characteristics for the placement of the Singer Substation.
- Preliminary layouts indicate that the Breaker-and-One-Half GIS substation arrangement could be located on Sites 1, 7, 8, 10, & 11. The preliminary arrangements on these sites have been completed to support a future expansion of the 345kV GIS substation. Please note that more detailed equipment information would be required to confirm actual layouts for each of the sites.
- Sites 1, 7, 8, 10, & 11 all possess multiple areas for direct access from city streets.
- Estimates of land cost, R-O-W cost, and building demolition costs are preliminary estimates and may need to be adjusted on a per site basis.
- The approximate maximum height of the building housing the GIS equipment would be 50 feet.
- This study assumes that sufficient aerial R-O-W can be obtained to route 115kV transmission line circuits to Sites #1 & #8 overhead. If sufficient aerial R-O-W can not be obtained for these lines, underground connections to both Sites #1 & #8 via the same routing as presently shown for the overhead lines would be necessary. There would be a cost increase of approximately $3.5 to $4 million dollars to use a 115kV underground cable system versus the 115kV overhead transmission line system.
- Sites are shown with perimeter walls to shield the substation site from the local residential areas. Actual lengths and heights of the perimeter walls will need to be determined during the detailed design.

Based on the comparative evaluation of the preferred sites (Sites 1, 7, 8, 10, & 11) presented in the "Detailed Site Evaluation" section of this study, Site 1 is recommended as the most suitable site for the new Singer Substation. The significant factors supporting this conclusion are summarized below:

- Site 1 offers the lowest estimated installed cost.
- Site 1 is of sufficient size to support the complete footprint of the new Singer Substation.
- Site 1 includes sufficient area to allow for future expansion of the 345kV GIS substation.
- Site 1 provides the best combination of access for both the 345kV underground cable circuits and the 115kV overhead transmission line circuits.
- Site 1 will require the least amount of perimeter walls to shield the substation from the local residential areas.

TABLE 1

SINGER SUBSTATION SITE SELECTION STUDY

PRELIMINARY SINGER SUBSTATION SITE COST ESTIMATES

TABLE 1

SINGER SUBSTATION SITE SELECTION STUDY

PRELIMINARY SINGER SUBSTATION SITE COST ESTIMATES

SITE LOCATION #	SINGER 345KV GIS SUBSTATION COST (EPC)	345KV UNDERGROUND CABLE CIRCUIT COST (EPC)	UNDERGROUND CABLE OIL PUMPING STATION (EPC)	115KV OVERHEAD TRANSMISSION LINE CIRCUIT COST (EPC)	115KV UNDERGROUND CABLE CIRCUIT COST (EPC)	GIS SUBSTATION SITE REAL ESTATE COST	OVERHEAD & UNDERGROUND CIRCUIT R-O-W COST	ESTIMATED EXISTING STRUCTURE DEMOLITION COST	ESTIMATED SITE TOTAL COST
1	$36,804,334.00	$6,261,660.00	$500,000.00	$1,646,090.00	$0.00	$1,755,000.00	$246,000.00	$500,000.00	**$47,713,084.00**
2	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	**N/A**
3	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	**N/A**
4	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	**N/A**
5	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	**N/A**
6	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	**N/A**
7	$36,941,423.00	$6,983,670.00	$500,000.00	$0.00	$6,098,800.00	$2,295,000.00	$210,000.00	$200,000.00	**$53,228,893.00**
8	$36,830,794.00	$7,920,850.00	$500,000.00	$1,910,050.00	$0.00	$2,122,500.00	$385,000.00	$0.00	**$49,669,194.00**
9	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	**N/A**
10	$36,947,350.00	$7,858,650.00	$500,000.00	$0.00	$8,584,770.00	$3,967,500.00	$214,000.00	$1,000,000.00	**$59,072,270.00**
11	$36,988,390.00	$8,734,790.00	$500,000.00	$0.00	$7,636,770.00	$8,250,000.00	$413,000.00	$1,000,000.00	**$63,522,950.00**

Notes:
1. The Site Selection Study revealed that sites 2, 3, 4, 5, 6, & 9 were determined to be not feasible locations for the Singer Substation installation.
2. For the purposes of comparison between sites in the Site Selection Study the start points of the two 345kV underground cable circuits were developed from a common start point for each of the sites selected. Costs associated with Circuit 1 are started at the corner of Railroad Court and Main Street. Costs associated with Circuit 2 are started at the corner of Railroad Avenue and Broad Street.
3. For the purposes of comparison between sites in the Site Selection Study real estate costs were estimated at $750,000 per acre.
4. For the purposes of comparison between sites in the Site Selection Study T-Line R-O-W costs were estimated at $100,000 per acre.

TABLE 2

SINGER SUBSTATION SITE SELECTION STUDY

PRELIMINARY COMPARISON OF DIFFERENTIAL COST ESTIMATES FOR POSSIBLE SINGER SUBSTATION SITE LOCATIONS RELATIVE TO SITE LOCATION 1

TABLE 2

SINGER SUBSTATION SITE SELECTION STUDY

PRELIMINARY COMPARISON OF DIFFERENTIAL COST ESTIMATES FOR POSSIBLE SINGER SUBSTATION SITE LOCATIONS RELATIVE TO SITE LOCATION 1

SITE LOCATION #	SINGER 345KV GIS SUBSTATION COST (EPC)	345KV UNDERGROUND CABLE CIRCUIT COST (EPC)	UNDERGROUND CABLE OIL PUMPING STATION (EPC)	115KV OVERHEAD TRANSMISSION LINE CIRCUIT COST (EPC)	115KV UNDERGROUND CABLE CIRCUIT COST (EPC)	GIS SUBSTATION SITE REAL ESTATE COST	OVERHEAD & UNDERGROUND CIRCUIT R-O-W COST	ESTIMATED EXISTING STRUCTURE DEMOLITION COST	MINIMUM ESTIMATED TOTAL DIFFERENTIAL COST
1	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	**$0.00**
2	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	**N/A**
3	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	**N/A**
4	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	**N/A**
5	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	**N/A**
6	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	**N/A**
7	$137,089.00	$722,010.00	$0.00	($1,646,090.00)	$6,098,800.00	$540,000.00	($36,000.00)	($300,000.00)	**$5,515,809.00**
8	$26,460.00	$1,659,190.00	$0.00	$263,960.00	$0.00	$367,500.00	$139,000.00	($500,000.00)	**$1,956,110.00**
9	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	**N/A**
10	$143,016.00	$1,596,990.00	$0.00	($1,646,090.00)	$8,584,770.00	$2,212,500.00	($32,000.00)	$500,000.00	**$11,359,186.00**
11	$184,056.00	$2,473,130.00	$0.00	($1,646,090.00)	$7,636,770.00	$6,495,000.00	$167,000.00	$500,000.00	**$15,809,866.00**

Notes:

1. The Site Selection Study revealed that sites 2, 3, 4, 5, 6, & 9 were determined to be not feasible locations for the Singer Substation installation.
2. For the purposes of comparison between sites in the Site Selection Study the start points of the two 345kV underground cable circuits were developed from a common start point for each of the sites selected. Costs associated with Circuit 1 are started at the corner of Railroad Court and Main Street. Costs associated with Circuit 2 are started at the corner of Railroad Avenue and Broad Street.
3. For the purposes of comparison between sites in the Site Selection Study real estate costs were estimated at $750,000 per acre.
4. For the purposes of comparison between sites in the Site Selection Study T-Line R-O-W costs were estimated at $100,000 per acre.

ATTACHMENT A

DRAWINGS

Drawing #	Drawing Title
SP-0A	POTENTIAL SINGER SUBSTATION SITES
OLD-1&8	SINGER SUBSTATION SITE #1 & #8 ONE LINE DIAGRAM
OLD-7&10	SINGER SUBSTATION SITE #7, #10, & #11 ONE LINE DIAGRAM
SP-1	SINGER SUBSTATION GENERAL ARRANGEMENT PLAN SITE #1
SP-1A	SINGER SUBSTATION LOCATION SITE #1
SP-7	SINGER SUBSTATION GENERAL ARRANGEMENT PLAN SITE #7
SP-7A	SINGER SUBSTATION LOCATION SITE #7
SP-8	SINGER SUBSTATION GENERAL ARRANGEMENT PLAN SITE #8
SP-8A	SINGER SUBSTATION LOCATION SITE #8
SP-10	SINGER SUBSTATION GENERAL ARRANGEMENT PLAN SITE #10
SP-10A	SINGER SUBSTATION LOCATION SITE #10
SP-11	SINGER SUBSTATION GENERAL ARRANGEMENT PLAN SITE #11
SP-11A	SINGER SUBSTATION LOCATION SITE #11

Appendix "F"

Letter from the City of Bridgeport

Office of Planning and Economic Development

Dated August 5, 2003

City of Bridgeport, Connecticut
OFFICE OF PLANNING & ECONOMIC DEVELOPMENT
DEPARTMENT OF CITY PLANNING
999 BROAD STREET- 2ND FLOOR
BRIDGEPORT, CONNECTICUT 06604
TELEPHONE: (203) 576-7760
FAX (203) 576-3979

JOHN M. FABRIZI
Mayor

MICHAEL W. FREIMUTH
Director of
Planning and
Economic Development

MICHAEL P. NIDOH
Director of Planning

August 5, 2003

Mr. John Prete, Middletown/Norwalk Project Director
The United Illuminating Company
157 Church Street
P.O. Box 1564
New Haven, CT 06506-0901

RE: Middletown To Norwalk Project
Within the City of Bridgeport

Dear Mr. Prete:

The City of Bridgeport and the United Illuminating Company have met several times now and have an on-going dialogue on several issues involving the proposed routing of the underground 345kV power line through the city of Bridgeport. The City supports the UI's proposed plan to place these power lines underground and we have an on-going discussion on the proposed route that has already resulted in a change that appears to be advantageous to both parties.

We continue to engage the UI in discussions on several aspects of the project as follows:

- The proposed route will take these power cables under several railroad, highway, and river crossings that we are interested in reviewing the specific design plans at these locations.

- The City is interested in seeing the development of a traffic management plan during all aspects of the construction together with an open line of communication for any plan changes that may occur during the work. The City also has local ordinances covering utility companies' excavations in the streets and nighttime construction prohibitions that we will work with the company to resolve.

- The City strongly supports the siting of the proposed substation in Bridgeport at the UI's first choice of sites, that being the Singer Substation site located on Main Street that is presently owned by PSEG Energy. This site is adjacent to the existing power generating plant, is appropriately industrially zoned, and would have the least number of adverse impacts of any of the proposed sites on the abutting residential neighborhood. The City would not look favorably on any sites that will adversely impact the residential land uses in the abutting South End neighborhood.

We would hope that the Connecticut Siting Council would act responsibly and use its authority to assist the UI in acquiring the Singer Site for the proposed Bridgeport substation thereby protecting the integrity of the residential character of the City's South End neighborhood. Even with the proposed architectural camouflage of the substation's façade, the placement of this facility in close proximity to a substantial number of historic residential structures could not help but have an adverse impact of the quality of life of City residents in the area.

- The proposed power line route will cross an existing high-pressure natural gas line at the intersection of Myrtle and Railroad Avenues. The City is concerned over how this crossing will be handled and is working with the UI Company on this issue.

- The City of Bridgeport has plans to build a new Intermodal Transportation Center (ITC) along the proposed route of the 345kV line and while the line itself is not an issue for us, the placement of the underground lines in proximity to the proposed structures would be. The City's plans call for the westward relocation of the existing Water Street at the current railroad station and the City desires to work with the company regarding the location of these lines in this area so as not to have to move them again. The City's ITC architectural/engineering firm is Wallace, Floyd, Associates, Inc. of Boston, MA and they will be in contact with the UI's technical staff regarding this item in the near future to work out any design and location issues.

- Finally, the City's Emergency Services has discussed a training issue with the UI Company on how to respond to any potential problems at manhole or substation locations. As first responders, the Police and Fire Departments will require knowledge and training regarding a safe approach to these potential problems. The City has also created an Emergency Management Response Plan that will now need to incorporate the existence of this underground high-voltage power line and substation in its plan and there will be an on-going dialogue with the company regarding these items.

The City has had a good line of communication with the United Illuminating Company on this Middletown To Norwalk Project and fully expects to continue this working relationship throughout the project. There has been an expressed interest by the company to work with the City on all outstanding issues and we would expect this dialogue to continue even after the construction has been completed.

Once again, the City of Bridgeport supports the proposed 345kV underground power line and the Singer Substation site and will work with the UI Company on all outstanding issues described above.

Should you have any questions regarding the above, please feel free to contact me via e-mail at nidohm0@ci.bridgeport.ct.us or by phone at 203.576-7191.

Very truly yours,

Michael P. Nidoh
Director of Planning

Pc: John Fabrizi – Mayor
Michael Freimuth – Office of Planning & Economic Development
Attorney Melanie Howlett – Office of the City Attorney
George Estrada – Public Facilities
Steve Tyliszczak – OPED: Special Projects

Site #10 - Corner of Gregory & Lafayette

Site #10 - Gregory St. looking West

Site 11

Description: Site 11 is an 11 acre site located at the southern end of Main St. The site is now occupied by Remington Rand. Remington has corporate offices as well as a manufacturing facility on the site presently. The site is bounded by Main St., Henry St., Loco Pl., and Long Island Sound. An extension of Loco Pl. bisects the site and separates the Remington buildings from their parking lot. All facilities are active at this time which would require us to relocate office space and manufacturing space. Remington presently employs about 200 people at this location. The owner has proposed a purchase price of $3,000,000.00 plus relocation of 46,000 sq. ft. of office space and 100,000 sq. ft. of manufacturing space. The office space should be located in the Shelton/Trumbull area and the manufacturing space should be located in the Bridgeport area. The development estimates for this site will include the projected relocation costs. During the course of this investigation we met with officials from Bridgeport Economic Development Corporation (BEDCO) and Bridgeport Port Authority. The purpose of the meeting was to investigate the possibilities of co-development of the site with the Bridgeport Port Authority and possible relocation of the existing facility to one of BEDCO's property. This discussion is ongoing.

Site Development: Clearly, the site is adequate for the substation with expansion. The substation would require approximately 3.7 acres of this 11 acre site. Because of the location of this site relative to Pequonnock/BE switching stations, the 115kV would have to be installed underground to get to this site. Both the 115kV and the 345kV cable circuits would enter the yard from Henry St. Also the 345kV loop connections would extend south from Railroad Ave. to Site 11. The yard itself would be positioned to the rear of the site bordering Henry St. The front of the building would face Long Island Sound and would be set back approximately 425 ft. from the shore line. From the existing manufacturing building to the shoreline would be available for development by others. Screening for noise abatement, aesthetics and security would be required for the west, south, and possibly north boundaries of the site. Along the eastern boundary, space is reserved for loading, moving equipment in and out, and service vehicles. We would need to reserve a 50 ft. ROW in front of the building for equipment movement during construction and in the event of a failure. This could be in the form of a roadway which could service either parcel on the 11 acre plot.

Pros:

- The site is of ample size to accommodate the substation with a modest expansion.
- The owner (Remington) will consider a sale with relocation.
- The site could be co-developed with Bridgeport Port Authority or others to help defray the land and the relocation costs for Remington.
- Small amount of screening is necessary, possibly 2 ½ sides.

Cons:

- The site is located approximately 1/3 of a mile away from the desired interconnection point (Pequonnock and BE).
- The acquisition of ROW for overhead 115kV lines is highly unlikely.
- Underground construction would be necessary from Pequonnock, Bridgeport Energy and Railroad Ave (345KV loop connection).
- High cost to interconnect even with sharing land and relocation costs for Remington.
- High demolition costs.

Estimated Costs with Relocation costs: The estimated cost of development, including transmission interconnection costs, is $45.25 million

Cost Estimates

The cost estimates for this report were prepared using a number of sources. The Black and Veatch Site Selection Report, attached as Appendix E, included costs for an EPC contract which tend to be slightly higher than other types of contracts. The estimates included in this Site Selection Study were compared with other published project estimates and found to be approximately 10% to 15% lower than the EPC estimates. Since the Site Selection Study is such a preliminary estimate it was felt that an EPC estimate should not be the basis for this comparative study. Additionally, land estimates and some listed land prices were used for land costs, which are more accurate than the price per acre estimate factored in the Black & Veatch report. Both the Site Selection Study and the Black & Veatch report arrive at the same outcome, though more site-specific information, other than cost, is reflected in the Site Selection Study. The estimated cost of the substation, based on unit prices for equipment and construction requirements is;

Singer Substation Preliminary Cost Estimate				
Item	Description	Unit Cost	# Req'd	Total
1	Bldg & Foundations	lot	lot	$ 2,500,000.00
2	Shunt Reactors- 75MVAR	$1,200,000.00	2	$ 2,400,000.00
3	Shunt Reactors 150MVAR	$1,500,000.00	2	$ 3,000,000.00
4	115/345KV Auto Txfrs.	$1,340,000.00	6	$ 8,040,000.00
5	GIS Equipment	$15,000,000.00	1	$15,000,000.00
7	Station Service & Grounding	$500,000.00	1	$500,000.00
8	Relaying & Control	$2,000,000.00	1	$2,000,000.00
		Totals		$33,440,000.00

Differential costs

Based upon the above estimate, the differential costs between sites were prepared. These costs are more site-specific estimates than the generic substation estimate. The differentials are driven by the following variables:

1. Land costs.

2. Additional costs for multi-story building construction.

3. The amount of screening and sidewalks required.

Differential costs (continued):

4. The interconnection costs for 115kV , both overhead and underground.

5. The interconnection costs of the underground 345kV loop.

6. The amount of demolition for existing structures and buildings required for each site.

These differential costs are summarized below:

Singer Substation Differential Cost Analysis							
Site #	115KV	345KV	Substation	Land	Demolition	Total	Differential
1	$250,000	$2,000,000	$33,440,000	$1,500,000	$250,000	$37,440,000	$0
7	$2,600,000	$1,700,000	$34,440,000	$4,000,000	$250,000	$42,990,000	$5,550,000
8	$2,887,500	$1,100,000	$33,940,000	$725,000	$0	$38,652,500	$1,212,500
10	$4,375,000	$2,000,000	$33,440,000	$4,000,000	$1,500,000	$45,315,000	$7,875,000
11	$2,800,000	3,548,000	$33,440,000	$4,458,000	$1,000,000	$45,246,000	$7,806,000

Purchase and Relocation Costs:

Site 11 was analyzed to include the cost of the land plus the relocation costs associated with moving the Remington facility. As mentioned previously, this is an active facility that employs about 200 people. Their needs include 46,000 square ft. of office space, 100,000 square ft. of manufacturing space and $3,000,000.00 for the land and buildings. The substation would occupy approximately 4 acres of the 11 acre site. This correlates to 36% of the site. The estimate below is based upon average costs in the area for office space and manufacturing space. Added to that was the lump sum for the land value. The estimated gross relocation cost for Remington is noted in the following table:

Estimated Relocation Costs For Remington				
Item	description	units	cost/unit	extension
1	Land cost	1	$3,000,000.00	$3,000,000.00
2	Office Space	46,000	$117.00	$5,382,000.00
3	Manufacturing Space	100,000	$40.00	$4,000,000.00
4	Total gross estimated cost to relocate			$12,382,000.00

If we were to assume a 36% share based upon the amount of the land we would need for the substation, the net relocation cost would be approximately $4,458,000.00. This was added in the site evaluation sheet for Site 11.

Conclusion

After reviewing the selected sites, the preferred site for locating the proposed Singer Substation is Site 1. The preferred alternate site is Site 8. The main reasons for the selections are as follows:

1. Both sites are big enough to accommodate the substation
2. Both sites border an industrial area with existing generation, substation and transmission facilities.
3. Both sites have reasonable access to the existing 115kV circuits from Bridgeport Energy and Pequonnock Substation
4. Both sites will have good access to the 345kV circuits
5. Both sites represent the 2 lowest cost viable alternatives.
6. Both sites would result in small impact to the surrounding community
7. Selection of Site 1 is supported by the City of Bridgeport.

Recommendation

It is recommended that UI proceed with the acquisition of Site 1. Site 1 represents the lowest differential cost alternative and with least impact the adjacent community, which is partially residential. This recommendation is supported by The City of Bridgeport, Office of Planning and Economic Development. Technical and aesthetic issues with this location can be overcome with the least amount disruption to the south end neighborhood. The Site has excellent access to the 115kV and 345kV circuits. This Site is superior in comparison to Site 8 because it is closer to the interconnecting transmission lines, it is zoned heavy industrial, and fits best with the City of Bridgeport’s neighborhood development plans. Site 8, the preferred alternate, would require the use of underground construction to interconnect the 115kV circuits.