Appendix F

Electrical Effects

Electrical Effects

for the I-5 Corridor Reinforcement Project

October 2011

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for

Bonneville Power Administration

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1.0 Introduction

The Bonneville Power Administration (BPA) is proposing to build an approximately 70-mile 500-kilovolt (kV) transmission line from a new BPA substation near Castle Rock in Cowlitz County, Washington, to a new BPA substation near Troutdale in Multnomah County, Oregon. The proposed line is designated the I-5 Corridor Reinforcement Project transmission line. Depending on the route selected, the proposed transmission line will traverse areas with a variety of land uses, including forest, agricultural, urban/suburban, and rural. Four alternatives – West, Central, East and Crossover – are under consideration for the proposed transmission line as shown in Maps 1-4. In addition, there are three additional routing options for portions of each alternative.

The purpose of this report is to describe and quantify the electrical effects of the proposed I-5 Corridor Reinforcement Project 500-kV transmission line along the alternatives and options. These effects include the following:

- the levels of 60-hertz (Hz; cycles per second) electric and magnetic fields (EMF) at 3.28 feet (ft.) or 1 meter (m) above the ground,
- the effects associated with those fields,
- the levels of audible noise produced by the line, and
- electromagnetic interference to radio and television reception associated with the line.

Electrical effects occur near all transmission lines, including those 500-kV lines already present in the area of the proposed route for the I-5 Corridor Reinforcement Project. Therefore, the levels of these quantities for the proposed line are computed and compared with those from the existing lines in Oregon, Washington and elsewhere.

The proposed line would be built on new and existing right-of-way, paralleling existing lines along portions of the route. Each of the four alternatives and options is described by a series of fixed, linear route segments between geographic locations. There are 60 segments total in the four alternatives and options. Although a route segment is unique geographically, it is not necessarily unique in the physical and electrical configurations that produce electrical effects. Therefore in some cases a route segment is broken up into two or more geographical line sections each with a constant configuration for calculation of electrical effects.

Electrical effects were analyzed for all line sections, with or without parallel lines, that had constant physical and electrical characteristics for at least one span between towers. There were 109 separate line sections identified for the four alternatives and their options. Identical configurations are present in different sections. Therefore calculations of electrical effects were required for only 36 different electrical configurations. In eight short sections where the line would change direction, cross other lines, change conductor location on the towers, and/or enter a substation, physical characteristics would not be constant and calculations of effects were not performed. However, the electrical effects associated with these short line sections would be very similar to those for the analyzed segments.

The results of electrical effects calculations for all the individual sections are described in the appendix to this report. These calculations are cross-referenced to alternative routes and segments to facilitate determination of electrical effects levels at specific locations along the proposed routes.

The voltage on the conductors of transmission lines generates an electric field in the space between the conductors and the ground. The electric field is calculated or measured in units of volts-per-meter (V/m) or kilovolts-per-meter (kV/m) at a height of 3.28 feet (ft.) (1 meter [m]) above the ground. The current flowing in the conductors of the transmission line generates a magnetic field in the air and earth near the transmission line; current is expressed in units of amperes (A). The magnetic field is expressed in milligauss (mG), and is usually measured or calculated at a height of 3.28 ft. (1 m) above the ground. The electric field at the surface of the conductors causes the phenomenon of corona. Corona is the electrical breakdown or ionization of air in very strong electric fields, and is the source of audible noise, electromagnetic radiation, and visible light.

To quantify EMF levels along the route, the electric and magnetic fields from the proposed and existing lines were calculated using the BPA Corona and Field Effects Program (USDOE, undated). In this program, the calculation of 60-Hz fields uses standard superposition techniques for vector fields from several line sources: in this case, the line sources are transmission-line conductors. (Vector fields have both magnitude and direction: these must be taken into account when combining fields from different sources.) Important input parameters to the computer program are voltage, current, and geometric configuration of the line. The transmission-line conductors are assumed to be straight, parallel to each other, and located above and parallel to an infinite flat ground plane. Although such conditions do not occur under real lines because of conductor sag and variable terrain, the validity and limitations of calculations using these assumptions have been well verified by comparisons with measurements. This calculation approach was used to estimate fields for the line segments in the proposed I-5 Corridor Reinforcement Project. Minimum clearances were assumed to provide worst-case (highest) estimates for the electric and magnetic fields.

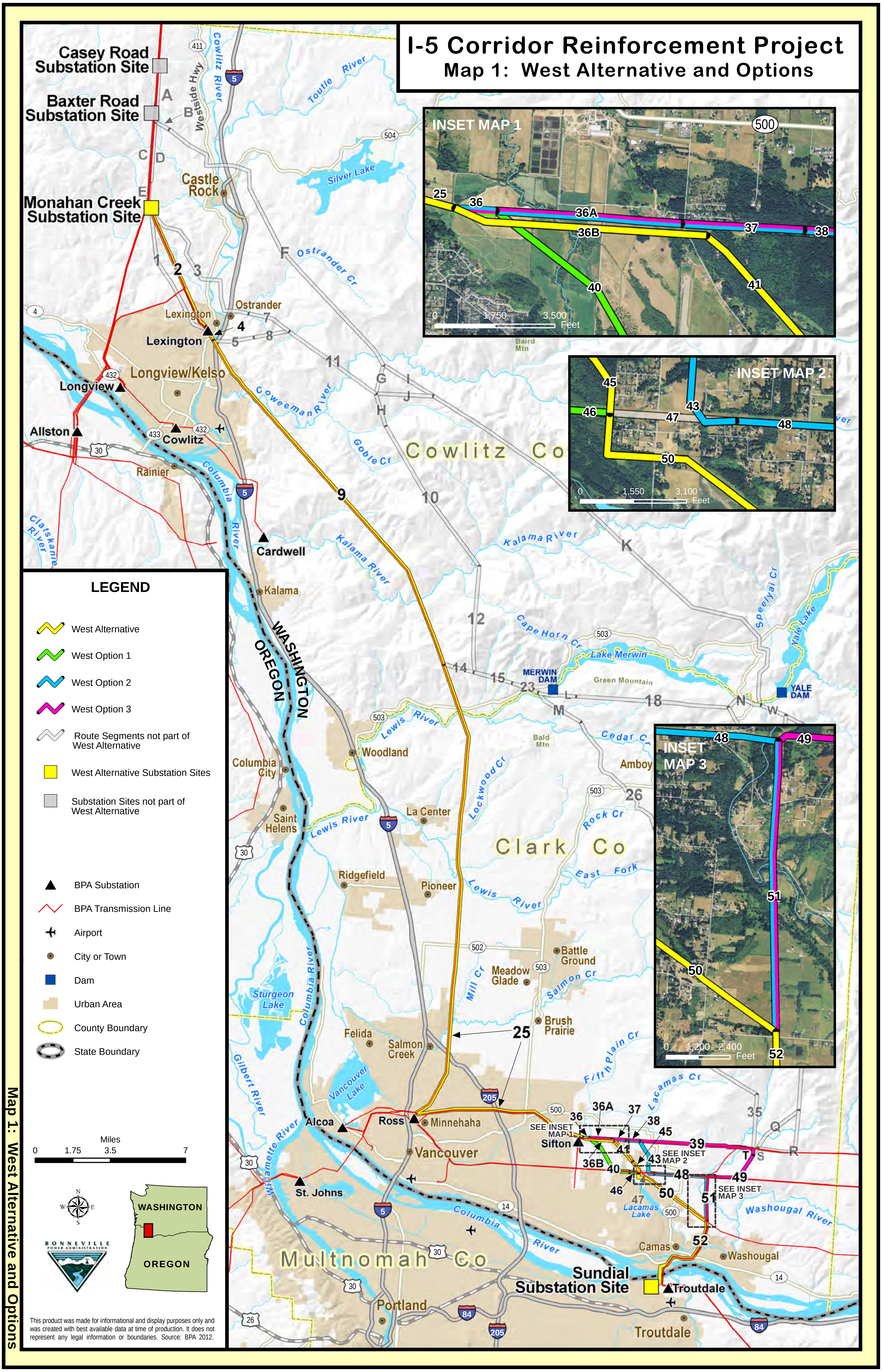
Electric fields are calculated using an imaging method. Fields from the conductors and their images in the ground plane are superimposed with the proper magnitude and phase to produce the total field at a selected location.

The total magnetic field is calculated from the vector summation of the fields from currents in all the transmission-line conductors. Balanced currents are assumed for each three-phase circuit and the contribution of induced image currents in the conductive earth is not included. Peak and average current and power flow direction for the proposed and existing lines in each segment were provided by BPA. These currents were estimated for the four action alternatives (a term used to discuss the alternatives and options together) that include the addition of the proposed line and the No-action Alternative that assumes the proposed line is not constructed. The currents in these cases were based on the projected system normal annual peak power loads in 2019, the selected year for modeling. A modeling year five to 10 years in the future provides meaningful estimates of loads for the proposed 500-kV transmission line during its initial years of operation. Projections beyond this timeframe may not be reliable.

Maximum and average electric and magnetic fields for the proposed transmission line were calculated at the standard height (3.28 ft. or 1 m) above the ground (IEEE, 1987). Calculations were performed out to 1000 ft. (305 m) from the centerline of the proposed line in each segment. The validity and limitations of such calculations have been well verified by measurements.

Because maximum voltage, maximum current, and minimum conductor height above-ground are used, ***the calculated maximum values given here represent worst-case conditions:*** i.e., the calculated fields are higher than they would be in practice. Such worst-case conditions would seldom occur. The average calculated values represent the average fields expected along the entire length of a route segment or line section within a segment.

The corona performance of the proposed line was also predicted using the BPA Corona and Field Effects Program (USDOE, undated). Corona performance is calculated using empirical equations that have been developed over several years from the results of measurements on numerous high-voltage lines


I-5 Corridor Reinforcement Project
Map 1: West Alternative and Options
INSET MAP 1
INSET MAP 2
INSET MAP 3
Casey Road Substation Site
Baxter Road Substation Site
Monahan Creek Substation Site
Sundial Substation Site
Castle Rock
Lexington
Ostrander
Longview/Kelso
Longview
Allston
Cowlitz
Rainier
Cardwell
Kalama
Woodland
Columbia City
Saint Helens
La Center
Ridgefield
Pioneer
Amboy
Battle Ground
Meadow Glade
Brush Prairie
Felida
Salmon Creek
Alcoa
Ross
Minnehaha
Vancouver
Sifton
St. Johns
Camas
Washougal
Troutdale
Portland
MERWIN DAM
YALE DAM
Lake Merwin
Yale Lake
Silver Lake
Green Mountain
Baird Mtn
Bald Mtn
Cowlitz Co
Clark Co
Multnomah Co
WASHINGTON
OREGON
Cowlitz River
Toutle River
Coweeman River
Goble Cr
Ostrander Cr
Kalama River
Columbia River
Clatskanie River
Lewis River
East Fork Lewis River
Cape Horn Cr
Cedar Cr
Speelyai Cr
Rock Cr
Lockwood Cr
Mill Cr
Salmon Cr
Fifth Plain Cr
Lacamas Cr
Lacamas Lake
Sturgeon Lake
Vancouver Lake
Gilbert River
Willamette River
Washougal River
Westside Hwy
SEE INSET MAP 1
SEE INSET MAP 2
SEE INSET MAP 3
LEGEND
West Alternative
West Option 1
West Option 2
West Option 3
Route Segments not part of West Alternative
West Alternative Substation Sites
Substation Sites not part of West Alternative
BPA Substation
BPA Transmission Line
Airport
City or Town
Dam
Urban Area
County Boundary
State Boundary
Miles
0 1.75 3.5 7
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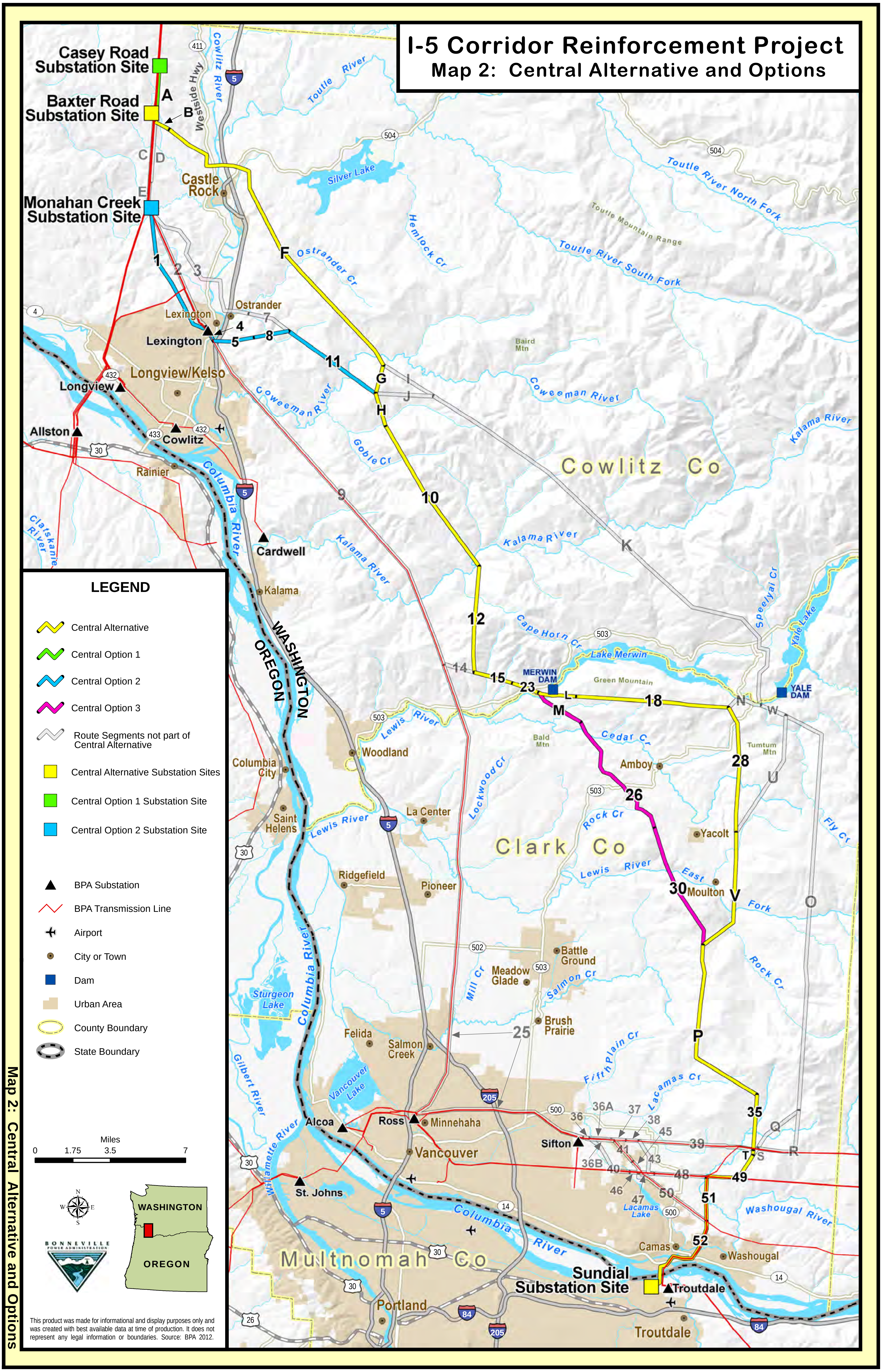
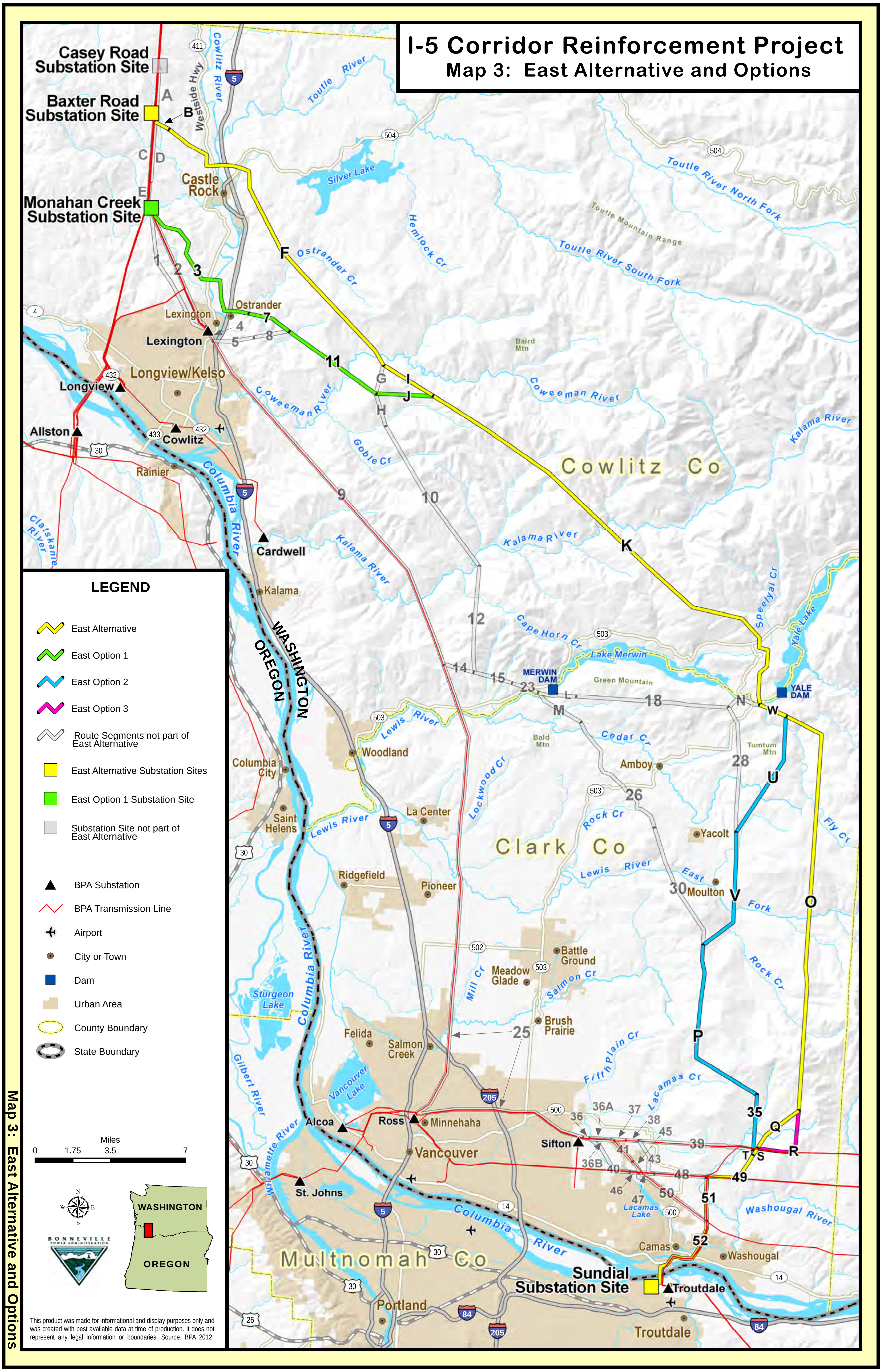
Map 1: West Alternative and Options



Map 2: Central Alternative and Options


I-5 Corridor Reinforcement Project
Map 3: East Alternative and Options
Casey Road Substation Site
Baxter Road Substation Site
Monahan Creek Substation Site
Sundial Substation Site
A
B
C
D
E
F
G
H
I
J
K
L
M
N
O
P
Q
R
S
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15
18
23
25
26
28
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36A
36B
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Castle Rock
Ostrander
Lexington
Longview/Kelso
Longview
Allston
Cowlitz
Rainier
Cardwell
Kalama
Woodland
Columbia City
Saint Helens
La Center
Ridgefield
Pioneer
Amboy
Yacolt
Moulton
Battle Ground
Meadow Glade
Brush Prairie
Felida
Salmon Creek
Alcoa
Ross
Minnehaha
Vancouver
Sifton
St. Johns
Camas
Washougal
Troutdale
Portland
Cowlitz Co
Clark Co
Multnomah Co
WASHINGTON
OREGON
MERWIN DAM
YALE DAM
Westside Hwy
Cowlitz River
Toutle River
Silver Lake
Toutle River North Fork
Toutle Mountain Range
Toutle River South Fork
Hemlock Cr
Ostrander Cr
Baird Mtn
Coweeman River
Goble Cr
Kalama River
Clatskanie River
Columbia River
Speelyai Cr
Yale Lake
Cape Horn Cr
Lake Merwin
Green Mountain
Lewis River
Bald Mtn
Cedar Cr
Tumtum Mtn
Lockwood Cr
Rock Cr
East Fork
Fly Cr
Mill Cr
Salmon Cr
Sturgeon Lake
Vancouver Lake
Gilbert River
Willamette River
Fifth Plain Cr
Lacamas Cr
Lacamas Lake
Washougal River
411
5
504
4
432
433
30
503
502
500
14
205
84
26
LEGEND
East Alternative
East Option 1
East Option 2
East Option 3
Route Segments not part of East Alternative
East Alternative Substation Sites
East Option 1 Substation Site
Substation Site not part of East Alternative
BPA Substation
BPA Transmission Line
Airport
City or Town
Dam
Urban Area
County Boundary
State Boundary
Miles
0 1.75 3.5 7
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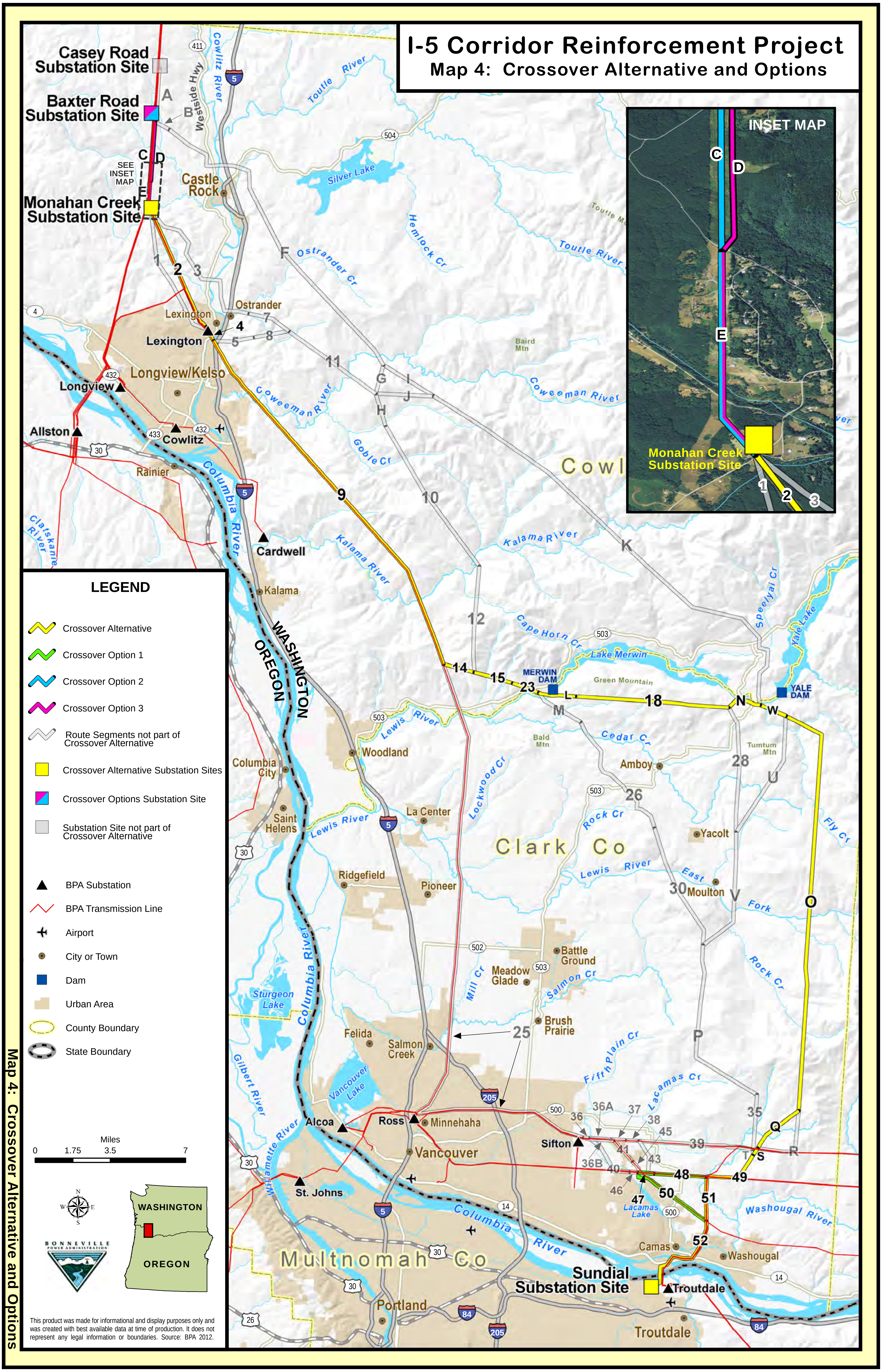
Map 3: East Alternative and Options


I-5 Corridor Reinforcement Project
Map 4: Crossover Alternative and Options
INSET MAP
Monahan Creek Substation Site
Casey Road Substation Site
Baxter Road Substation Site
SEE INSET MAP
Castle Rock
Ostrander
Lexington
Longview/Kelso
Longview
Allston
Cowlitz
Rainier
Cardwell
Kalama
WASHINGTON
OREGON
Columbia City
Saint Helens
Woodland
La Center
Ridgefield
Pioneer
Battle Ground
Meadow Glade
Brush Prairie
Amboy
Yacolt
Moulton
Felida
Salmon Creek
Alcoa
Ross
Minnehaha
Vancouver
Sifton
St. Johns
Camas
Washougal
Sundial Substation Site
Troutdale
Portland
Multnomah Co
Clark Co
Cowl
MERWIN DAM
YALE DAM
Lake Merwin
Yale Lake
Silver Lake
Lacamas Lake
Vancouver Lake
Sturgeon Lake
Baird Mtn
Bald Mtn
Tumtum Mtn
Green Mountain
Columbia River
Cowlitz River
Toutle River
Coweeman River
Kalama River
Lewis River
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Route Segments not part of Crossover Alternative
Crossover Alternative Substation Sites
Crossover Options Substation Site
Substation Site not part of Crossover Alternative
BPA Substation
BPA Transmission Line
Airport
City or Town
Dam
Urban Area
County Boundary
State Boundary
Miles
0 1.75 3.5 7
WASHINGTON
OREGON
BONNEVILLE POWER ADMINISTRATION
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Map 4: Crossover Alternative and Options

(Chartier and Stearns, 1981; Chartier, 1983). The validity of this approach for corona-generated audible noise has been demonstrated through comparisons with measurements on other lines all over the United States (IEEE Committee Report, 1982). The accuracy of this method for predicting corona-generated radio and television interference from transmission lines has also been established (Olsen et al., 1992). Important input parameters to the computer program are voltage, current, conductor size, and geometric configuration of the line.

Corona is a highly variable phenomenon that depends on conditions along a length of line. Predictions of the levels of corona effects are reported in statistical terms to account for this variability. Calculations of audible noise and electromagnetic interference levels were made under conditions of estimated average operating voltage (539 kV for the proposed line) and with the average line height over a span.

Levels of audible noise, radio interference, and television interference are predicted for both fair and foul weather; however, corona is basically a foul-weather phenomenon. Wet conductors can occur during periods of rain, fog, snow, or icing. Along the route of the proposed I-5 Corridor Reinforcement Project transmission line, such conditions are expected to occur about 21 percent of the time during a year, based on hourly precipitation records during years with complete records for the Portland International Airport (2005-2009). Corona activity also increases with altitude. For purposes of evaluating corona effects from the proposed line, an altitude of 0 to 1000 feet (305 m) was assumed. Sixty-two percent of spans were below an elevation of 1000 feet and 94 percent were below 2000 feet. Most of the population along the line is at the lower elevations.

2.0 Physical Description

2.1 Proposed Line

BPA provided the physical and operating characteristics of the proposed and existing lines that were used in the calculations. In almost all segments the proposed 500-kV transmission line would be a three-phase, single-circuit line. Each phase is carried on a separate set of conductors (wires). The voltage and current waves on each phase are displaced by 120° in time (one-third of a cycle) from the waves on the other phases. For the proposed single-circuit configuration the phases would be arranged in a delta (triangular) configuration (Figure 1). In this configuration, the horizontal spacing between phases in the lower conductor positions would be 46 ft. (14 m). The vertical spacing between the conductor positions would be 31.5 ft. (9.6 m). The physical dimensions and electrical characteristics of the proposed single circuit line are shown in Table 1.

In a few segments where there is limited right-of-way available, it would be necessary to place the proposed line on a new tower with one or two existing lines in a double- or triple-circuit configuration. In these cases, the three phases of each line would be arranged vertically. The approximate conductor locations for all sections with calculations are shown in the appendix to this report.

For the 500-kV line, each phase is carried on a bundle of three conductors (wires) and there are three bundles per circuit as shown in Figure 1. Each bundle of the proposed 500-kV line will have three 1.300-inch diameter conductors arranged in an inverted triangle bundle configuration with approximately 17-in. (43.3 cm) spacing between conductors.

The height of the conductor above ground – the ground clearance – depends on conductor temperature: higher temperature produces smaller clearance because the conductors sag. The minimum conductor-to-ground clearance used in the calculations of electric and magnetic fields is 35 ft.

(10.7 m) at a conductor temperature of 122°F (50°C). This conductor temperature is specified by the National Electric Safety Code (NESC) (IEEE, 2002) for calculation of electric fields and is used by BPA to characterize the maximum electric and magnetic fields from transmission lines; it represents heavy operating conditions and high ambient air temperatures. Clearances above ground under normal operating temperatures are greater than the clearance used for calculations. Under very infrequent extreme conditions, conductor temperatures could exceed 122°F (50°C), resulting in smaller clearances and somewhat higher fields, but the line would still be in compliance with the NESC.

In some line sections, larger clearances would be employed to ensure that the BPA criterion for maximum electric field at ground level of 9 kV/m is met along the entire route. The increases in conductor height usually range from 1 to 4 ft. (0.3 to 1.2 m) depending on the voltage, relative phases and location of the adjacent line(s). At road crossings, the ground clearance would be at least 50 ft. (15.2 m). The average height above ground along a span at a conductor temperature of 122°F (50°C) is approximately 12 ft. (3.7 m) greater than the minimum clearance. The average line height was used to calculate average electric and magnetic fields and corona noise levels along the line.

The maximum phase-to-phase voltage for the proposed line would be 550 kV and the average voltage would be 539 kV. The maximum electrical current on the line would be 1080 amperes (A) per phase, based on the BPA projected system annual peak load in 2019 as the base year. The load factor for this line will be about 0.30 (average load = peak load x load factor), resulting in an average current of 324 A.

New right-of-way for the proposed line will be 150 ft. (46 m) wide. When placed on existing right-of-way the centerline of the proposed line will be at least 75 ft. (23 m) from the edge of the existing or newly acquired right-of-way.

2.2 Existing Lines

The proposed I-5 Corridor Reinforcement Project 500-kV line would parallel existing transmission lines along parts of all four action alternatives. The existing lines that will be parallel to the proposed line and the lengths of the parallel sections are dependent on the route. These lines are included in calculations for the four action alternatives and for the No Action Alternative.

2.3 Action Alternatives

Four action alternatives are under consideration for the proposed line. Each action alternative is comprised of many route segments. Some route segments are divided into line sections to account for changes in line configuration within the segment. (Detailed information about each route segment and line section can be found in tables in the appendix to this report.)

Comparison of the fields and corona effects for the alternatives and options requires more than examination or comparison of calculated results for individual route segments or line sections. To produce a general summary of levels for an action alternative, the distance-weighted means of the average and maximum values for all sections in an alternative or option were computed. These summary measures do not necessarily represent any particular location along a route. However they do provide a means of comparing overall levels between alternatives and options.

The proposed line would be located on two types of right-of-way: "new" right-of-way without adjacent transmission lines and "existing" right-of-way with existing adjacent lines. In some cases, an existing right-of-way may still require purchase of additional right-of-way to be purchased for the proposed line. However, this situation is considered "existing," because of the presence of adjacent line(s).

The mileage by type of right-of-way (new or existing) for the four alternatives and their options are shown in Table 2. This table also shows the number of route segments in each alternative and option.

The West Alternative is almost entirely on existing right-of-way (98%) while the Central and East alternatives are primarily on new right-of-way (90%). The Crossover Alternative is distributed about equally on new right-of-way (58%) and existing right-of-way (42%).

The composition of right-of-way type in an alternative or option affects the overall field levels and the change in field levels between the action and No Action alternatives. New right-of-way sections have higher edge-of-right-of-way fields than existing right-of-way sections and introduce fields and corona effects where none exist in the No Action Alternative. The electrical effects summary measures were computed separately for the new and existing rights-of-way types within each alternative and option and then combined to provide overall summary measures for the action alternatives.

2.4 No Action Alternative

A decision to not build the proposed line constitutes the No Action Alternative. Electrical effects levels for the No Action Alternative are calculated from the existing lines along the various routes in the absence of the proposed 500-kV line. Electrical effects for the No Action Alternative along the routes of the four action alternatives are summarized by computing distance-averaged means for the levels from the existing lines. There are no electrical effects along the new right-of-way sections for the No Action Alternative.

3.0 Electric Field

3.1 Basic Concepts

An electric field is said to exist in a region of space if an electrical charge, at rest in that space, experiences a force of electrical origin (i.e., electric fields cause free charges to move). Electric field is a vector quantity: that is, it has both magnitude and direction. The direction corresponds to the direction that a positive charge would move in the field. Sources of electric fields are unbalanced electrical charges (positive or negative) and time-varying magnetic fields. Transmission lines, distribution lines, house wiring, and appliances generate electric fields in their vicinity because of the unbalanced electrical charges associated with voltage on the conductors. On the power system in North America, the voltage and charge on the energized conductors are cyclic (plus to minus to plus) at a rate of 60 times per second. This changing voltage results in electric fields near sources that are also time-varying at a frequency of 60 hertz (Hz; a frequency unit equivalent to cycles per second).

As noted earlier, electric fields are expressed in units of volts per meter (V/m) or kilovolts (thousands of volts) per meter (kV/m). Electric- and magnetic-field magnitudes in this report are expressed in root-mean-square (rms) units. For sinusoidal waves, the rms amplitude is given as the peak amplitude divided by the square root of two.

The spatial uniformity of an electric field depends on the source of the field and the distance from that source. On the ground, under a transmission line, the electric field is nearly constant in magnitude and direction over distances of several feet (1 meter). However, close to transmission- or distribution-line conductors, the field decreases rapidly with distance from the conductors. Similarly, near small sources such as appliances, the field is not uniform and falls off even more rapidly with distance from the device. If an energized conductor (source) is inside a grounded conducting enclosure, then the electric field outside the enclosure is zero, and the source is said to be shielded.

Electric fields interact with the charges in all matter, including living systems. When a conducting object, such as a vehicle or person, is located in a time-varying electric field near a transmission line, the external electric field exerts forces on the charges in the object, and electric fields and currents are induced in the object. If the object is grounded, then the total current induced in the body (the "short-circuit current") flows to earth. The distribution of the currents within, say, the human body, depends on the electrical conductivities of various parts of the body: for example, muscle and blood have higher conductivity than bone and would therefore experience higher currents.

At the boundary surface between air and the conducting object, the field in the air is perpendicular to the conductor surface and is much, much larger than the field in the conductor itself. For example, the average surface field on a human standing in a 10 kV/m field is 27 kV/m; the internal fields in the body are much smaller: approximately 0.008 V/m in the torso and 0.45 V/m in the ankles.

3.2 Transmission Line Electric Fields

The electric field created by a high-voltage transmission line extends from the energized conductors to other conducting objects such as the ground, towers, vegetation, buildings, vehicles, and people. The calculated strength of the electric field at a height of 3.28 ft. (1 m) above an unvegetated, flat earth is frequently used to describe the electric field under straight parallel transmission lines. The most important transmission-line parameters that determine the electric field at a 1-m height are conductor height above ground and line voltage.

Calculations of electric fields from transmission lines are performed with computer programs based on well-known physical principles (cf., Deno and Zaffanella, 1982). The calculated values under these conditions represent an ideal situation. When practical conditions approach this ideal model, measurements and calculations agree. Often, however, conditions are far from ideal because of variable terrain and vegetation. In these cases, fields are calculated for ideal conditions, with the lowest conductor clearances to provide upper bounds on the electric field under the transmission lines. With the use of more complex models or empirical results, it is also possible to account accurately for variations in conductor height, topography, and changes in line direction. Because the fields from different sources add vectorially, it is possible to compute the fields from several different lines if the electrical and geometrical properties of the lines are known. However, in general, electric fields near transmission lines with vegetation below are highly complex and cannot be calculated. Measured fields in such situations are highly variable.

For evaluation of EMF from transmission lines, the fields must be calculated for a specific line condition. The NESC states the condition for evaluating electric-field-induced short-circuit current for lines with voltage above 98 kV, line-to-ground, as follows: conductors are at a minimum clearance from ground corresponding to a conductor temperature of 120°F (50°C), and at a maximum voltage (IEEE, 2002). BPA has supplied the needed information for calculating electric and magnetic fields from the proposed transmission lines: the maximum operating voltage, the estimated peak current in 2019, and the minimum conductor clearances.

There are standard techniques for measuring transmission-line electric fields (IEEE, 1987). Provided that the conditions at a measurement site closely approximate those of the ideal situation assumed for calculations, measurements of electric fields agree well with the calculated values. If the ideal conditions are not approximated, the measured field can differ substantially from calculated values. Usually the actual electric field at ground level is reduced from the calculated values by various common objects that act as shields.

Maximum or peak field values occur over a small area on the right-of-way at mid-span, where conductors are closest to the ground (minimum clearance). As the location of an electric-field profile approaches a tower, the conductor clearance increases, and the peak field decreases. A grounded tower will reduce the electric field considerably by shielding.

For traditional transmission lines, such as the proposed line, where the right-of-way extends laterally well beyond the conductors, electric fields at the edge of the right-of-way are not as sensitive as the peak field to conductor height. Computed values at the edge of the right-of-way for any line height are fairly representative of what can be expected all along the transmission-line corridor. However, the presence of vegetation on and at the edge of the right-of-way will reduce actual electric-field levels below calculated values.

3.3 Calculated Values of Electric Fields

The calculated values of electric fields at 3.28 ft. (1 m) above ground for all route segments and line sections in the proposed I-5 Corridor Reinforcement Project are presented in the appendix to this report. The appendix also contains lateral profiles of the electric field out to 1,000 feet on either side of the centerline of the proposed line for all route segments. Maximum and average field values are also tabulated. Tables in the appendix allow readers to look up calculated values by alternative, option, route segment, line section, or calculation number.

Data for each alternative and option, including the No Action Alternative, are then summarized in Tables 3 to 7 in this report. Calculated maximum electric fields at various distances from the proposed line on new right-of-way are summarized in Table 3; tables 4 to 7 show electric field calculations for both new and existing right-of-way for all alternatives and options.

For all alternatives and options, the calculated electric fields expected on the right-of-way of the proposed line will depend on the particular segment. To facilitate comparison among alternatives and options, calculations shown in Tables 4 to 7 are of distance-weighted means for electric fields on and at the edge of the right-of-way. The electric fields designated as maximum on-right-of-way values (identified as “On ROW” in the tables) are the distance-weighted mean of the maximum (peak) fields for all segments in an alternative or option. These maximum fields would occur in a small area near mid-span with the conductors at minimum clearance and maximum voltage (550 kV). The average “On ROW” field values estimate the average along an entire span of these maximum (peak) fields with the proposed line operating at average voltage (539 kV). Both the maximum and average “On ROW” values represent conservative (upper limit) estimates for the electric fields expected to occur on the right-of-way.

The maximum and average edge-of-right-of-way (identified as “Edge of ROW” in the tables) fields are also distance-weighted averages across all segments in an alternative or option. They represent the fields at the edge of the right-of-way under the clearance and voltage conditions specified for the maximum and average fields on the right-of-way.

For all alternatives and options the maximum (peak) values “On ROW” range from 8.8 to 9.0 kV/m. The average peak field “On ROW” ranges from 5.3 to 5.8 kV/m. The peak fields for the proposed line on new right-of-way would be 8.8 kV/m under maximum conditions and 5.3 kV/m under average conditions.

The maximum values expected at the “Edge of ROW” of the proposed line range from 0.6 to 2.4 kV/m. The low field values would occur when low voltage lines are present at the opposite edge from the proposed 500-kV line. The maximum and average electric fields at the “Edge of ROW” on new right-of-way would be 2.3 kV/m.

Electric field plots for all sections of the proposed line on existing and new rights-of-way are contained in the appendix to this report. Two examples are included in this report. The electric field plot for the proposed line operating on a new right-of-way is shown in Figure 2. An example of the electric fields near the proposed line on an existing right-of-way is shown in Figure 3.

Calculated electric field levels for the proposed line on new right-of-way are shown in Table 3 for locations on the right-of-way ("Peak on ROW"), at the edge of the right-of-way ("at Edge of ROW"), and at 150 and 300 feet from centerline. The maximum levels, which would occur very infrequently, would be 8.8 kV/m "Peak on ROW" and 2.3 kV/m "at Edge of ROW" (75 feet from the proposed line). The average levels would be 5.3 kV/m "Peak on ROW" and slightly less than 2.3 kV/m "at Edge of ROW." By 150 feet from the proposed line both the maximum and average electric fields would be 0.5 kV/m; by 300 feet from the proposed line, the electric fields would be 0.1 kV/m.

The maximum (peak) electric field values on the right-of-way would occur only at locations almost directly under the conductors, near mid-span, where the conductors are at minimum clearance. The conditions of minimum conductor clearance at maximum voltage occur very infrequently. Thus, the calculated peak electric field levels are rarely reached under real-life conditions, because the actual line height is generally above the minimum value used in the computer model, because the actual voltage is below the maximum value used in the model, and because vegetation within and near the edge of the right-of-way tends to shield the field at ground level.

As noted, Tables 4 to 7 show distance-weighted means for electric fields on and at the edge of the right-of-way to allow comparison among alternatives and options. The maximum peak fields on the existing rights-of-way averaged over the entire route would be very similar to the maximum peak field expected for the proposed line on new right-of-way: that is, maximum peak fields of 8.8 kV/m and average peak fields of about 5.3 kV/m. However, electric fields at the edges of existing rights-of-way tend to be lower than for the new rights-of-way, because the existing rights-of-way have one edge adjacent to a lower voltage line.

The No Action Alternative would produce lower fields on and at the edges of the rights-of-way than the four alternatives (excluding options). When the 12 options are considered, the field levels from the No Action Alternative field levels can be higher than the proposed line, particularly where 500-kV lines are present: Central Options 1 and 2, and Crossover Options 2 and 3. The segments with adjacent 500-kV lines are all located between the three possible substation locations at the northern end of the project.

Where new right-of-way is required, there are currently no electric fields present for the No Action Alternative.

3.4 Environmental Electric Fields

The electric fields associated with the proposed I-5 Corridor Reinforcement Project can be compared with those found in other environments. Sources of 60-Hz electric (and magnetic) fields exist everywhere electricity is used; levels of these fields in the modern environment vary over a wide range. Electric-field levels associated with the use of electrical energy are orders of magnitude greater than the naturally occurring 60-Hz fields of about 0.0001 V/m, which stem from atmospheric and extraterrestrial sources.

Electric fields in outdoor, publicly accessible places range from less than 1 V/m to 12 kV/m; the large fields exist close to high-voltage transmission lines of 500 kV or higher. In remote areas without electrical service, 60-Hz field levels can be much lower than 1 V/m. Electric fields in home and work environments generally are not spatially uniform like those of transmission lines; therefore, care must be taken when making comparisons between fields from different sources such as appliances and electric lines. In addition, fields from all sources can be strongly modified by the presence of conducting objects. However, it is helpful to know the levels of electric fields generated in domestic and office environments to compare commonly experienced field levels with those near transmission lines.

Numerous measurements of residential electric fields have been reported for various parts of the United States, Canada, and Europe. Measurements of domestic 60-Hz electric fields indicate that levels are highly variable and source-dependent. Electric-field levels are not easily predicted because walls and other objects act as shields, because conducting objects perturb the field, and because homes contain numerous localized sources. Internal sources (wiring, fixtures, and appliances) seem to predominate in producing electric fields inside houses. Average measured electric fields in residences are generally in the range of 5 to 20 V/m. In a large occupational exposure monitoring project that included electric-field measurements at homes, average exposures for all groups away from work were generally less than 10 V/m (Bracken, 1990).

Electric fields from household appliances are localized and decrease rapidly with distance from the source. Local electric fields measured at 1 ft. (0.3 m) from small household appliances are typically in the range of 30 to 60 V/m. In a survey, reported by Deno and Zaffanella (1982), field measurements at a 1-ft. (0.3-m) distance from common domestic and workshop sources were found to range from 3 to 70 V/m. The localized fields from appliances are not uniform, and care should be taken in comparing them with transmission-line fields.

Electric blankets can generate higher localized electric fields. Florig et al. (1987) carried out extensive empirical and theoretical analysis of electric-field exposure from electric blankets and presented results in terms of uniform equivalent fields such as those near transmission lines. Depending on what parameter was chosen to represent intensity of exposure and the grounding status of the subject, the equivalent vertical 60-Hz electric-field exposure ranged from 20 to over 3500 V/m. The largest equivalent field corresponds to the measured field on the chest with the blanket-user grounded. The average field on the chest of an ungrounded blanket-user yields an equivalent vertical field of 960 V/m. As manufacturers have become aware of the controversy surrounding EMF exposures, electric blankets have been redesigned to reduce magnetic fields. However, electric fields from these "low field" blankets are still comparable with those from older designs (Bassen et al., 1991).

Generally, people in occupations not directly related to high-voltage equipment are exposed to electric fields comparable with those of residential exposures. For example, the average electric field measured in 14 commercial and retail locations in rural Wisconsin and Michigan was 4.8 V/m (IIT Research Institute, 1984). Median electric field was about 3.4 V/m. These values are about one-third the values in residences reported in the same study. Electric field levels in public buildings such as shops, offices, and malls appear to be comparable with levels in residences.

In a survey of 1,882 volunteers from utilities, electric field exposures were measured for 2,082 work days and 657 non-work days (Bracken, 1990). Electric field exposures for occupations other than those directly related to high-voltage equipment were equivalent to those for non-work exposure.

Thus, except for the relatively few occupations where high-voltage sources are prevalent, electric fields encountered in the workplace are probably similar to those of residential exposures. Even in electric utility occupations where high field sources are present, exposures to high fields are limited on average to minutes per day.

Electric fields found in publicly accessible areas near high-voltage transmission lines can typically range up to 3 kV/m for 230-kV lines, to 10 kV/m for 500-kV lines, and to 12 kV/m for 765-kV lines. Although these peak levels are considerably higher than the levels found in other public areas, they are present only in limited areas on rights-of-way.

The calculated electric fields for the proposed I-5 Corridor Reinforcement 500-kV transmission line are consistent with the levels reported for other 500-kV transmission lines in Washington, Oregon and elsewhere. The calculated electric fields on and at the edge of the right-of-way of the proposed transmission line would be much higher than levels normally encountered in residences and offices.

4.0 Magnetic Field

4.1 Basic Concepts

Magnetic fields can be characterized by the force they exert on a moving charge or on an electrical current. As with the electric field, the magnetic field is a vector quantity characterized by both magnitude and direction. Electrical currents generate magnetic fields. In the case of transmission lines, distribution lines, house wiring, and appliances, the 60-Hz electric current flowing in the conductors generates a time-varying, 60-Hz magnetic field in the vicinity of these sources. The strength of a magnetic field is measured in terms of magnetic lines of force per unit area, or magnetic flux density. The term “magnetic field,” as used here, is synonymous with magnetic flux density and is expressed in units of gauss (G) or milligauss (mG). (The tesla (T) is the unit of magnetic flux density preferred in scientific publications, where 1.0 gauss equals one ten-thousandth of a tesla (0.1 mT) and 1.0 mG equals 0.1 microtesla [µT]).

The uniformity of a magnetic field depends on the nature and proximity of the source, just as the uniformity of an electric field does. Transmission-line-generated magnetic fields are quite uniform over horizontal and vertical distances of several feet near the ground. However, for small sources such as appliances, the magnetic field decreases rapidly over distances comparable with the size of the device.

The interaction of a time-varying magnetic field with conducting objects results in induced electric fields and currents in the object. A changing magnetic field through an area generates a voltage around any conducting loop enclosing the area (Faraday's law). This is the physical basis for the operation of an electrical transformer. For a time-varying sinusoidal magnetic field, the magnitude of the induced voltage around the loop is proportional to the area of the loop, the frequency of the field, and the magnitude of the field. The induced voltage around the loop results in an induced electric field and current flow in the loop material. The induced current that flows in the loop depends on the conductivity of the loop as well as its area.

4.2 Transmission-line Magnetic Fields

The magnetic field generated by currents on transmission-line conductors extends from the conductors through the air and into the ground. The magnitude of the field at a height of 3.28 ft. (1 m) is frequently used to describe the magnetic field under transmission lines. Because the magnetic field is not affected by non-ferrous materials, the field is not influenced by normal objects on the ground under the line. The direction of the maximum field varies with location. (The electric field, by contrast, is essentially vertical near the ground.) The most important transmission-line parameters that determine the magnetic field at 3.28 ft. (1 m) height are conductor height above ground and magnitude of the currents flowing in the conductors. As distance from the transmission line conductors increases, the magnetic field decreases.

Calculations of magnetic fields from transmission lines are performed using well-known physical principles (cf., Deno and Zaffanella, 1982). The calculated values usually represent the ideal straight parallel-conductor configuration. For simplicity, a flat earth is usually assumed. Balanced currents (currents of the same magnitude for each phase) are also assumed. This is usually valid for transmission lines, where loads on all three phases are maintained in balance during operation. Induced image currents in the earth are usually ignored for calculations of magnetic field under or near the right-of-way. The resulting error is negligible. Only at distances greater than 300 ft. (91 m) from a line do such contributions become significant (Deno and Zaffanella, 1982). The clearance for magnetic field calculations for the proposed line was the same as that used for electric field evaluations.

Standard techniques for measuring magnetic fields near transmission lines are described in ANSI IEEE Standard No. 644-1994 (1994). Measured magnetic fields agree well with calculated values, provided the currents and line heights that go into the calculation correspond to the actual values for the line. To realize such agreement, it is necessary to get accurate current readings during field measurements (because currents on transmission lines can vary considerably over short periods of time) and also to account for all field sources in the vicinity of the measurements.

As with electric fields, maximum (peak) magnetic fields occur in areas near the centerline and at mid-span where conductors are the lowest. The magnetic field at the edge of the right-of-way is not very dependent on line height. If more than one line is present, the peak field will depend on the relative electrical phasing of the conductors and the relative direction of power flow in the lines.

4.3 Calculated Values for Magnetic Fields

The appendix to this report contains tables and plots of the calculated values of the magnetic field at 3.28 ft. (1 m) height for all of the proposed 500-kV transmission line sections. Field values on the right-of-way and at the edge of the right-of-way are given for projected maximum currents and minimum clearance. Field levels at the same locations for average current and average conductor clearance are also given. This information is then summarized in Tables 3 to 7 in this report. Calculated maximum magnetic fields on new right-of-way are summarized in Table 3. Tables 4 to 7 show calculated magnetic fields (expressed in distance-weighted means) on new and existing right-of-way by alternative and option. In addition, examples of magnetic field plots for the proposed line operating on a new right-of-way and existing right-of-way are shown in Figures 4 and 5.

The magnetic fields designated as maximum on-right-of-way values (designated as “On ROW” in the tables) represent the maximum (peak) fields that could occur infrequently in a small area near mid-span with the conductors at minimum clearance and maximum current (1080 A). The average on-right-of-way field values estimate the average along an entire span of these maximum (peak) fields with the proposed line operating at average current (324 A). Both the maximum and average on-right-of-way values represent conservative (upper limit) estimates for the electric fields expected to occur on the right-of-way.

The maximum and average edge-of-right-of-way (“Edge of ROW”) magnetic fields represent calculated values at the edge of the right-of-way under the clearance and voltage conditions specified for the maximum and average fields on the right-of-way.

Maximum magnetic field levels along the four alternatives (excluding options) would be 184 mG “On ROW” and 48 mG at “Edge of ROW” (75 feet from the proposed line). The average levels would be much lower: 35 mG “On ROW” and 12 mG at “Edge of ROW.” By 150 feet from the proposed line, magnetic fields would fall to a maximum of 13 mG and an average of 4 mG; at 300 feet from the proposed line, the maximum field would be 4 mG and the average 1 mG. The latter is comparable to average levels in homes in the United States.

Figures 4 and 5 in this report provide visual representations of the potentially highest magnetic fields under the proposed I-5 Corridor Reinforcement 500-kV line. The actual day-to-day magnetic field levels would be lower. They would vary as currents change daily and seasonally and as clearances change with ambient temperature. As shown in these tables and figures, the average fields along the line over a year would be considerably reduced from the maximum values, as a result of increased clearances and reduced current.

The large number of existing right-of-way sections that comprise the alternative routes makes it impractical to tabulate results off the right-of-way for each of these. However, the field values for the proposed line alone shown in Table 3 provide an indication of the magnetic fields that can be expected off the right-of-way when the proposed line is on an existing right-of-way. In such cases, one edge of the right-of-way will be adjacent to the proposed line and it will be the dominant source of fields outside the right-of-way. Consequently, the values at 150 and 300 feet shown in Table 3 will be representative of the fields beyond the edge nearest to the proposed line. On the far side of an existing right-of-way, an existing lower voltage line with lower currents will be present and magnetic (and electric) fields will be lower than on the near side. In this case, the field values off the right-of-way from the proposed line alone can be considered an upper bound on the fields off the fight-of-way. However, if an existing 500-kV line is present on the far side of the right-of-way then the fields can be higher than those for the proposed line alone. This occurs in Central Option 1 and Crossover Options 2 and 3 (Tables 5 and 6).

To compare the magnetic field levels between action alternatives, the magnetic fields for each alternative and option were characterized in the same manner as were electric fields. A distance-weighted average of each parameter was computed using the tabulated values in the appendix of this report for each line section along the entire length of each alternative and option. The distance-weighted average fields were calculated separately for sections with new and existing right-of-way for the four alternatives. Similar computations were performed for the options in each alternative.

For clarity, the results for the 12 options are presented separately in Tables 4 to7, and discussed only in instances where there would be a significant change to the results for the overall action alternative. The tables show the distance-weighted average of the maximum and average fields on and at the edge of the right-of-way. The No Action levels are also shown for those sections where the proposed transmission line would be located on existing rights-of-way.

The maximum “On ROW” 60-Hz magnetic fields along the four alternatives (excluding options) would range between 174 to 184 mG (all numbers in this section are distance-weighted averages). The lowest value would occur on existing rights-of-way for the West Alternative and the highest value applies to the other three alternatives. The range of maximum fields “On ROW” for the 12 options would be 139 to 276 mG. The larger upper limit for the options would be due to the presence of existing 500-kV lines with high maximum currents on short segments (2.5 to 4.1 miles) of the Central and Crossover options.

For the No Action Alternative, maximum fields “On ROW” along the four alternatives (excluding options) would range from 96 to 135 mG. When considering all options, the range of maximum fields “On ROW” on existing rights-of-way for the No Action Alternative would be 63 to 235 mG, with the highest value occurring where there is an existing 500-kV lines.

Estimated average fields “On ROW” for the four alternatives (excluding options) would range from 32 to 36 mG. The range of average fields “On ROW” for the 12 options would be 28 to 68 mG. The average field on the existing rights-of-way for the No Action Alternative would range from 11 to 49 mG under all options. In sections where new right-of-way would be used for the proposed line, magnetic fields for the No Action Alternative would be zero. Distance-weighted maximum and average fields for the “Edge of ROW” for all action alternatives and the No Action Alternative are shown in Tables 4 to 7.

Beyond the edge of rights-of-way, magnetic fields fall off rapidly. For example, a maximum magnetic field of 48 mG at the edge of new right-of-way would drop to 13 mG at a distance of 150 feet from centerline, and to 3 mG at 300 feet. For the same example, the average field would drop from 12 mG at the edge of the right-of-way to 4 mG at 150 feet to 1 mG at 300 feet. This means that beyond a few hundred feet, transmission line magnetic fields approach common ambient levels.

4.4 Environmental Magnetic Fields

Transmission lines are not the only source of magnetic fields; as with 60-Hz electric fields, 60-Hz magnetic fields are present throughout the environment of a society that relies on electricity as a principal energy source. The magnetic fields associated with the proposed I-5 Corridor Reinforcement 500-kV line can be compared with fields from other sources. The range of 60-Hz magnetic-field exposures in publicly accessible locations such as open spaces, transmission-line rights-of-way, streets, pedestrian walkways, parks, shopping malls, parking lots, shops, hotels, public transportation, and so on range from less than 0.1 mG to about 1 G, with the highest values occurring near small appliances with electric motors. In occupational settings in electric utilities, where high currents are present, magnetic-field exposures for workers can be above 1 G. At 60 Hz, the magnitude of the natural magnetic field is approximately 0.0005 mG.

Several investigations of residential fields have been conducted. In a large study to identify and quantify significant sources of 60-Hz magnetic fields in residences, measurements were made in 996 houses, randomly selected throughout the country (Zaffanella, 1993). The most common sources of residential fields were power lines, the grounding system of residences, and appliances. Field levels were characterized by both point-in-time (spot) measurements and 24-hour measurements. Spot measurements averaged over all rooms in a house exceeded 0.6 mG in 50 percent of the houses and 2.9 mG in 5 percent of houses. Power lines generally produced the largest average fields in a house over a 24-hour period. On the other hand, grounding system currents proved to be a more significant source of the highest fields in a house. Appliances were found to produce the highest local fields; however, fields fell off rapidly with increased distance. For example, the median field near microwave ovens was 36.9 mG at a distance of 10.5 in (0.27 m) and 2.1 mG at 46 in (1.17 m). Across the entire sample of 996 houses, higher magnetic fields were found in, among others, urban areas (vs. rural); multi-unit dwellings (vs. single-family); old houses (vs. new); and houses with grounding to a municipal water system.

In an extensive measurement project to characterize the magnetic-field exposure of the general population, over 1000 randomly selected persons in the United States wore a personal exposure meter for 24 hours and recorded their location in a simple diary (Zaffanella and Kalton, 1998). Based on the measurements of 853 persons, the estimated 24-hour average exposure for the general population is 1.24 mG and the estimated median exposure is 0.88 mG. The average field “at home, not in bed” is 1.27 mG and “at home, in bed” is 1.11 mG. Average personal exposures were found to be largest “at work” (mean of 1.79 mG and median of 1.01 mG) and lowest “at home, in bed” (mean of 1.11 mG and median of 0.49 mG). Average fields in school were also low (mean of 0.88 mG and median of 0.69 mG). Factors associated with higher exposures at home were smaller residences, duplexes and apartments, metallic rather than plastic water pipes, and nearby overhead distribution lines.

As noted above, magnetic fields from appliances are localized and decrease rapidly with distance from the source. Localized 60-Hz magnetic fields have been measured near about 100 household appliances such as ranges, refrigerators, electric drills, food mixers, and shavers (Gauger, 1985). At a distance of 1 ft. (0.3 m), the maximum magnetic field ranged from 0.3 to 270 mG, with 95 percent of the measurements below 100 mG. Ninety-five percent of the levels at a distance of 4.9 ft. (1.5 m) were less than 1 mG. Devices that use light-weight, high-torque motors with little magnetic shielding exhibited the largest fields. These included vacuum cleaners and small hand-held appliances and tools. Microwave ovens with large power transformers also exhibited relatively large fields. Electric blankets have been a much-studied source of magnetic-field exposure because of the length of time they are used and because of the close proximity to the body. Florig and Hoburg (1988) estimated that the average magnetic field in a person using an electric blanket was 15 mG, and that the maximum field could be 100 mG. New "low-field" blankets have magnetic fields at least 10 times lower than those from conventional blankets (Bassen et al., 1991).

In a domestic magnetic-field survey, Silva et al. (1989) measured fields near different appliances at locations typifying normal use (e.g., sitting at a typewriter or standing at a stove). Specific appliances with relatively large fields included can openers (n = 9), with typical fields ranging from 30 to 225 mG and a maximum value up to 2.7 G; shavers (n = 4), with typical fields from 50 to 300 mG and maximum fields up to 6.9 G; and electric drills (n = 2), with typical fields from 56 to 190 mG and maximum fields up to 1.5 G. The fields from such appliances fall off very rapidly with distance and are only present for short periods. Thus, although instantaneous magnetic-field levels close to small hand-held appliances can be quite large, they do not contribute to average area levels in residences. The technology of newer energy-efficient appliances is likely to reduce fields from appliances further. Battery-powered appliances and devices generally do not generate 60-Hz magnetic fields.

Although studies of residential magnetic fields have not all considered the same independent parameters, the following consistent characterization of residential magnetic fields emerges from the data:

1. External sources play a large role in determining residential magnetic-field levels. Transmission lines, when nearby, are an important external source. Unbalanced ground currents on neutral conductors and other conductors, such as water pipes in and near a house, can represent a significant source of magnetic field. Distribution lines per se, unless they are quite close to a residence, do not appear to be a traditional distance-dependent source.
2. Homes with overhead electrical service appear to have higher average fields than those with underground service.
3. Appliances represent a localized source of magnetic fields that can be much higher than average or area fields. However, fields from appliances approach area levels at distances greater than 3 ft. (1 m) from the device.

Although important variables in determining residential magnetic fields have been identified, quantification and modeling of their influence on fields at specific locations is not yet possible. However, a general characterization of residential magnetic-field level is possible: average levels in the United States are in the range of 0.5 to 1.0 mG, with the average field in a small number of homes exceeding this range by as much as a factor of 10 or more. Average personal exposure levels are slightly higher, possibly due to use of appliances and varying distances to other sources. Maximum fields can be much higher.

Magnetic fields in commercial and retail locations are comparable with those in residences. As with appliances, certain equipment or machines can be a local source of higher magnetic fields. Utility workers who work close to transformers, generators, cables, transmission lines, and distribution systems clearly experience high-level fields. Other sources of fields in the workplace include motors, welding machines, computers, and office equipment. In publicly accessible indoor areas, such as offices and stores, field levels are generally comparable with residential levels, unless a high-current source is nearby.

Because high-current sources of magnetic field are more prevalent than high-voltage sources, occupational environments with relatively high magnetic fields encompass a more diverse set of occupations than do those with high electric fields. For example, in occupational magnetic-field measurements reported by Bowman et al. (1988), the geometric mean field from 105 measurements of magnetic field in "electrical worker" job locations was 5.0 mG. "Electrical worker" environments showed the following elevated magnetic-field levels (geometric mean greater than 20 mG): industrial power supplies, alternating current (ac) welding machines, and sputtering systems for electronic assembly.

Measurements of personal exposure to magnetic fields were made for 1,882 volunteer utility workers for a total of 4,411 workdays (Bracken, 1990). Median workday mean exposures ranged from 0.5 mG for clerical workers without computers to 7.2 mG for substation operators. Occupations not specifically associated with transmission and distribution facilities had median workday exposures less than 1.5 mG, while those associated with such facilities had median exposures above 2.3 mG. Magnetic-field exposures measured in homes during this study were comparable with those recorded in offices.

Magnetic fields in publicly accessible outdoor areas seem to be, as expected, directly related to proximity to electric-power transmission and distribution facilities. Near such facilities, magnetic fields are generally higher than indoors (residential). Higher-voltage facilities tend to have higher fields. Typical maximum magnetic fields in publicly accessible areas near transmission facilities can range from less than a few milligauss up to 300 mG or more, near heavily loaded lines operated at 230 to 765 kV. The levels depend on the line load, conductor height, and location on the right-of-way. Because magnetic fields near high-voltage transmission lines depend on the current in the line, they can vary daily and seasonally.

Fields near distribution lines and equipment are generally lower than those near transmission lines. Measurements in Montreal indicated that typical fields directly above underground distribution systems were 5 to 19 mG (Heroux, 1987). Beneath overhead distribution lines, typical fields were 1.5 to 5 mG on the primary side of the transformer, and 4 to 10 mG on the secondary side. Near ground-based transformers used in residential areas, fields were 80 to 1000 mG at the surface and 10 to 100 mG at a distance of 1 ft. (0.3 m).

The magnetic fields from the proposed line would be comparable to or less than those from existing 500-kV lines in Washington and elsewhere. On and near the right-of-way of the proposed line, magnetic fields would be well above average residential levels. However, the fields from the line would decrease rapidly and approach common ambient levels at distances greater than a few hundred feet from the line. Furthermore, the fields at the edge of the right-of-way would not be above those encountered during normal activities near common sources such as hand-held appliances.

5.0 Electric and Magnetic Field (EMF) Effects

Possible effects associated with the interaction of EMF from transmission lines with people on and near a right-of-way fall into two categories: short-term effects that can be perceived and may represent a nuisance, and possible long-term health effects. Only short-term effects are discussed here. Whether there are long-term health effects associated with transmission-line fields is controversial. In recent years, considerable research on possible biological effects of EMF has been conducted. A review of these studies and their implications for health-related effects is provided in a separate technical report (see Appendix G).

5.1 Electric Fields: Short-term Effects

Short-term effects from transmission line electric fields are associated with perception of induced currents and voltages or perception of the field. Induced current or spark discharge shocks can be experienced under certain conditions when a person contacts objects in an electric field. Such effects occur in the fields associated with transmission lines that have voltages of 230-kV or higher. These effects could occur infrequently under the proposed I-5 Corridor Reinforcement 500-kV line.

Steady-state currents are those that flow continuously after a person contacts an object and provides a path to ground for the induced current. The amplitude of the steady-state current depends on the induced current to the object in question and on the grounding path. The magnitude of the induced current to vehicles and objects under the proposed line will depend on the electric-field strength and the size and shape of the object. When an object is electrically grounded, the voltage on the object is reduced to zero, and it is not a source of current or voltage shocks. If the object is poorly grounded or not grounded at all, then it acquires some voltage relative to earth and is a possible source of current or voltage shocks.

The responses of persons to steady-state current shocks have been extensively studied, and levels of response documented (Keesey and Letcher, 1969; IEEE, 1978). Primary shocks are those that can result in direct physiological harm. Such shocks will not be possible from induced currents under the existing or proposed lines, because clearances above ground required by the NESC preclude such shocks from large vehicles and grounding practices eliminate large stationary objects as sources of such shocks.

Secondary shocks are defined as those that could cause an involuntary and potentially harmful movement, but no direct physiological harm. Secondary shocks could occur under the proposed 500-kV line when making contact with ungrounded conducting objects such as vehicles or equipment. However, such occurrences are anticipated to be very infrequent. Shocks, when they occur under the 500-kV line, are most likely to be below the nuisance level. Induced currents are extremely unlikely to be perceived off the right-of-way of the proposed line.

Induced currents are always present in electric fields under transmission lines and will be present near the proposed line. However, during initial construction, BPA routinely grounds metal objects that are located on or near the right-of-way. The grounding eliminates these objects as sources of induced current and voltage shocks. Multiple grounding points are used to provide redundant paths for induced current flow. After construction, BPA would respond to any complaints and install or repair grounding to mitigate nuisance shocks.

Unlike fences or buildings, mobile objects such as vehicles and farm machinery cannot be grounded permanently. Limiting the possibility of induced currents from such objects to persons is accomplished in several ways. First, required clearances for above-ground conductors tend to limit field strengths to levels that do not represent a hazard or nuisance. The NESC (2002) requires that, for lines with voltage exceeding 98 kV line-to-ground (170 kV line-to-line), sufficient conductor clearance be maintained to limit the induced short-circuit current in the largest anticipated vehicle under the line to 5 milliamperes (mA) or less. This can be accomplished by limiting access or by increasing conductor clearances in areas where large vehicles could be present. BPA and other utilities design and operate lines to be in compliance with the NESC.

For the proposed line, conductor clearances at 50°C conductor temperature would be increased to at least 50 ft. (15.2 m) over road crossings along the route to meet the BPA requirement that electric fields be less than 5.0 kV/m at road crossings. The actual clearance to meet the criterion would depend on the configuration and parallel lines. As indicated earlier, in some sections line heights were increased by from 1 to 4 feet to meet the BPA limit of 9 kV/m on the right-of-way. Similarly, the conductor clearance at each road crossing would be checked during the line design stage to ensure that the BPA 5-kV/m and NESC 5-mA criteria are met. Line clearances would also be increased in accordance with the NESC, such as over railroads and water areas suitable for sailing.

The largest truck allowed on roads in Oregon and Washington without a special permit is 14 feet high by 8.5 feet wide by 75 feet long (4.3 x 2.6 x 22.9 m). The induced currents to such a vehicle oriented perpendicular to the line in a maximum field of 5 kV/m (at 3.28 foot height) would be 4.5 mA (Reilly, 1979). For smaller trucks, the maximum induced currents for perpendicular orientation to the proposed line would be less than this value. (Larger special-permitted trucks, such as triple trailers, can be up to 105 feet in length, but are not expected on the roads crossed by the proposed line. However, because they average the field over such a long distance, the maximum induced current to a 105-foot vehicle oriented perpendicular to the 500-kV line at a road crossing would be less than 4.5 mA.) Thus, the NESC 5-mA criterion would be met for perpendicular road crossings of the proposed line. These large vehicles are not anticipated to be off highways or oriented parallel and on the right-of-way of the proposed line. As discussed below, these are worst-case estimates of induced currents at road crossings; conditions for their occurrence are rare.

Several factors tend to reduce the levels of potential induced current shocks from vehicles:

1. Activities are distributed over the whole right-of-way, and only a small percentage of time is spent in areas where the field is at or close to the maximum value.
2. At road crossings, vehicles are aligned perpendicular to the conductors, resulting in a substantial reduction in induced current.
3. The conductor clearance at road crossings may not be at minimum values because of lower conductor temperatures and/or location of the road crossing away from mid-span.
4. The largest vehicles are permitted only on certain highways.
5. Off-road vehicles are in contact with soil or vegetation, which reduces shock currents substantially.

Induced voltages occur on objects, such as vehicles, in an electric field where there is an inadequate electrical ground. If the voltage is sufficiently high, then a spark discharge shock can occur as contact is made with the object. Such shocks are similar to "carpet" shocks that occur, for example, when a person touches a doorknob after walking across a carpet on a dry day. The number and severity of spark discharge shocks depend on electric-field strength. Based on the low frequency of complaints reported by Glasgow and Carstensen (1981) for 500-kV ac transmission lines (one complaint per year for each 1,500 mi. or 2400 km of 500-kV line), nuisance shocks, which are primarily spark discharges, do not appear to be a serious impediment to allowed activities under 500-kV lines. Recommended safety practices and restricted activities on BPA transmission line rights-of-way are described in the BPA booklet “Living and Working Safely Around High-Voltage Transmission Lines” (USDOE, 2007; www.bpa.gov/corporate/pubs/Public_Service/LivingAndWorking.pdf).

In electric fields higher than will occur under the proposed line, it is theoretically possible for a spark discharge from the induced voltage on a large vehicle to ignite gasoline vapor during refueling. The probability for exactly the right conditions to occur for ignition is extremely remote. The additional clearance of conductors provided at road crossings reduces the electric field in areas where vehicles are prevalent and reduces the chances for such events. Even so, BPA recommends that vehicles should not be refueled under the proposed line unless specific precautions are taken to ground the vehicle and the fueling source (USDOE, 2007).

Under certain conditions, the electric field can be perceived through hair movement on an upraised hand or arm of a person standing on the ground under high-voltage transmission lines. The median field for perception in this manner was 7 kV/m for 136 persons; only about 12 percent could perceive fields of 2 kV/m or less (Deno and Zaffanella, 1982). In areas under the conductors at mid-span, the fields at ground level would exceed the levels where field perception normally occurs. In these instances, field perception could occur on the right-of-way of the proposed line. It is unlikely that the field would be perceived beyond the edge of the right-of-way. Where vegetation provides shielding, the field would not be perceived.

Conductive shielding reduces both the electric field and induced effects such as shocks. Persons inside a vehicle cab or canopy are shielded from the electric field. Similarly, a row of trees or a lower-voltage distribution line reduces the field on the ground in the vicinity. Metal pipes, wiring, and other conductors in a residence or building shield the interior from the transmission-line electric field.

The electric fields from the proposed 500-kV line would be comparable to those from existing 500-kV lines in the project area and elsewhere. Potential impacts of electric fields can be mitigated through grounding policies, adherence to the NESC, and increased clearances above the minimums specified by the NESC. Worst-case levels are used for safety analyses but, in practice, induced currents and voltages are reduced considerably by unintentional grounding. Shielding by conducting objects, such as vehicles and vegetation, also reduces the potential for electric-field effects.

5.2 Magnetic Field: Short-term Effects

Magnetic fields associated with transmission and distribution systems can induce voltage and current in long conducting objects that are parallel to the transmission line. As with electric-field induction, these induced voltages and currents are a potential source of shocks. A fence, irrigation pipe, pipeline, electrical distribution line, or telephone line forms a conducting loop when it is grounded at both ends. The earth forms the other portion of the loop. The magnetic field from a transmission line can induce a current to flow in such a loop if it is oriented parallel to the line. If only one end of the fence is grounded, then an induced voltage appears across the open end of the loop. The possibility for a shock exists if a person closes the loop at the open end by contacting both the ground and the conductor. The magnitude of this potential shock depends on the following factors: the magnitude of the field; the length of the object (the longer the object, the larger the induced voltage); the orientation of the object with respect to the transmission line (parallel as opposed to perpendicular, where no induction would occur); and the amount of electrical resistance in the loop (high resistance limits the current flow).

Magnetically induced currents from power lines have been investigated for many years; calculation methods and mitigating measures are available. A comprehensive study of gas pipelines near transmission lines developed prediction methods and mitigation techniques specifically for induced voltages on pipelines (Dabkowski and Taflove, 1979; Taflove and Dabkowski, 1979). Similar techniques and procedures are available for irrigation pipes and fences. Grounding policies employed by utilities for long fences reduce the potential magnitude of induced voltage.

The magnitude of the coupling with both pipes and fences is very dependent on the electrical unbalance (unequal currents) among the three phases of the line. Thus, a distribution line where a phase outage may go unnoticed for long periods of time can represent a larger source of induced currents than a transmission line where the loads are well-balanced (Jaffa and Stewart, 1981).

Knowledge of the phenomenon, grounding practices, and the availability of mitigation measures mean that magnetic-induction effects from the proposed 500-kV transmission line will be minimal.

Magnetic fields from transmission and distribution facilities can interfere with certain electronic equipment. Magnetic fields have been observed to cause distortion of the image on older VDTs and computer monitors that employ cathode ray tubes. This can occur in fields as low as 10 mG, depending on the type and size of the monitor (Baishiki et al., 1990; Banfai et al., 2000). Generally, the problem arose when computer monitors were in use near electrical distribution facilities in large office buildings.

Contemporary display devices using flat-panel technologies, such as liquid-crystal or plasma displays are not affected.

Interference from magnetic fields can be mitigated by shielding the affected device or moving it to an area with lower fields. Interference from 60-Hz fields with computers and control circuits in vehicles and other equipment is not anticipated at the field levels found under and near the proposed 500-kV transmission line.

The magnetic fields from the proposed line will be comparable to or less than those from existing 500-kV lines in the area of the proposed line and elsewhere in Washington and Oregon.

6.0 Regulations

Regulations that apply to transmission-line electric and magnetic fields fall into two categories. Safety standards or codes are intended to limit or eliminate electric shocks that could seriously injure or kill persons. Field limits or guidelines are intended to limit electric- and magnetic-field exposures that can cause nuisance shocks or might cause health effects. In no case has a limit or standard been established because of a known or demonstrated health effect.

The proposed line would be designed to meet the NESC (IEEE, 2002), which specifies how far transmission-line conductors must be from the ground and other objects. The clearances specified in the code provide safe distances that prevent harmful shocks to workers and the public. In addition, people who live and work near transmission lines must be aware of safety precautions to avoid electrical (which is not necessarily physical) contact with the conductors. For example, farmers should not up-end irrigation pipes under a transmission or other electrical line. In addition, as a matter of safety, the NESC specifies that electric-field-induced currents from transmission lines to vehicles must be below the 5 mA ("let go") threshold deemed a lower limit for primary shock. BPA publishes and distributes a booklet that describes safe practices to protect against shock hazards around power lines (USDOE, 2007).

Field limits or guidelines have been adopted in several states and countries and by national and international organizations (Maddock, 1992). Electric field limits have generally been based on minimizing nuisance shocks or field perception. The intent of magnetic-field limits has been to limit exposures to existing levels, given the uncertainty of their potential for health effects.

General guidelines for EMF exposure have been established for occupational and public exposure by national and international organizations. The limits established by three such guidelines are described in Table 8.

The American Conference of Governmental Industrial Hygienists (ACGIH) sets guidelines (Threshold Limit Values or TLVs) for occupational exposures to environmental agents (ACGIH, 2009). In general, a TLV represents the level below which it is believed that nearly all workers may be exposed repeatedly without adverse health effects. For EMF, the TLVs represent ceiling levels. For 60-Hz electric fields, occupational exposures should not exceed the TLV of 25 kV/m. However, the ACGIH also recognizes the potential for startle reactions from spark discharges and short-circuit currents in fields greater than 5 kV/m, and recommends implementing grounding practices. They recommend the use of conductive clothing for work in fields exceeding 15 kV/m. The TLV for occupational exposure to 60-Hz magnetic fields is a ceiling level of 10 G (10,000 mG) (ACGIH, 2009).

The International Committee on Non-ionizing Radiation Protection (ICNIRP), working in cooperation with the World Health Organization (WHO) has developed guidelines for occupational and public exposures to EMF (ICNIRP, 2010). For occupational exposures at 60 Hz, the recommended limits to exposure are 8.3 kV/m for electric fields and 4.2 G (4,200 mG) for magnetic fields. The electric-field level can be exceeded, provided precautions are taken to prevent spark discharge and induced current shocks. For the general public, the ICNIRP guidelines recommend exposure limits of 4.2 kV/m for electric fields and 2.0 G (2000 mG) for magnetic fields (ICNIRP, 2010).

More recently the International Committee on Electromagnetic Safety (ICES) under the auspices of the IEEE has established exposure guidelines for 60-Hz electric and magnetic fields (ICES, 2002). The ICES recommended limits for occupational exposures are 20 kV/m for electric fields and 27,100 mG for magnetic fields. The recommended limits for the general public are lower: 5 kV/m for the general public, except on power line rights-of-way where the limit is 10 kV/m; and 9,040 mG for magnetic fields.

Electric and magnetic fields from various sources (including automobile ignitions, appliances and, possibly, transmission lines) can interfere with implanted cardiac pacemakers. In light of this potential problem, manufacturers design devices to be immune from such interference. However, research has shown that these efforts have not been completely successful and that a few models of older pacemakers still in use could be affected by 60-Hz fields from transmission lines. There were also numerous models of pacemakers that were not affected by fields larger than those found under transmission lines. Because of the known potential for interference with pacemakers by 60-Hz fields, the ACGIH recommends that, lacking additional information from the manufacturer of their pacemaker, wearers of pacemakers and similar medical-assist devices limit their exposure to electric fields of 1 kV/m or less and to magnetic fields to 1 G (1,000 mG) or less (ACGIH, 2009). Additional discussion of interference with implanted devices is given in the accompanying technical report on health effects (Appendix G).

There are currently no national standards in the United States for 60-Hz electric and magnetic fields. The state of Washington does not have guidelines for electric or magnetic fields from transmission lines. The state of Oregon has a limit on the maximum electric field allowed under a line of 9 kV/m. Several other states have established mandatory or suggested limits on 60-Hz electric and (in two cases) magnetic fields. Six states have specific electric-field limits that apply to transmission lines: Florida, Minnesota, Montana, New Jersey, New York, and Oregon. Florida and New York have established regulations for magnetic fields. These regulations are summarized in Table 9.

Government agencies and utilities operating transmission systems have established design criteria that include EMF levels. BPA has maximum allowable electric fields of 9 and 2.5 kV/m on and at the edge of the right-of-way, respectively (USDOE, 2010). BPA also has maximum-allowable electric field strengths of 5 kV/m, 3.5 kV/m, and 2.5 kV/m for road crossings, shopping center parking lots, and commercial/ industrial parking lots, respectively. The latter levels are based on limiting the maximum short-circuit currents from anticipated vehicles to less than 1 mA in shopping center lots and to less than 2 mA in commercial parking lots.

The electric fields from the proposed 500-kV line would meet the ACGIH standards, provided wearers of pacemakers and similar medical-assist devices are discouraged from unshielded right-of-way use. (A passenger in an automobile under the line would be shielded from the electric field.) The electric fields in limited areas on the right-of-way would exceed the ICNIRP guideline for public exposure, but would be below IEEE guideline limits. The magnetic fields from the proposed line would be below the ACGIH, ICNIRP, and IEEE limits.

The estimated peak electric fields on the right-of-way of the proposed transmission line would meet limits set in Florida, New York and Oregon, but not those of Minnesota and Montana (see Table 9). The BPA maximum allowable electric field limit would be met for all configurations of the proposed line. The edge of right-of-way electric fields from the proposed line would be below limits set in Florida and New Jersey, but above those in Montana and New York.

The magnetic field at the edge of the right-of-way from the proposed line would be below the regulatory levels of states where such regulations exist.

7.0 Audible Noise

7.1 Basic Concepts

Audible noise (AN), as defined here, represents an unwanted sound, as from a transmission line, transformer, airport, or vehicle traffic. Sound is a pressure wave caused by a sound source vibrating or displacing air. The ear converts the pressure fluctuations into auditory sensations. AN from a source is superimposed on the background or ambient noise that is present before the source is introduced.

The amplitude of a sound wave is the incremental pressure resulting from sound above atmospheric pressure. The sound-pressure level is the fundamental measure of AN; it is generally measured on a logarithmic scale with respect to a reference pressure. The sound-pressure level (SPL) in decibels (dB) is given by:

$$SPL = 20 \log (P/P_o)dB$$

where P is the effective rms (root-mean-square) sound pressure, P_O is the reference pressure, and the logarithm (log) is to the base 10. The reference pressure for measurements concerned with hearing is usually taken as 20 micropascals (Pa), which is the approximate threshold of hearing for the human ear. A logarithmic scale is used to encompass the wide range of sound levels present in the environment. The range of human hearing is from 0 dB up to about 140 dB, a ratio of 10 million in pressure (EPA, 1978).

Logarithmic scales, such as the decibel scale, are not directly additive: to combine decibel levels, the dB values must be converted back to their respective equivalent pressure values, the total rms pressure level found, and the dB value of the total recalculated. For example, adding two sounds of equal level on the dB scale results in a 3 dB increase in sound level. Such an increase in sound pressure level of 3 dB, which corresponds to a doubling of the energy in the sound wave, is barely discernible by the human ear. It requires an increase of about 10 dB in SPL to produce a subjective doubling of sound level for humans. The upper range of hearing for humans (140 dB) corresponds to a sharply painful response (EPA, 1978). The computation method described above was incorporated into the derivation of a distance weighted mean noise level as a summary measure for each alternative,

Humans respond to sounds in the frequency range of 16 to 20,000 Hz. The human response depends on frequency, with the most sensitive range roughly between 2000 and 4000 Hz. The frequency-dependent sensitivity is reflected in various weighting scales for measuring audible noise. The A-weighted scale weights the various frequency components of a noise in approximately the same way that the human ear responds. This scale is generally used to measure and describe levels of environmental sounds such as those from vehicles or occupational sources. The A-weighted scale is also used to characterize transmission-line noise. Sound levels measured on the A-scale are expressed in units of dBA.

AN levels and, in particular, corona-generated audible noise (see below) vary in time. In order to account for fluctuating sound levels, statistical descriptors have been developed for environmental noise. Exceedence levels (L levels) refer to the A-weighted sound level that is exceeded for a specified percentage of the time. Thus, the L_5 level refers to the noise level that is exceeded only 5 percent of the time. L_{50} refers to the sound level exceeded 50 percent of the time. Sound-level measurements and predictions for transmission lines are often expressed in terms of exceedence levels, with the L_5 level representing the maximum level and the L_{50} level representing a median level.

Table 10 shows AN levels from various common sources. Clearly, there is wide variation. Noise exposure depends on how much time an individual spends in different locations. Outdoor noise generally does not contribute to indoor levels (EPA, 1974). Activities in a building or residence generally dominate interior AN levels.

BPA has established a transmission-line design criterion for corona-generated audible noise (L_{50}, foul weather) of 50 dBA at the edge of the right-of-way (USDOE, 2006). This criterion applies to new line construction and is under typical conditions of foul weather, altitude, and system voltage for the line. It is generally only of concern for 500-kV lines. If a new line is being built adjacent to an existing line, possibly of an older and noisier design, the criterion allows the 50 dBA criterion to be exceeded if the increase from the existing noise level is no more than 3 dBA.

The Washington Administrative Code provides noise limitations by class of property, residential, commercial or industrial (Washington State, 1975). Transmission lines are classified as industrial and may cause a maximum permissible noise level of 60 dBA to intrude into residential property. During nighttime hours (10 p.m. to 7 a.m.), the maximum permissible limit for noise from industrial to residential areas is reduced to 50 dBA. This latter level applies to transmission lines that operate continuously. The state of Washington Department of Ecology accepts the 50 dBA level at the edge of the right-of-way for transmission lines, but encouraged BPA to design lines with lower audible noise levels (WDOE, 1981).

Audible noise from substations is generated predominantly by equipment such as transformers, reactors and other wire-wound equipment. It is characterized by a 120 Hz hum that is associated with magnetic-field caused vibrations in the equipment. Noise from such equipment varies by voltage and other operating conditions. The BPA design level for substation noise is 50 dBA at the substation property line for new construction (USDOE, 2010). The design level is met by obtaining equipment that meets specified noise limits and, for new substations, by securing a no-built buffer beyond the substation perimeter fence.

In industrial, business, commercial, or mixed use zones the AN level from substations may exceed 50 dBA but must still meet any state or local AN requirements. The design criteria also allow the 50 dBA design level to be exceeded in remote areas where development of noise sensitive properties is highly unlikely.

The EPA has established a guideline of 55 dBA for the annual average day-night level (L_{dn}) in outdoor areas [EPA, 1978]. In computing this value, a 10 dB correction (penalty) is added to night-time noise between the hours of 10 p.m. and 7 a.m.

7.2 Transmission Line Audible Noise

Corona is the partial electrical breakdown of the insulating properties of air around the conductors of a transmission line. In a small volume near the surface of the conductors, energy and heat are dissipated. Part of this energy is in the form of small local pressure changes that result in audible noise. Corona-generated audible noise can be characterized as a hissing, crackling sound that, under certain conditions, is accompanied by a 120-Hz hum. Corona-generated audible noise is of concern primarily for contemporary lines operating at voltages of 345 kV and higher during foul weather. The proposed 500-kV line will produce some noise under foul weather conditions.

The conductors of high-voltage transmission lines are designed to be corona-free under ideal conditions. However, protrusions on the conductor surface—particularly water droplets on or dripping off the conductors—cause electric fields near the conductor surface to exceed corona onset levels, and corona occurs. Therefore, audible noise from transmission lines is generally a foul-weather (wet-conductor) phenomenon. Wet conductors can occur during periods of rain, fog, snow, or icing. Based on hourly meteorological records from 2005 to 2009 at the Portland International Airport, such conditions are expected to occur about 21 percent of the time during the year in the general area of the proposed line. Continuous records for these meteorological conditions were not found for other locations in the project area.

For a few months after line construction, residual grease or oil on the conductors can cause water to bead up on the surface. This results in more corona sources and slightly higher levels of audible noise and electromagnetic interference if the line is energized. However, the new conductors "age" in a few months, and the level of corona activity decreases to the predicted equilibrium value. During fair weather, insects and dust on the conductor can also serve as sources of corona.

7.3 Predicted Audible Noise Levels

L_{50} foul-weather audible noise levels were calculated for average voltage of 539 kV and average conductor heights for foul-weather conditions. The calculated values of the L_{50} foul-weather audible noise level for all of the proposed 500-kV transmission-line sections can be found in the appendix to this report. Specifically, the appendix contains a table of noise levels at the edge of the right-of-way and a plot of noise levels as a function of distance from the line for each proposed transmission line section.

An audible noise plot for the proposed line operating on a new right-of-way is shown in Figure 6. The L_{50} foul-weather level at the edge of the right-of-way is 47 dBA. The audible noise falls about 3 dBA for every doubling of distance. Therefore at 150 feet from the proposed centerline the noise level would be about 44 dBA; at 300 feet, 41 dBA and at 600 feet, 38 dBA.

The large number of existing right-of-way sections that comprise the alternative routes make it impractical to tabulate results for each of these. However, the 3 dBA drop in audible noise at the distances described above for the new right-of-way provide an indication of the noise levels that can be expected off the right-of-way when the proposed line is on an existing right-of-way.

The distance-weighted average levels of corona-generated audible noise at the edge of the right-of-way for the alternatives, options and No Action alternative are given in Tables 11 to 14. Across all alternatives and options, the calculated L_{50} foul-weather noise levels at the edge of the right-of-way depend on the width of the right-of-way and the adjacent lines in the route segment or line section. The highest of the distance-weighted average noise levels from the two sides of the right-of-way was used to characterize the summary measure for each alternative.

Where existing lines are in the right-of-way, distance-weighted average foul-weather noise levels for the alternatives (excluding options) at the edge of the right-of-way would range from 47 to 48 dBA as shown in Tables 11-14. Thus, audible noise from all four alternatives would be comparable by this measure. Calculated noise levels at the edge of existing rights-of-way for all 12 options would range from 47 to 56 dBA. Audible noise would exceed 50 dBA in some sections in West Option 3, Central Option 1, and Crossover Options 2 and 3. (There is one section exceeding 50 dBA in East Option 3.) In all these instances, the increase in the noise levels above the No Action Alternative would be less than 3 dBA, so all sections would meet BPA noise criteria. As noted above the L_{50} foul-weather level at the edge of a new right-of-way with no adjacent lines is 47 dBA.

Noise levels at the edge of the No Action Alternative’s existing rights-of-way range from 37 to 57 dBA. In the highest case, an existing 500-kV of older design is on the existing right-of-way. Audible noise levels for the No Action Alternative are lower than those for the action alternatives, with one exception (Crossover Option 2).

During fair-weather conditions, which occur about 80 percent of the time, audible noise levels at the edge of the right-of-way would be about 20 dBA lower (if corona were present). These lower levels could be masked by ambient noise on and off the right-of-way.

7.4 Discussion

Along much of the proposed routes there would be increases in the perceived noise above current ambient levels during foul weather at the edges of the right-of-way. This would be especially true in areas adjacent to the edge of the right-of-way next to the proposed 500-kV line. However, even there, the corona-generated noise during foul weather would be masked to some extent by naturally occurring sounds such as wind and rain on foliage. The calculated foul-weather corona noise levels for the proposed line would be comparable to, or less, than those from existing 500-kV lines in Oregon and Washington. Relatively lower levels would be especially prevalent in line segments with existing wide rights-of-way that allow a large separation between the proposed 500-kV line and the opposite edge.

Off the right-of-way corona-generated noise during fair weather will likely be masked or so low as to not be perceived even in fair weather. During foul-weather ambient noise levels can be high due to rain hitting foliage or buildings and wind. These sounds can mask corona noise both on and off the right-of-way. Furthermore people tend to be inside with windows closed, providing additional attenuation when corona noise is present.

Off the right-of-way, the foul-weather levels of audible noise from the proposed line would be well below the 55 dBA level that can produce interference with speech outdoors. Residential buildings provide significant sound attenuation (-12 dBA with windows open; -24 dBA with windows closed). Therefore indoor noise levels off the right-of-way would be well below the 45 dBA level where interference with speech indoors can occur and below the 35 dBA level where sleep interference can occur (EPA, 1973; EPA, 1978).

The highest noise level of 50-dBA for the action alternatives (without options) would meet the BPA design criterion and, hence, the statutory limits established in both Oregon and Washington. The computed annual L_{dn} level for transmission lines operating in areas with 20 percent foul weather is about $L_{dn} = L_{50} + 1$ dB (Bracken, 1987). Therefore, assuming such conditions in the I-5 Corridor Reinforcement Project area, the estimated worst case L_{dn} at the edge of the right-of-way would be approximately 51 dBA, which is below the EPA L_{dn} guideline of 55 dBA.

At the proposed substations, audible noise levels will be predominantly due to foul weather corona noise from incoming and outgoing transmission lines. There are no transformers proposed for the new substations. (Even if there were, noise levels produced from new transformers are required to meet BPA specifications that limit noise to 50 dBA at the edge of the substation.) Thus, the proposed substations would meet the 50 dBA criterion as it applies to substations (USDOE, 2010).

Thus all applicable federal, state, and local regulations will be met by the proposed transmission line and substations.

8.0 Electromagnetic Interference

8.1 Basic Concepts

Corona on transmission-line conductors can also generate electromagnetic noise in the frequency bands used for radio and television signals. The noise can interfere with AM radio signals and, in the past, with broadcast television signals on Channels 2 to 6. With the introduction of digital television technology, the broadcast frequencies for these channels have been increased and corona-generated interference with their signals is no longer a potential problem.

In certain circumstances, corona-generated electromagnetic interference (EMI) can also affect communications systems and other sensitive receivers. Interference with electromagnetic signals by corona-generated noise is generally associated with lines operating at voltages of 345 kV or higher. The bundle of three 1.3-inch diameter conductors used in the design of the proposed 500-kV line will mitigate corona generation and keep EMI levels at acceptable levels.

Spark gaps on distribution lines and on low-voltage wood-pole transmission lines have been a more common source of RI/TVI than is corona from high-voltage electrical systems. This gap-type interference is primarily a fair-weather phenomenon caused by loose hardware and wires. The proposed transmission line would be constructed with modern hardware that eliminates such problems and therefore minimizes gap noise. Consequently, this source of EMI is not anticipated for the proposed line.

No state has limits for either RI or TVI. In the United States, electromagnetic interference from power transmission systems is governed by the Federal Communications Commission (FCC) Rules and Regulations presently in existence (Federal Communications Commission, 1988). A power transmission system falls into the FCC category of "incidental radiation device," which is defined as "a device that radiates radio frequency energy during the course of its operation although the device is not intentionally designed to generate radio frequency energy." Such a device "shall be operated so that the radio frequency energy that is emitted does not cause harmful interference. In the event that harmful interference is caused, the operator of the device shall promptly take steps to eliminate the harmful interference." For purposes of these regulations, harmful interference is defined as: "any emission, radiation or induction which endangers the functioning of a radio navigation service or of other safety services or seriously degrades, obstructs or repeatedly interrupts a radio communication service operating in accordance with this chapter" (Federal Communications Commission, 1988: Vol II, part 15. 47CFR, Ch. 1).

Electric power companies have been able to work quite well under the present FCC rule because harmful interference can generally be eliminated. It has been estimated that more than 95 percent of power line sources that caused interference were due to gap-type discharges. These can be found and completely eliminated, when required to prevent interference (USDOE, 1980). Complaints related to corona-generated interference occur infrequently. This is especially true due to increased use of FM radio, cable television and satellite television, which are not subject to corona-generated interference. Mitigation of corona-generated interference with conventional broadcast radio and television receivers can be accomplished in several ways, such as use of a directional antenna or relocation of an existing antenna (USDOE, 1977; USDOE, 1980; Loftness et al., 1981).

8.2 Radio Interference (RI)

Radio reception in the AM broadcast band (535 to 1605 kilohertz (kHz)) is most often affected by corona-generated EMI. FM radio reception is rarely affected. Generally, only residences very near to transmission lines can be affected by RI. The IEEE Radio Noise Design Guide identifies an acceptable limit of fair-weather RI as expressed in decibels above 1 microvolt per meter (dBμV/m) of about 40 dB(μV/m) at 1 megahertz (MHz) (IEEE Committee Report, 1971). This limit applies at 100 ft. (30 m) from the outside conductor. As a general rule, average levels during foul weather (when the conductors are wet) are 16 to 22 dBμV/m higher than average fair-weather levels.

8.2.1 Predicted RI Levels

Distance-weighted L_{50} fair-weather RI levels were predicted for all line sections at 100 ft. (30 m) from the outside conductor. The results are summarized in Tables 11 to 14. The L_{50} fair weather levels for all configurations are at or below the acceptable limit of about 40 dBμV/m and are therefore compliant with the IEEE guideline level. The RI levels for the proposed 500-kV configurations would exceed those from the existing lower voltage lines.

8.3 Television Interference (TVI)

Corona-caused TVI occurs during foul weather and generally has been of concern for transmission lines with voltages of 345 kV or above, and only for conventional receivers within about 600 ft. (183 m) of a line. As indicated above, the conversion to digital television signals has resulted in the affected channels (2 to 6) being broadcast at much higher frequencies where TVI has not been present.

8.3.1 Predicted TVI Levels

For comparison with existing 500-kV lines, the predicted foul-weather TVI levels at 75MHz from the proposed configurations operating at 539 kV are shown in Tables 11 to 14. These distance-weighted average levels are given for 100 ft. (30 m) from the outside conductor. The highest average levels at these points for the alternatives and options would range from 18 to 21 dBμV/m with two exceptions: Levels near Crossover Options 2 and 3 that include an existing 500-kV are higher, 27 and 24 dBμV/m, respectively. In these cases, the higher levels are also present from the existing lines in the No Action Alternative. These levels are comparable to or lower than those from existing 500-kV lines in Oregon and Washington. As with RI the largest values occur when the proposed 500-kV line is directly adjacent to the edge of the right-of-way.

The conversion of broadcast television signals from analog to digital has reduced the likelihood of interference with television reception significantly. Several factors further reduce the likelihood of TVI occurrence. Corona-generated EMI occurs only in foul weather; consequently, signals will not be interfered with most of the time, which is characterized by fair weather. Because television antennas are directional, the impact of TVI is related to the location and orientation of the antenna relative to the transmission line. If the antenna were pointed away from the line, then TVI from the line would affect reception much less than if the antenna were pointed towards the line. Since the level of TVI falls off with distance, the potential for interference becomes minimal at distances greater than several hundred feet from the centerline.

Other forms of TVI from transmission lines are signal reflection (ghosting) and signal blocking caused by the relative locations of the transmission structure and the receiving antenna with respect to the incoming television signal. Again only houses within several hundred feet of the proposed line would possibly be affected.

Television systems that operate at higher frequencies, such as satellite receivers, are not affected by corona-generated EMI. Cable television systems are also not affected.

In the unlikely event that interference with television reception occurs, it can be corrected by any of several approaches: improving the receiving antenna system; installing a remote antenna; installing an antenna for TV stations less vulnerable to interference; connecting to an existing cable system; or installing a translator (cf. USDOE, 1977). BPA has an active program to identify, investigate, and mitigate legitimate RI and TVI complaints. It is anticipated that any instances of TVI caused by the proposed line could be effectively mitigated.

8.4 Interference with Other Devices

Corona-generated interference can conceivably cause disruption on other communications bands. However, interference is very unlikely with newer devices (cell phones and GPS units) that operate with digital signals and at frequencies well above those where corona-generated interference is prevalent. Mobile-radio communications are not susceptible to transmission-line interference because they are generally frequency modulated (FM). In the unlikely event that interference occurs with these or other communications, mitigation can be achieved with the same techniques used for TV and AM radio interference. To be in compliance with FCC regulations, BPA will work with owners and operators of communications facilities along the alternative routes to identify possible mitigation measures and to implement them in the event of interference from the proposed transmission line.

8.5 Conclusion

Predicted EMI levels for the proposed 500-kV transmission line are comparable to, or lower, than those that already exist near 500-kV lines and no impacts of corona-generated interference on radio, television, or other reception are anticipated. Based on land use surveys and population density estimates, the number of houses that could be affected by EMI would vary by alternative, with the West Alternative having the most potential for impact and the East Alternative the least. Whether interference occurs will depend on which action alternative or option is selected, as well as the type of receivers and devices that are present. Furthermore, if interference should occur, there are various methods for correcting it; BPA has a program to respond to legitimate complaints.

9.0 Other Corona Effects

Corona is visible as a bluish glow or as bluish plumes. On the proposed 500-kV line, corona levels would be very low, so that corona on the conductors would be observable only under the darkest conditions and only with the aid of binoculars, if at all. Without a period of adaptation for the eyes and without intentional looking for the corona, it would probably not be noticeable.

When corona is present, the air surrounding the conductors is ionized and many chemical reactions take place, producing small amounts of ozone and other oxidants. Ozone is approximately 90 percent of the oxidants, while the remaining 10 percent is composed principally of nitrogen oxides. The national primary ambient air quality standard for ozone is 75 parts per billion averaged over eight hours. The maximum incremental ozone levels at ground level produced by corona activity on the proposed transmission line during foul weather would be much less than 1 part per billion. This level is insignificant when compared with natural levels and fluctuations in natural levels.

10.0 Summary

Electric and magnetic fields from the proposed transmission line have been characterized using well-known techniques accepted within the scientific and engineering community. The expected maximum electric and magnetic fields on and at the edge of the right-of-way from the proposed line at minimum design clearance would be comparable to those from existing 500-kV lines in Washington, Oregon and elsewhere.

The electric fields from the proposed line would meet regulatory limits for public exposure in some states and guidelines established by IEEE. However, the electric fields from the line could exceed the regulatory limits or guidelines for peak fields established in one state (Minnesota) and by ICNIRP. The magnetic fields from the proposed line would be within the regulatory limits of the two states that have established such limits and below the guidelines for public exposure established by ICNIRP and IEEE. Washington does not have any electric- or magnetic-field regulatory limits or guidelines.

Short-term effects from transmission-line fields are well understood and can be mitigated. Nuisance shocks arising from electric-field induced currents and voltages could be perceivable on the right-of-way of the proposed line. It is common practice to ground permanent conducting objects during and after construction to mitigate against such occurrences.

Corona-generated audible noise from the line would be perceivable during foul weather. The levels would be comparable to or less than those near existing 500-kV transmission lines in Oregon and Washington, would meet BPA design criteria, would be in compliance with noise regulations in Oregon and Washington, and would be below levels specified in EPA guidelines.

Corona-generated electromagnetic interference from the proposed line would be comparable to or less than that from existing 500-kV lines in Washington. AM radio interference levels would be at or below limits identified as acceptable. Television interference, a foul-weather phenomenon, is anticipated to be comparable to or less than that from existing 500-kV lines in Washington and Oregon. The recent introduction of digital television technology significantly reduces the potential for corona-generated TVI from both new and existing lines. However, if legitimate complaints arise, BPA has a mitigation program.

Table 15 presents a group of summary measures for average electric field, magnetic field and audible noise levels at the edge of the right-of-way along each alternative. This table provides a means to compare long-term levels of the three parameters among action alternatives. Line segments in the action alternative options were included only in the computation of the segment maximum and minimum levels. The impact of this exclusion on the other summary measures is expected to be minimal, except for the three options that include existing 500-kV lines. The effects on magnetic fields and audible noise of inclusion of these options have been cited previously.

The differences in average levels of electric fields between alternatives are dependent to some extent on right-of-way type. The Central and East alternatives with 90 percent new right-of-way tend to have higher electric fields at the edge-of the right-of way. The West Alternative with only 2 percent of new right-of-way has the lowest average electric fields at the edge of the right-of-way. However, the differences in electric-field levels are not sufficient to affect the anticipated induction effects that occur under all 500-kV lines.

A comparison of magnetic fields in Table 15 indicates that the preponderance of new right-of-way in the Central and East alternatives also leads to slightly higher average magnetic fields at the edge of the right-of-way. The route segment maximums in all alternatives are very comparable. The differences in magnetic field levels between alternatives are all slight.

The average audible noise levels for all alternatives are about 47 dBA. Incorporation of the option(s) with existing 500-kV lines would result in localized areas with perceptibly higher noise levels. However, in these cases, changes to noise levels from the No Action Alternative at the edge of the right-of-way would not be discernable to the human ear. Like audible noise, radio and television interference levels are directly related to corona level and will exhibit the same consistency across alternatives.

The comparison of average edge of right-of-way values in Table 15 indicates differences between some of the alternatives. However the magnitude of the differences is not deemed sufficient to differentiate the level of effects that are anticipated from the different alternatives. Therefore the level of impact as measured by frequency of occurrence of effects such as nuisance shocks, audible noise annoyance or television interference will depend more on the number of people living on or utilizing the land within several hundred feet of the line than on the levels of the physical parameters.

Summaries of land-use area crossed by the action alternatives and zoning within 1,000 feet of the proposed line indicate that there are significant differences in the estimated number of people that live or will ultimately live and use the land near the different alternatives (Chapter 5; Golder, 2011).

- The West Alternative and options would occupy predominantly (98 percent) existing right-of-way, which crosses the highest proportion (17 percent) of populated area compared to the other action alternatives – about 7 percent urban/suburban and 10 percent rural. Most of the rural area is undeveloped. Beyond the right-of-way – from the right-of-way edge out to 1,000 feet on either side of the line – the West Alternative and options would encompass a greater percentage of property zoned for residential use than the other alternatives: about 46 percent of property along the West Alternative is zoned for residential use.
- The Central Alternative and options would primarily use new right-of-way (about 90 percent) that would run through predominantly forest land (around 90 percent of land use crossed). Only 3 percent of the land crossed by the right-of-way would be populated – 1 percent urban/suburban and 2 percent rural (exception: Central Option 2 would cross 4 percent rural land). About 14 percent of the land beyond the right-of-way (out to 1,000 feet on both sides) of the East Alternative and options is zoned for residential use.
- The East Alternatives and options would primarily use new right-of-way (about 90 percent) that would run through predominantly forest land (around 90 percent of land use crossed). Only 3 percent of the land crossed by the right-of-way would be populated – about 1 percent urban/suburban and 2 percent rural (exception: East Option 1 would cross 4 percent rural land). About 7 percent of the land beyond the right-of-way (out to 1,000 feet) of the East Alternative and options is zoned for residential use.
- The Crossover Alternative and options would require about 55 percent new right-of-way that would cross predominantly forest land (about 76 percent). About 8 percent of the land crossed by the right-of-way would be populated – about 1 percent urban/suburban and 7 percent rural. About 14 percent of the land beyond the right-of-way (out to 1,000 feet) of the Crossover Alternative and options is zoned for residential use.

The distribution of land uses and zoning along the various alternatives suggests that the overall impact of electrical effects would be greater along the West Alternative than along the other alternatives. The impacts of electrical effects would be comparable along the other three alternatives.

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Table 1: Physical Dimensions and Electrical Characteristics of the Proposed Single-circuit 500 kV transmission line for the I-5 Corridor Reinforcement Project.

Line Characteristic	Proposed I-5 Corridor Reinforcement 500-kV Line[2]
Voltage, kV Maximum/Average[1]	550/539
Circuit Configuration[2]	Single
Proposed Current, A Peak/Average	1080/324
Electric Phasing	Orientation varies.
Clearance, ft. Minimum/Average[1, 2]	35/47
Tower configuration	Delta
Phase spacing, ft.	46H, 31.5V
Conductor: #/Diameter, in.	3/1.3
Centerline distance to edge of ROW, ft.[3]	75
Centerline distance to existing lines, ft.	Variable
Average altitude, ft.	500-1000

[1] Average voltage and average clearance used for corona calculations.

[2] To meet the BPA 9 kV/m limit for peak electric field, the minimum and average design clearances were increased by from 1 to 4 feet in some sections.

[3] The distance to the edge of the right-of-way on existing rights-of-way will vary but will always be at least 75 feet.

Table 2: Mileage and Segments of the Action Alternatives of the I-5 Corridor Reinforcement Project

Characteristic		Action Alternative			
		West	Central	Crossover	East
Length, miles	Total	67.5	77.3	74	75.5
	New ROW	1.4 (2%)	69.5 (90%)	42.7 (58%)	67.7 (90%)
	Existing ROW	66.1	7.8	31.3	7.8
	Option 1	3.1	2.5	7.3	17.6
	Option 2	9.0	15.7	4.1	23.5
	Option 3	13.1	14.9	4.2	3.7
Segments, number	Alternative	9	18	18	11
	Option 1	3	1	3	4
	Option 2	7	5	2	5
	Option 3	7	3	2	1

Table 3: Electric and Magnetic Fields from the Proposed 500-kV Transmission Line When Operated on New Right-of-way

Field Location	Electric Field, kV/m[1]		Magnetic Field, mG[2]	
	Maximum	Average	Maximum	Average
Peak on ROW	8.8	5.3	184	35
At Edge of ROW	2.3	2.3	48	12
At 150 feet from Centerline	0.5	0.5	13	4
At 300 feet from Centerline	0.1	0.1	3	1

[1] Maximum electric fields are calculated for maximum voltage and minimum clearance. Average electric fields are calculated for average voltage and average clearance.

[2] Maximum magnetic fields are calculated for maximum current and minimum clearance. Average magnetic fields are calculated for average current and average clearance.

Table 4: Distance-weighted Average Electric and Magnetic Field Levels for the West Alternative and Options

West Alternative				Electric Field, kV/m		Magnetic Field, mG	
Right-of-Way	Length, miles[1, 2]	Field Location	Field Descriptor[3]	Proposed Action	No Action	Proposed Action	No Action
New	1.4	On ROW	Average	5.3	–	35	–
			Maximum	8.8		184	
		Edge of ROW	Average	2.3		12	
			Maximum	2.3		48	
Existing	64.2	On ROW	Average	5.4	2.0	36	24
			Maximum	8.8	3.8	182	134
		Edge of ROW	Average	1.4	0.5	10	5
			Maximum	1.4	0.5	36	21
West Option 1[4]							
New	2.0 (0.3)	Same as new ROW values shown above for West Alternative					
Existing	1.1 (2.7)	On ROW	Average	5.6	2.3	28	19
			Maximum	8.9	4.0	139	94
		Edge of ROW	Average	0.6	0.6	10	4
			Maximum	0.6	0.5	35	13
West Option 2							
New	1.7 (1.0)	Same as new ROW values shown above for West Alternative					
Existing	7.3 (6.1)	On ROW	Average	5.6	2.4	35	32
			Maximum	8.8	4.4	158	119
		Edge of ROW	Average	1.0	0.8	10	8
			Maximum	1.1	0.8	34	23
West Option 3							
New	1.5 (1.0)	Same as new ROW values shown above for West Alternative					
Existing	11.5 (6.1)	On ROW	Average	5.6	2.8	41	43
			Maximum	8.8	5.2	163	136
		Edge of ROW	Average	1.3	0.6	12	9
			Maximum	1.3	0.5	35	21

[1] Lengths in parentheses are for the original segments in the West Alternative that would be replaced by the option.
[2] The lengths for alternatives and options cited in this table include only those segments used in the calculations of average levels. The omitted segments included the Columbia River crossing and short segments where conductor locations varied over the length of the segment and/or where another line crossed the route. Calculations in these segments were not practical with the calculation model. Inclusion of these segments would not significantly change the average values of fields and corona effects along the alternatives or options.
[3] All field descriptors are distance-weighted means of the fields on or at the edge of the ROW. The edge-of-ROW values are computed from fields on both sides of the route. Average electric fields are computed for maximum voltages and average clearances along the route; likewise, average magnetic fields are computed for average

currents and average clearances. Maximum electric fields are computed for maximum voltages and minimum clearances; maximum magnetic fields are computed for maximum currents and minimum clearances.
[4] The field levels for all West options are very similar to those in the segments they would replace. The inclusion of one of these options would not significantly affect the overall mean field levels for the alternative.

Table 5: Distance-weighted Average Electric and Magnetic Field Levels for the Central Alternative and Options

Central Alternative				**Electric Field, kV/m**		**Magnetic Field, mG**	
Right-of-Way	Length, miles[1, 2]	Field Location	Field Descriptor[3]	Proposed Action	No Action	Proposed Action	No Action
New	69.5	On ROW	Average	5.3	—	35	–
			Maximum	8.8		184	
		Edge of ROW	Average	2.3		12	
			Maximum	2.3		48	
Existing	6.8	On ROW	Average	5.4	2.1	33	31
			Maximum	8.9	3.8	175	135
		Edge of ROW	Average	1.1	1.0	9	11
			Maximum	1.1	1.0	32	36
Central Option 1[4]							
New	0	Same as edge of ROW values shown above for Central Alternative					
Existing	2.5 (0.0)	On ROW	Average	5.5	5.5	62	49
			Maximum	9.0	9.0	257	235
		Edge of ROW	Average	2.3	1.4	15	10
			Maximum	2.4	1.5	59	40
Central Option 2							
New	15.0 (18.0)	Same as edge of ROW values shown above for Central Alternative					
Existing	0.4 (0.0)	On ROW	Average	5.5	2.0	34	11
			Maximum	8.8	3.7	180	78
		Edge of ROW	Average	1.6	0.7	7	3
			Maximum	1.7	0.8	27	15
Central Option 3							
New	14.9 (20.8)	Same as edge of ROW values shown above for Central Alternative					
Existing	0	On ROW	Average	—	—	—	—
			Maximum				
		Edge of ROW	Average				
			Maximum				

[1] Lengths in parentheses are for the original segments in the Central Alternative that would be replaced by the option.
[2] See note 2 of Table 4.
[3] All field descriptors are distance-weighted means of the fields on or at the edge of the ROW. The edge-of-ROW values are computed from fields on both sides of the route. Average electric fields are computed for maximum voltages and average clearances along the route; likewise, average magnetic fields are computed for average currents and average clearances. Maximum electric fields are computed for maximum voltages and minimum clearances; maximum magnetic fields are computed for maximum currents and minimum clearances.
[4] The segments in the Central options do not replace any existing segments. Using one of these options would not significantly affect average field levels for the alternative. However, there would be localized increases in magnetic fields for Option 1.

Table 6: Distance-weighted Average Electric and Magnetic Field Levels for the Crossover Alternative and Options

Crossover Alternative				Electric Field, kV/m		Magnetic Field, mG	
Right-of-Way	Length, miles[1,2]	Field Location	Field Descriptor[3]	Proposed Action	No Action	Proposed Action	No Action
New	42.7	On ROW	Average	5.3	–	35	–
			Maximum	8.8		184	
		Edge of ROW	Average	2.3		12	
			Maximum	2.3		48	
Existing	29.7	On ROW	Average	5.4	2.0	34	17
			Maximum	8.9	3.7	182	96
		Edge of ROW	Average	1.3	0.5	3	3
			Maximum	1.3	0.5	26	12
Crossover Option 1[4]							
New	0.7 (2.1)	Same as edge of ROW values shown above for Crossover Alternative					
Existing	6.6	On ROW	Average	5.5	1.5	29	11
			Maximum	8.8	2.8	150	63
		Edge of ROW	Average	0.9	0.3	9	2
			Maximum	0.9	0.3	34	24
Crossover Option 2							
New	0	Same as edge of ROW values shown above for Crossover Alternative					
Existing	4.1 (0.0)	On ROW	Average	5.8	5.5	68	49
			Maximum	8.8	9	270	235
		Edge of ROW	Average	1.9	2	14	16
			Maximum	2.1	2.1	51	57
Crossover Option 3							
New	0	Same as edge of ROW values shown above for Crossover Alternative					
Existing	4.2 (0.0)	On ROW	Average	5.8	5.5	68	49
			Maximum	8.9	9	276	235
		Edge of ROW	Average	2.2	1.6	13	12
			Maximum	2.3	1.7	52	45

[1] Lengths in parentheses are for the original segments in the Crossover Alternative that would be replaced by the option.
[2] See note 2 of Table 4.
[3] All field descriptors are distance-weighted means of the fields on or at the edge of the ROW. The edge-of-ROW values are computed from fields on both sides of the route. Average electric fields are computed for maximum voltages and average clearances along the route; likewise, average magnetic fields are computed for average currents and average clearances. Maximum electric fields are computed for maximum voltages and minimum clearances; maximum magnetic fields are computed for maximum currents and minimum clearances.
[4] The segments in the Crossover options do not replace any existing segments. Using one of these options would not significantly affect average field levels for the alternative. However, there would be localized increases in the magnetic fields for Options 2 and 3.

Table 7: Distance-weighted Average Electric and Magnetic Field Levels for the East Alternative and Options

East Alternative				Electric Field, kV/m		Magnetic Field, mG	
Right-of-Way	Length, miles[1, 2]	Field Location	Field Descriptor[3]	Proposed Action	No Action	Proposed Action	No Action
New	67.7	On ROW	Average	5.3	–	35	–
			Maximum	8.8		184	
		Edge of ROW	Average	2.3		12	
			Maximum	2.3		48	
Existing	6.8	On ROW	Average	5.4	2.1	32	31
			Maximum	8.9	3.8	174	135
		Edge of ROW	Average	1.1	1.0	9	11
			Maximum	1.1	1.0	32	36
East Option 1[4]							
New	17.6 (19.4)	Same as edge of ROW values shown above for East Alternative					
Existing	0	On ROW	Average	–	–	–	–
			Maximum				
		Edge of ROW	Average				
			Maximum				
East Option 2							
New	23.5 (22.5)	Same as edge of ROW values shown above for East Alternative					
Existing	0	On ROW	Average	–	–	–	–
			Maximum				
		Edge of ROW	Average				
			Maximum				
East Option 3							
New	1.9 (2.6)	Same as edge of ROW values shown above for East Alternative					
Existing	1.8	On ROW	Average	5.7	2.9	53	48
			Maximum	8.8	5.3	186	133
		Edge of ROW	Average	1.2	0.2	6	4
			Maximum	1.4	0.2	27	8

[1] Lengths in parentheses are for the original segments in the East Alternative that would be replaced by the option.
[2] See note 2 of Table 4.
[3] All field descriptors are distance-weighted means of the fields on or at the edge of the ROW. The edge-of-ROW values are computed from fields on both sides of the route. Average electric fields are computed for maximum voltages and average clearances along the route; likewise, average magnetic fields are computed for average currents and average clearances. Maximum electric fields are computed for maximum voltages and minimum clearances; maximum magnetic fields are computed for maximum currents and minimum clearances.

[4] The segments in the East options do not replace any existing segments. Using one of these options would not significantly affect average field levels for the alternative.

Table 8: Electric- and Magnetic-field Exposure Guidelines

Organization	Type of Exposure	Electric Field, kV/m	Magnetic Field, mG
ACGIH	Occupational	25[1]	10,000
ICNIRP	Occupational	8.3[2]	4,200
	General Public	4.2	2000
IEEE	Occupational	20	27,100
	General Public	5[3]	9,040

[1] Grounding is recommended above 5 –7 kV/m and conductive clothing is recommended above 15 kV/m.
[2] Increased to 16.7 kV/m if nuisance shocks are eliminated.
[3] Within power line rights-of-way, the guideline is 10 kV/m.

Sources: ACGIH, 2009; ICNIRP, 2010; ICES, 2002

Table 9: States with Transmission Line Field Limits

State Agency	Within Right-of-Way	At Edge of Right-of-Way	Comments
a. 60-Hz ELECTRIC-FIELD LIMIT, kV/m			
Florida Department of Environmental Regulation	8 (230 kV) 10 (500 kV)	2	Codified regulation, adopted after a public rulemaking hearing in 1989.
Minnesota Environ- mental Quality Board	8	–	12-kV/m limit on the high voltage direct current (HVDC) nominal electric field.
Montana Board of Natural Resources and Conservation	7[1]	1[2]	Codified regulation, adopted after a public rulemaking hearing in 1984.
New Jersey Department of Environmental Protection	–	3	Used only as a guideline for evaluating complaints.
New York State Public Service Commission	11.8 (7,11)[3]	1.6	Explicitly implemented in terms of a specified right-of-way width.
Oregon Facility Siting Council	9	–	Codified regulation, adopted after a public rulemaking hearing in 1980.
b. 60-Hz MAGNETIC-FIELD LIMIT, mG			
Florida Department of Environmental Regulation	–	150 (230 kV) 200 (500 kV)	Codified regulations, adopted after a public rulemaking hearing in 1989.
New York State Public Service Commission	–	200	Adopted August 29, 1990.

[1] At road crossings
[2] Landowner may waive limit
[3] At highway and private road crossings, respectively

Source: USDOE, 1996

Table 10: Common Noise Levels

Sound Level, dBA	Noise Source or Effect
130	Threshold of pain
110	Rock-and-roll band
80	Truck at 50 ft. (15.2 m)
70	Gas lawnmower at 100 ft. (30 m)
60	Normal conversation indoors
50	Moderate rainfall on foliage
49	Highest foul-weather L_{50} at edge of proposed 500-kV right-of-way
40	Refrigerator
25	Bedroom at night
0	Hearing threshold

Adapted from: USDOE, 1986; USDOE, 1996.

Table 11: Distance-weighted L_{50} Foul Weather Audible Noise Levels and Radio and Television Interference Levels for the West Alternative and Options

West Alternative		Audible Noise, dBA At Edge of ROW		Radio Interference, dBA(µV/m) At 100 ft from Outside Conductor		Television Interference, dBA(µV/m) At 100 ft from Outside Conductor	
Right-of-Way	Length, miles[1,2,3]	Proposed Action	No Action	Proposed Action	No Action	Proposed Action	No Action
New	1.4	47	—	36	—	21	—
Existing	64.2	48	43	34	29	19	15
West Option 1							
New	2.0	47	—	36	—	21	—
Existing	1.1	47	40	37	26	18	13
West Option 2							
New	1.7	47	—	36	—		—
Existing	7.3	49	47	36	32	19	18
West Option 3							
New	1.5	47	—	36	—		—
Existing	11.5	50	49	36	35	21	21

[1] Audible noise levels are distance-weighted means of the L50 foul weather levels at the edge of the right-of-way. The highest average value from the two edges is shown. Audible noise levels are computed for average voltages and average conductor heights.

[2] See note 2 of Table 4.

[3] All RI and TVI levels are distance-weighted means of interference levels at the edge of the ROW for average voltage and average line height. RI levels are computed for fair weather conditions and TVI for foul weather.

Table 12: Distance-weighted L_{50} Foul Weather Audible Noise Levels and Radio and Television Interference Levels for the Central Alternative and Options

Central Alternative		Audible Noise, dBA At Edge of ROW		Radio Interference, dBA(μV/m) At 100 ft from Outside Conductor		Television Interference, dBA(μV/m) At 100 ft from Outside Conductor	
Right-of-Way	**Length, miles[1,2,3]**	**Proposed Action**	**No Action**	**Proposed Action**	**No Action**	**Proposed Action**	**No Action**
New	69.5	47	—	36	—	21	—
Existing	6.8	47	42	37	27	18	14
Central Option 1							
New	0	—	—	—	—	—	—
Existing	2.5	53	52	36	36	21	20
Central Option 2							
New	15	47	—	36	—	21	—
Existing	0.4	47	41	34	24	19	11
Central Option 3							
New	14.9	47	—	36	—	21	—
Existing	0	—	—	—	—	—	—

[1] Audible noise levels are distance-weighted means of the L_{50} foul weather levels at the edge of the right-of-way. The highest average value from the two edges is shown. Audible noise levels are computed for average voltages and average conductor heights.

[2] See note 2 of Table 4.

[3] All RI and TVI levels are distance-weighted means of interference levels at the edge of the ROW for average voltage and average line height. RI levels are computed for fair weather conditions and TVI for foul weather.

Table 13: Distance-weighted L_{50} Foul Weather Audible Noise Levels and Radio and Television Interference Levels for the Crossover Alternative and Options

Crossover Alternative		Audible Noise, dBA At Edge of ROW		Radio Interference, dBA(μV/m) At 100 ft from Outside Conductor		Television Interference, dBA(μV/m) At 100 ft from Outside Conductor	
Right-of-Way	**Length, miles[1,2,3]**	**Proposed Action**	**No Action**	**Proposed Action**	**No Action**	**Proposed Action**	**No Action**
New	42.7	47	—	36	—	21	—
Existing	29.7	47	40	34	26	19	13
Crossover Option 1							
New	0.7	47	—	36	—	21	—
Existing	6.6	47	37	42	36	18	10
Crossover Option 2							
New	0	—	—	—	—	—	—
Existing	4.1	56	57	43	42	27	27
Crossover Option 3							
New	0	—	—	—	—	—	—
Existing	4.2	54	54	39	42	24	27

[1] Audible noise levels are distance-weighted means of the L_{50} foul weather levels at the edge of the right-of-way. The highest average value from the two edges is shown. Audible noise levels are computed for average voltages and average conductor heights.

[2] See note 2 of Table 4.

[3] All RI and TVI levels are distance-weighted means of interference levels at the edge of the ROW for average voltage and average line height. RI levels are computed for fair weather conditions and TVI for foul weather.

Table 14: Distance-weighted L_{50} Foul Weather Audible Noise Levels and Radio and Television Interference Levels for the East Alternative and Options

East Alternative		Audible Noise, dBA At Edge of ROW		Radio Interference, dBA(μV/m) At 100 ft from Outside Conductor		Television Interference, dBA(μV/m) At 100 ft from Outside Conductor	
Right-of-Way	Length, miles[1,2,3]	Proposed Action	No Action	Proposed Action	No Action	Proposed Action	No Action
New	67.7	47	—	36	—	21	—
Existing	6.8	48	42	35	27	—	—
East Option 1							
New	17.6	47	—	36	—	21	—
Existing	0	—	—	—	—	—	—
East Option 2							
New	23.5	47	—	36	—	21	—
Existing	0	—	—	—	—	—	—
East Option 3							
New	1.9	47	—	36	—	—	—
Existing	1.8	50	48	34	35	18	20

[1] Audible noise levels are distance-weighted means of the L_{50} foul weather levels at the edge of the right-of-way. The highest average value from the two edges is shown. Audible noise levels are computed for average voltages and average conductor heights.

[2] See note of Table 4.

[3] All RI and TVI levels are distance-weighted means of interference levels at the edge of the ROW for average voltage and average line height. RI levels are computed for fair weather conditions and TVI for foul weather.

Table 15: Average Electric Fields, Magnetic Fields and Audible Noise at the Edge of the Right-of-Way by Alternative.[1]

	Average Electric Field at Edge of ROW, kV/m			
Alternative	West	Central	Crossover	East
Section Maximum, kV/m	2.3	2.6	2.6	2.3
Distance-weighted Average, kV/m	1.4	2.2	1.8	2.2
Section Minimum, kV/m	0.1	0.1	0.1	0.1
Percentage of Route > 2 kV/m	28	89	62	91
Percentage of Route > 1 kV/m	51	92	76	94
Percent of Route with New ROW	2	90	58	90
	Average Magnetic Field at Edge of ROW, mG			
Alternative	West	Central	Crossover	East
Section Maximum, mG	20	19	19	13
Distance-weighted Average, mG	10	12	9	12
Section Minimum, mG	1	2	1	2
Percentage of Route > 20 mG	0	0	0	0
Percentage of Route > 10 mG	62	93	74	95
Percent of Route with New ROW	2	90	58	90
	Foul Weather L50 Audible Noise at Edge of ROW, dBA			
Alternative	West	Central	Crossover	East
Section Maximum, dBA	52	53	56	50
Distance-weighted Average, dBA	47	47	47	48
Section Minimum, dBA	41	43	41	43
Percentage of Route > 48 dBA	11	0	0	0
Percentage of Route > 45 dBA	78	95	81	96
Percent of Route with New ROW	2	90	58	90

[1] Levels from the options are not included in distance-weighted averages and percentages along routes.

Figure 1: Single-circuit Tower for I-5 Corridor Reinforcement Project

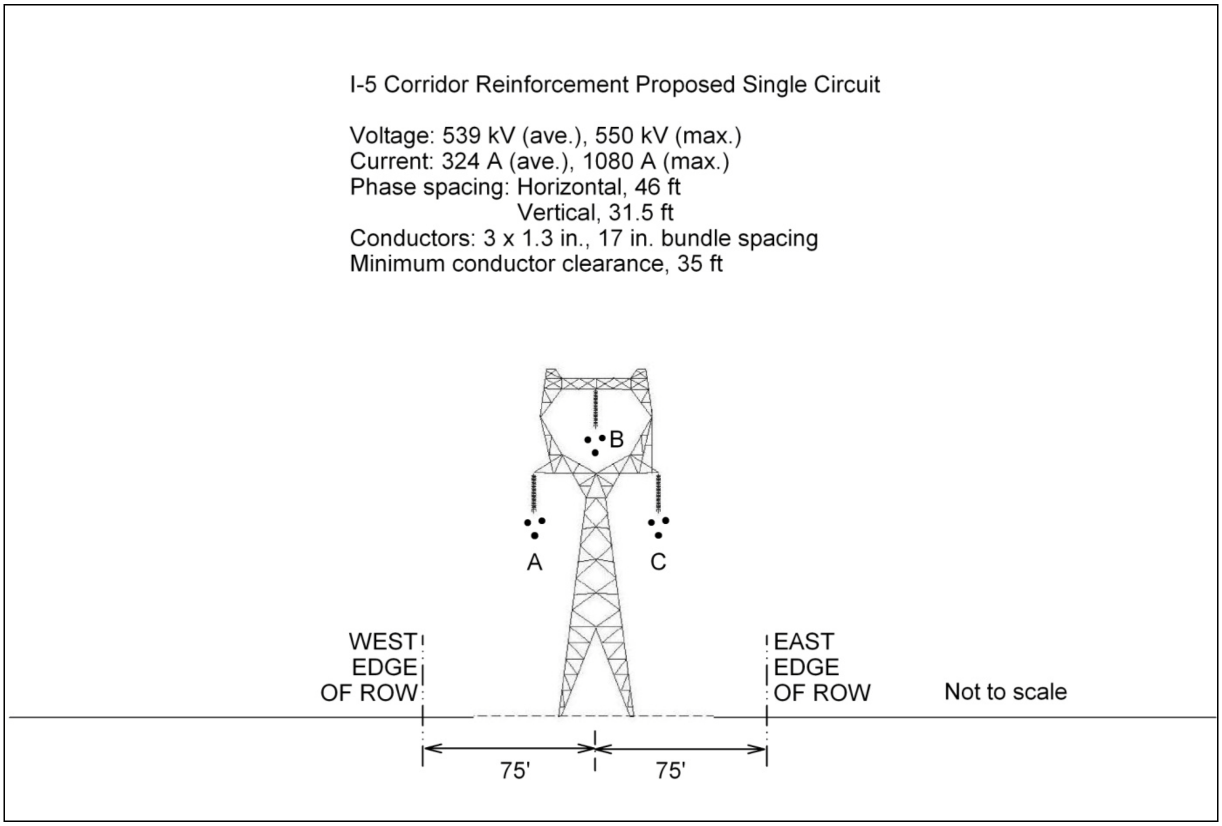


Figure 2: Plot of Electric Fields from Proposed Line on New ROW (Calculation 1.1.0)

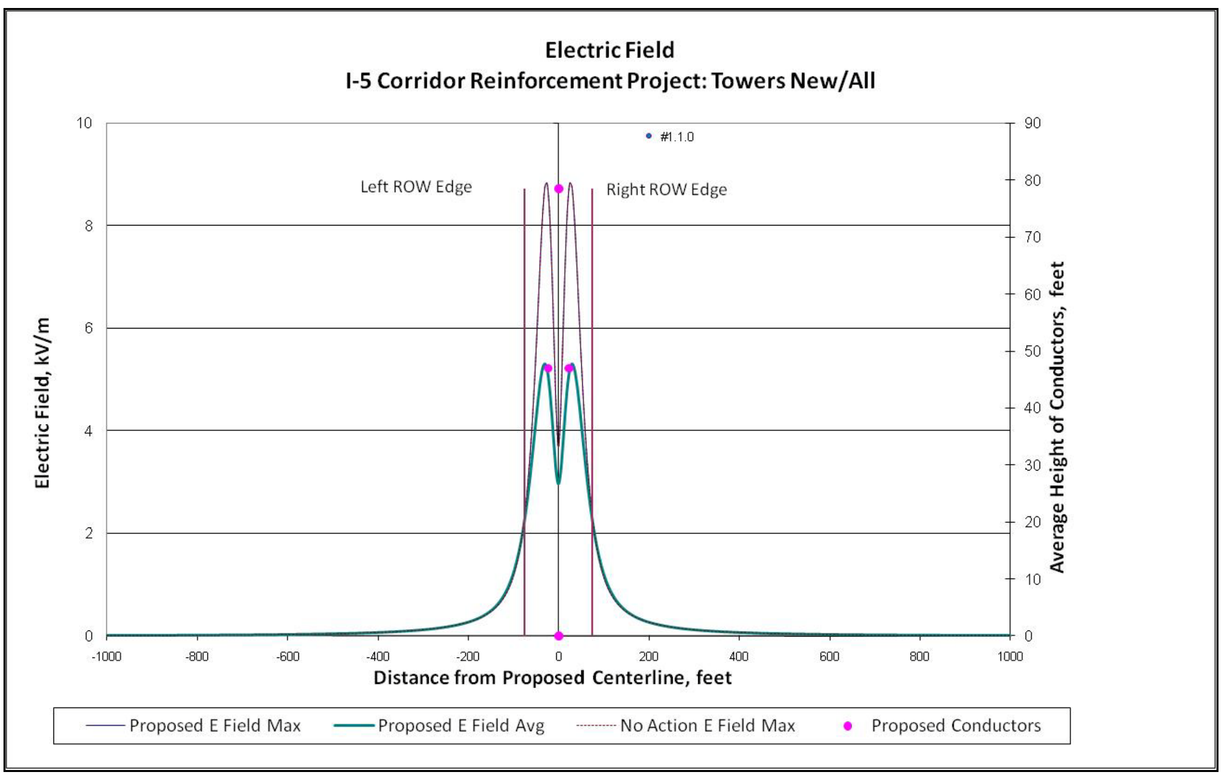


Figure 3: Example Plot of Electric Field from Proposed Line on Existing ROW (Calculation 25.2.0)

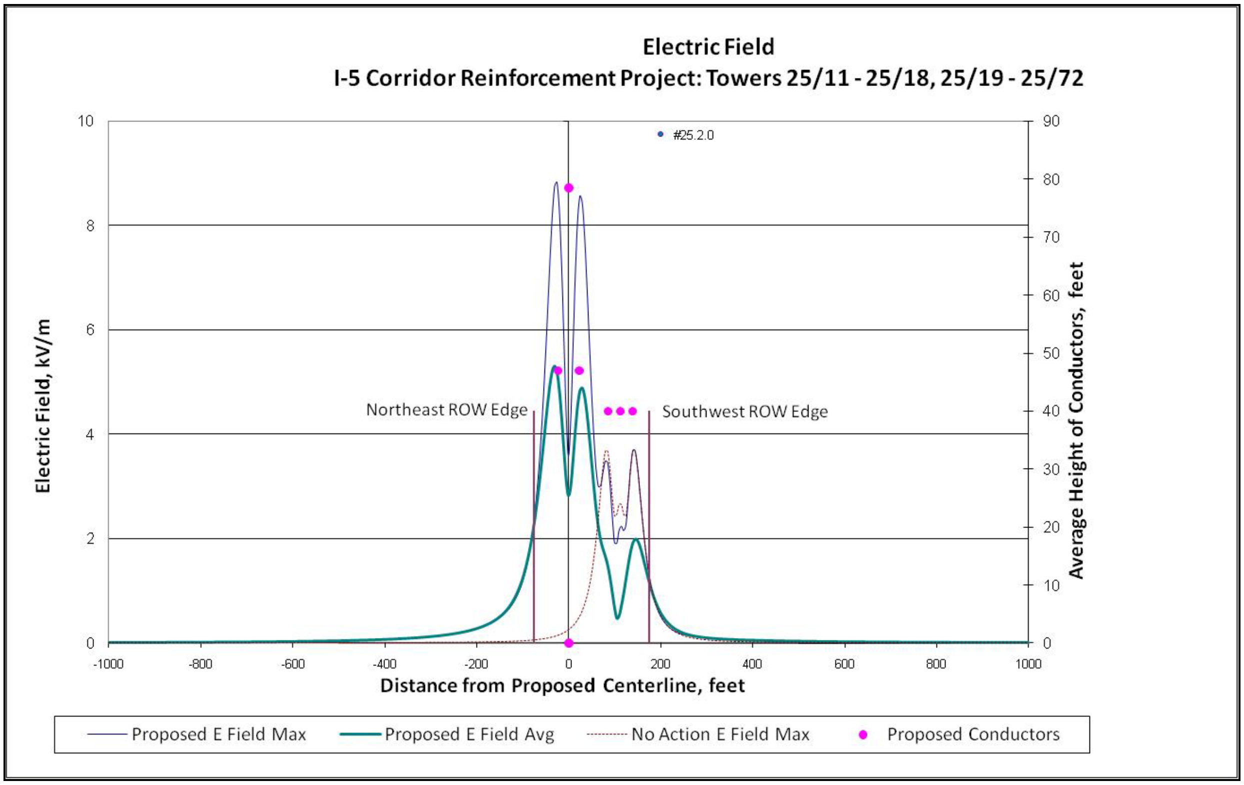


Figure 4: Plot of Magnetic Fields from Proposed Line on New ROW (Calculation 1.1.0)

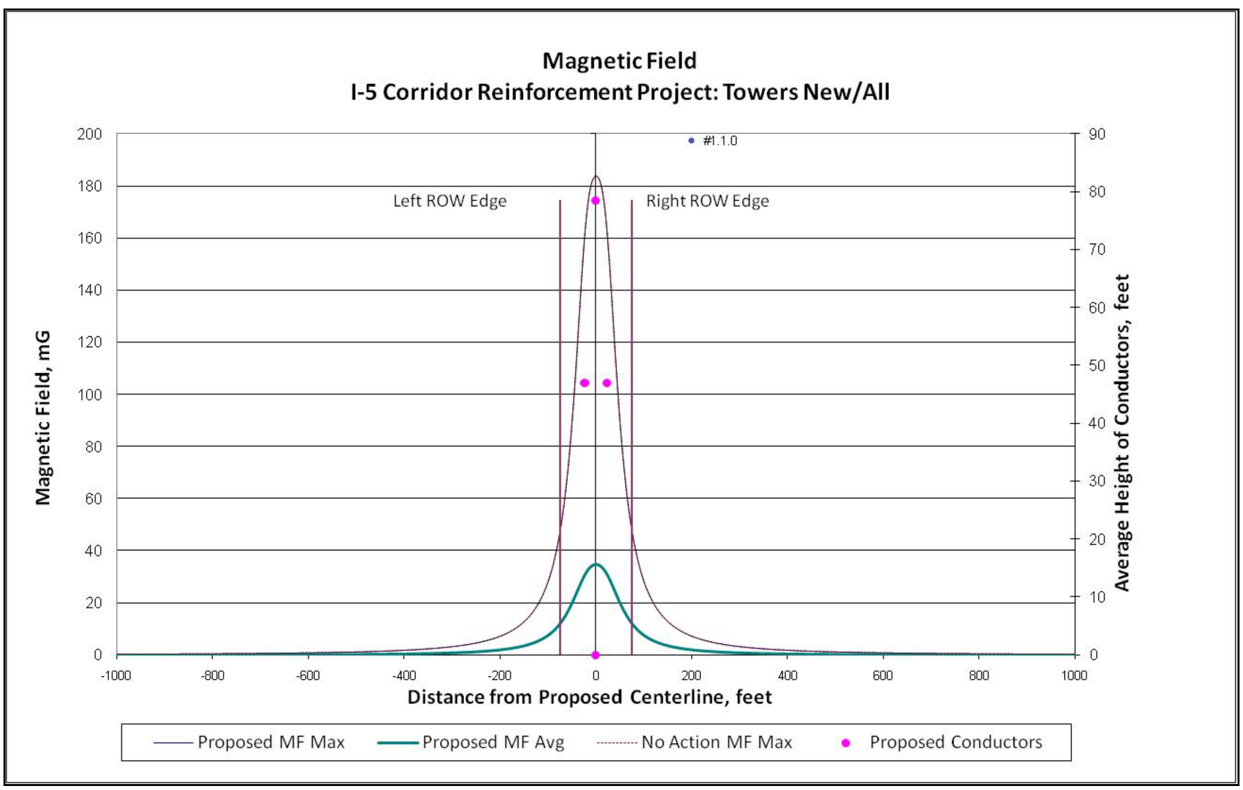


Figure 5: Example Plot of Magnetic Fields from Proposed Line on Existing ROW (Calculation 25.2.0)

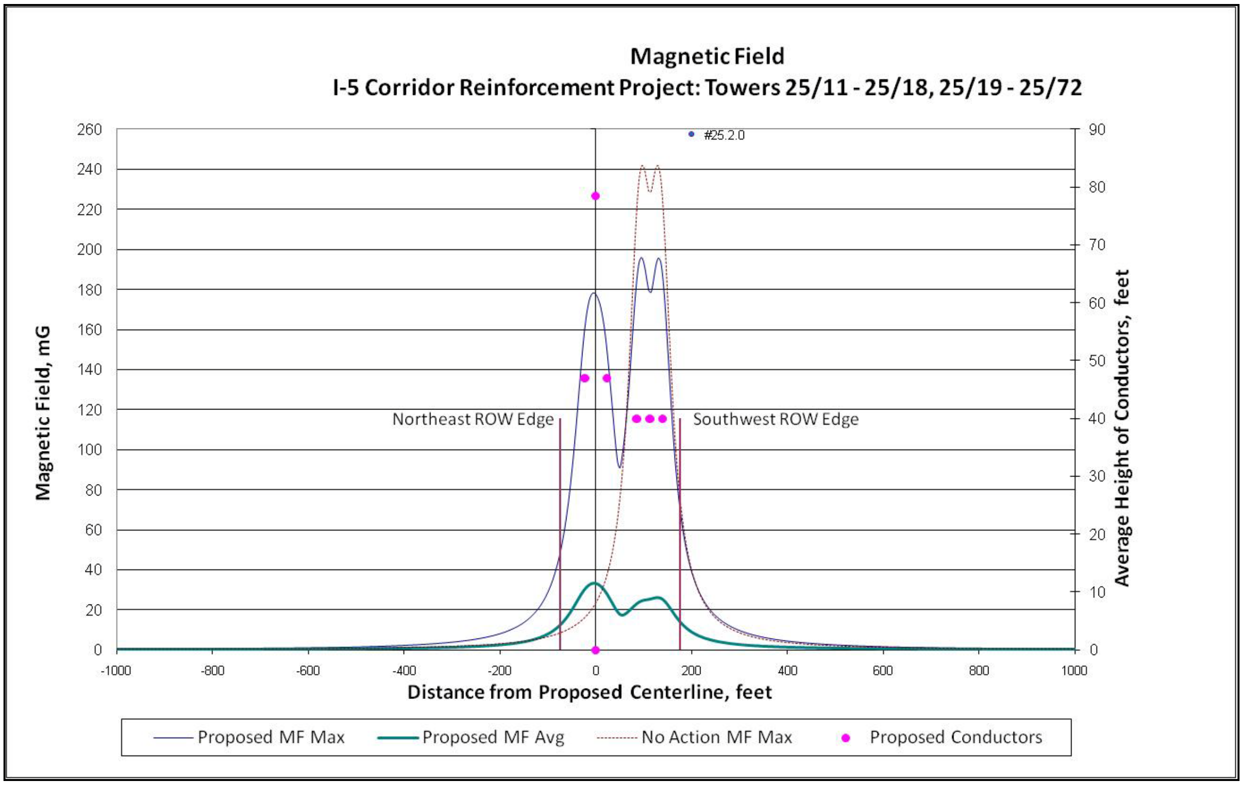


Figure 6: Plot of Audible Noise from Proposed Line on New ROW (Calculation 1.1.0)

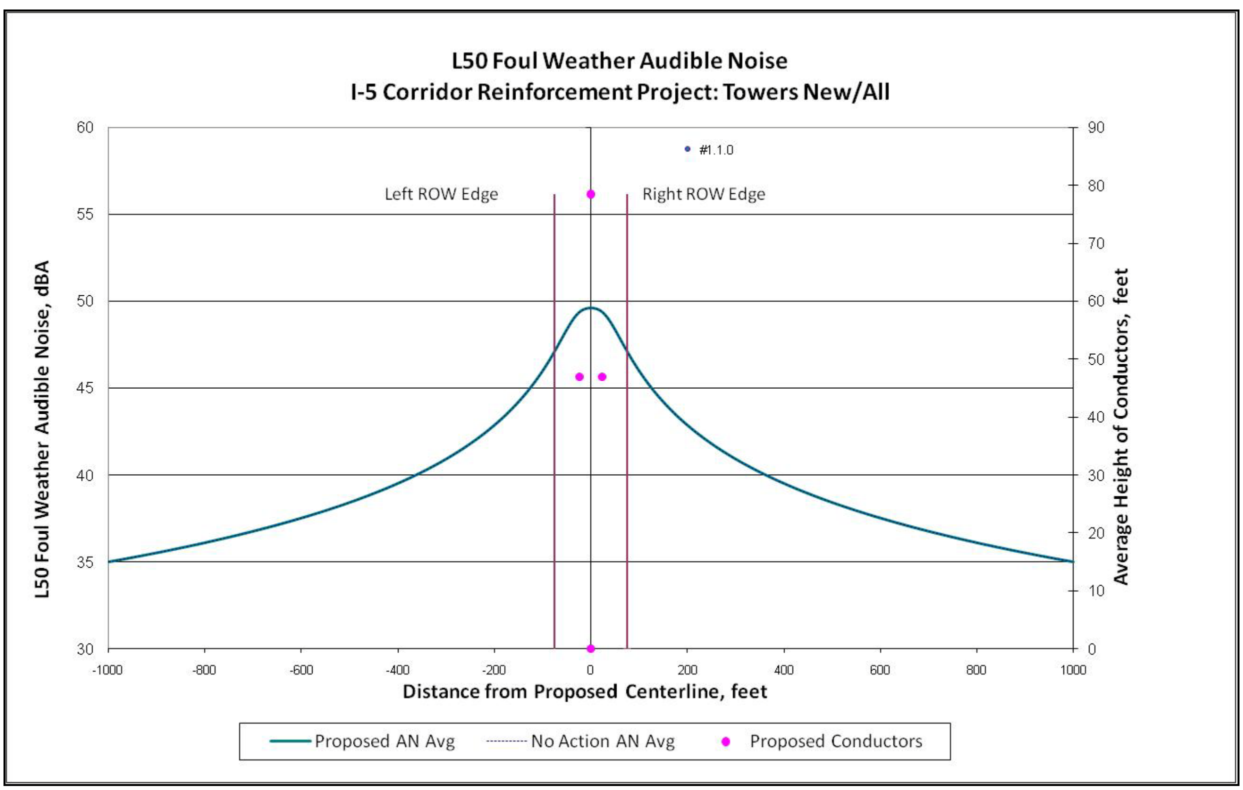
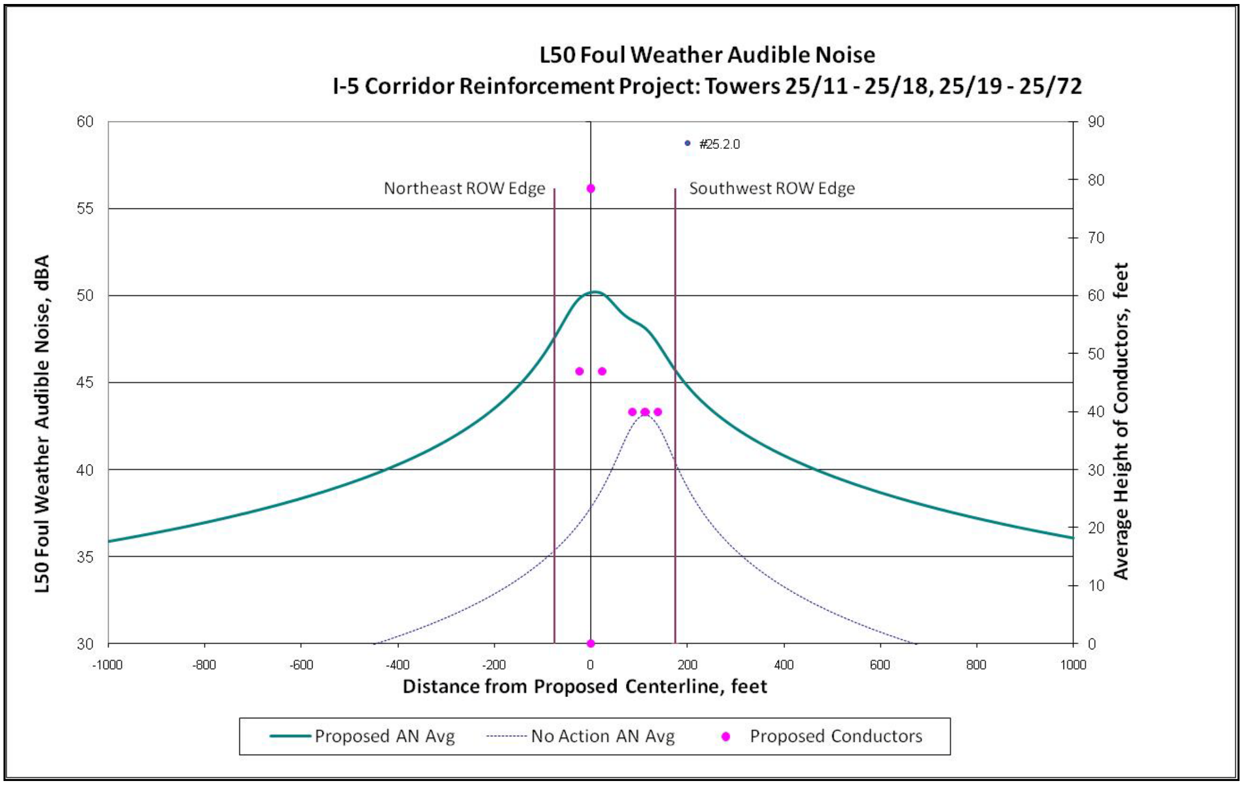


Figure 7: Example Plot of AN from Proposed Line on Existing ROW (Calculation 25.2.0)



Appendix

Electrical Effects Summaries by Route Segments for the I-5 Corridor Reinforcement Project

October 2011

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Summaries of Electrical Effects by Proposed Route Segments

This appendix presents summaries of the levels of electric fields, magnetic fields, and corona-generated audible noise, radio interference, and television interference that would be produced by the I-5 Corridor Reinforcement Project. To characterize the electrical effects of the project, they have been calculated for each route segment and/or line section (see definitions below) that has unique physical and electrical characteristics. Calculations for 101 of 109 sections are included in this appendix. Calculations were not performed for eight sections due to their very short length, non-parallel conductors at transition points (which can skew calculations), or height at the Columbia River crossing (where conductors would be very high above the ground or river).

Definitions

The following terms are used in the summary data. Understanding them will help readers use tables later in the appendix, which list field summaries for specific locations along the transmission line routes. The summary data include: plots of average and maximum electric and magnetic fields for minimum ground clearance; plots of L50 (median) audible noise; tables of average and maximum electric and magnetic fields on and at the edge of the right-of-way; and tables of L50 levels for audible noise, radio interference, and television interference levels at the edge of the right-of-way (audible noise) or at 100 feet from the outside conductor (radio and television interference).

Action Alternatives. There are four action alternatives proposed for the transmission line. Each alternative includes constructing a 500-kV transmission line from a substation near Castle Rock, Washington, to a substation near Troutdale, Oregon. There are three possible locations for the substation at the northern terminus near Castle Rock and one location for the new substation near Troutdale. The action alternatives are shown in Maps 1-4 in the report.

Route Segments and Options. Each of the four alternatives is described by a series of fixed, linear route segments between geographic locations. Each alternative has a primary route, composed of one set of route segments, and three optional routes: Options 1, 2 and 3. Each option is composed of a different mix of route segments. Segments can be present in one or more alternatives and are designated by a unique alphanumeric label: for example, 25, A or 36A. Route segments and options for all four alternatives are shown in Maps 1-4 in the report and listed in Tables 1 through 4 in this appendix.

Tower Numbers. Location along a route segment is denoted by tower numbers beginning with Tower 1 and ending with the last tower in the segment: for example, Segment 25 extends from Tower 25/1 to Tower 25/152. Towers are numbered per the direction of power flow from the Castle Rock to Troutdale substations, which is generally north to south. The first and last tower of each route segment may have more than one number where segments intersect. For example, towers 1/18, 2/28 and 4/1 are the same tower, but have three designations because the tower is part of segments 1, 2, and 4. Tower numbers are shown on detailed project maps and can be found online at: http://gis.bpa.gov/gis/i5/gmviewer.html.

Line Sections. Although a route segment is unique geographically, it is not necessarily unique in the physical and electrical configurations that produce electrical effects. Therefore in some cases a route segment is broken up into two or more line sections for calculations. These sections are delineated by starting and ending tower numbers. Possible changes along a route segment that can create a new section for calculations of electrical effects include the addition or absence of a parallel line on the right-of-way, a change in the electrical phasing of the new line, or a change in tower type.

Calculation Numbers. Each unique calculation represents a distinct physical and electrical configuration along a line section or sections, and includes fields from the new transmission lines and existing transmission lines, when present. A specific calculation may apply in one or more line sections in a route segment or in more than one segment. For example, many route segments and line sections require new right-of-way where there are no existing lines. The same calculation (1.0.0) is used to describe the electrical effects for all new rights-of-way sections.

Each calculation is identified by a calculation number consisting of three numbers: the first number is generally selected from the first route segment where the configuration occurs; the second number refers to a line section within a segment; and the third number, called a version number, refers to a section where the physical layout of the lines are the same as for a previous section, but a change in electrical phasing occurs. For example, 2.1.0 refers to the field calculation along Segment 2, line section 1, while 2.1.1 refers to the field calculation along the same segment but where there is a transposition in phasing along line section 1. Table 5 shows calculations listed by route segment and line section (tower numbers). Table 6 shows route segments and line sections (by tower numbers) listed by calculation number. Tables 7 through 41 show details for each distinct calculation (segment or section) and Figures 1 through 105 provide visual examples of maximum and average fields for each calculation.

Determining Field Levels at Specific Locations

The process for locating a specific site along a segment and determining the levels of electric fields, magnetic fields, audible noise, radio interference and television interference at the site is as follows:

1. From Maps 1 through 4 in the report, or the online project map, determine the route segment that is adjacent to the specific site.
2. From Table 5, determine if the segment is comprised of two or more line sections:
   - If the segment is not divided, then the electrical effects data is described by the calculation number associated with the segment.
   - If the segment is divided into two or more line sections, then determine the tower numbers closest to the specific site from the online project map. Using these tower numbers, determine from Table 5 which calculation number within the segment is associated with the towers near the specific site.
3. Locate the summary sheet for the selected calculation number. The summary sheets are in sequential order by segment following Table 6.
4. The summary sheets provide illustrated profiles of data for electric fields, magnetic fields, and audible noise as well as tabular data for these parameters and for radio and television interference.

Abbreviations and Acronyms

AN	Audible noise
Avg	Average
dB(µV/m)	Unit of electric field for radio and television interference: decibels above one microvolt per meter
dBA	Unit of sound level: decibels (A-weighted)
E Field	Electric field
Ft	Unit of distance: feet or foot
kV/m:	Unit of electric field: kilovolts per meter
L50	Statistical descriptor: Level of physical quantity exceeded 50 percent of the time (median)
Max	Maximum
MF	Magnetic field
mG	Unit of magnetic field: milligauss
PUD	Public Utility District
RI	Radio interference
ROW	Right-of-way
TVI	Television interference

Table 1: Route Segments and Substations for West Alternative and Options

Route Segments and Substations	West Alternative	West Option 1		West Option 2		West Option 3	
		Add	*Remove*	*Add*	*Remove*	*Add*	*Remove*
Northern Substation	Monahan						
Segments	2	36	36B	36	36B	36	36B
	4	40	41	36A	41	36A	41
	9	46	45	37	45	37	45
	25			38	50	38	50
	36B			43		39	
	41			48		T	
	45			51		49	
	50					51	
	52						
Southern Substation	Sundial						

Table 2: Route Segments and Substations for Central Alternative and Options

Route Segments and Substations	Central Alternative	Central Option 1		Central Option 2		Central Option 3	
		Add	*Remove*	*Add*	*Remove*	*Add*	*Remove*
Northern Substation	Baxter	Casey	Baxter	Monahan	Baxter		
Segments	B	A		1	B	M	L
	F			4	F	26	18
	G			5	G	30	28
	H			8			V
	10			11			
	12						
	15						
	23						
	L						
	18						
	28						
	V						
	P						
	35						
	T						
	49						
	51						
	52						
Southern Substation	Sundial						

Table 3: Route Segments and Substations for Crossover Alternative and Options

Route Segments and Substations	Crossover Alternative	Crossover Option 1		Crossover Option 2		Crossover Option 3	
		Add	*Remove*	*Add*	*Remove*	*Add*	*Remove*
Northern Substation	Monahan			Baxter	Monahan	Baxter	Monahan
Segments	B	47	51	C		D	
	F	48		E		E	
	G	50					
	H						
	10						
	12						
	15						
	23						
	L						
	18						
	28						
	V						
	P						
	35						
	T						
	49						
	51						
	52						
Southern Substation	Sundial						

Table 4: Route Segments and Substations for East Alternative and Options

Route Segments and Substations	East Alternative	East Option 1		East Option 2		East Option 3	
		Add	***Remove***	***Add***	***Remove***	***Add***	***Remove***
Northern Substation	Baxter	Monahan	Baxter				
Segments	B	3		U	O	R	Q
	F	7		V	Q		
	I	11		P	S		
	K	J		35			
	W			T			
	O						
	Q						
	S						
	49						
	51						
	52						
Southern Substation	Sundial						

Table 5: Electrical Effects Calculation Numbers by Route Segment and Tower Numbers

Segment	Calculation Section (tower to tower)	Calculation Number	Length Covered by Calculation (miles)	Comments
1	1/1-1/28	1.0.0	6.42	New ROW
2	2/1-2/7	2.1.0	1.64	
	2/7-2/18	2.1.1	2.32	Transposition[1]
	2/18-2/24	2.2.0	1.38	
	2/24-2/27	2.2.1	0.46	Transposition
	2/27-2/28	No Calc	0.24	Transposition
3	3/1-3/38	1.0.0	7.82	New ROW
4	4/1-4/3	No Calc	0.37	Transition spans[2]
	4/3-4/5	9.2.0	0.40	
5	5/1-5/10	1.0.0	1.93	New ROW
7	7/1-7/10	1.0.0	2.05	New ROW
8	8/1-8/9	1.0.0	1.61	New ROW
9	9/1-9/3	9.2.0	0.52	
	9/3-9/11	9.2.0	1.61	Configuration change
	9/11-9/20	9.2.0	1.94	
	9/20-9/21	9.3.0	0.50	
	9/21-9/28	9.3.0	1.54	
	9/28-9/82	9.3.1	12.62	Transposition
10	10/1-10/34	1.0.0	7.93	New ROW
11	11/1-11/21	1.0.0	5.00	New ROW
12	12/1-12/20	1.0.0	4.96	New ROW
14	14/1-14/7	1.0.0	1.50	New ROW
15	15/1-15/9	1.0.0	1.86	New ROW
18	18/1-18/32	1.0.0	7.17	New ROW
23	23/1-23/7	1.0.0	1.29	New ROW
25	25/1-25/7	9.3.1	1.35	
	25/7-25/11	9.3.2	0.75	Transposition
	25/11-25/18	25.2.0	1.64	Current change
	25/18-25/19	No Calc	0.47	25.2.0 with 12.5’ extra ROW; use 25.2.0

Segment	Calculation Section (tower to tower)	Calculation Number	Length Covered by Calculation (miles)	Comments
	25/19-25/72	25.2.0	11.00	
	25/72-25/106	25.2.1	6.47	Transposition
	25/106-25/110	25.3.0	0.63	
	25/110-25/141	25.4.0	5.67	
	25/141-25/151	25.5.0	1.71	
	25/151-25/152	25.5.0	0.18	
26	26/1-26/35	1.0.0	6.54	New ROW
28	28/1-28/27	1.0.0	5.94	New ROW
30	30/1-30/31	1.0.0	6.01	New ROW
35	35/1-35/15	1.0.0	2.52	New ROW
36	36/1-36/2	36A.1.0	0.22	
36A	36A/1-36A/5	36A.1.0	0.80	
	36A/5-36A/6	36A.2.0	0.23	
36B	36B/1-36B2	No Calc	0.18	Transition span
	36B/2-36B/7	36B.1.0	1.04	
	36B/7-36B/8	No Calc	0.19	Transition span
37	37/1-37/2	36A.2.0	0.21	
	37/2-37/4	37.2.0	0.46	
38	38/1-38/5	37.2.0	0.66	
39	39/1-39/20	37.2.0	4.05	
	39/20-39/23	39.2.0	0.62	
	39/23-39/27	39.3.0	0.68	
40	40/1-40/11	1.0.0	2.02	New ROW
	40/11-40/14	40.1.0	0.67	
41	41/1-41/2	41.1.0	0.14	
	41/2-41/8	41.1.0	1.13	
43	43/1-43/9	1.0.0	1.69	New ROW
	43/9-43/10	40.1.0	0.17	
45	45/1-45/3	41.1.0	0.35	
	45/3-45/6	1.0.0	0.32	New ROW
46	46/1-46/3	40.1.0	0.46	
47	47/1-47/4	40.1.0	0.69	

Segment	Calculation Section (tower to tower)	Calculation Number	Length Covered by Calculation (miles)	Comments
48	48/1-48/14	40.1.0	2.49	
	48/1-48/14	40.1.0	2.49	Reversed current for Crossover Opt. 1
49	49/1-49/7	1.0.0	1.23	New ROW
	49/7-49/10	49.1.0	0.69	
	49/7-49/10	49.1.1	0.69	Phasing change for Central Alt. and all options
	49/10-49/15	49.2.0	0.80	
	49/10-49/15	49.2.1	0.80	Phasing change for Central Alt. and all options
50	50/1-50/5	1.0.0	0.67	New ROW
	50/5-50/13	50.1.0	1.46	
	50/5-50/13	50.1.1	1.46	Phasing change for West Opt. 1 and Crossover Opt. 1
	50/13-50/21	41.1.0	1.16	
	50/21-50/26	50.1.0	0.80	
	50/21-50/26	50.1.1	0.80	Phasing change for West Opt. 1 and Crossover Opt. 1
51	51/1-51/11	51.1.0	2.07	
52	52/1-52/2	51.1.0	0.13	
	52/2-52/9	52.2.0	1.48	
	52/9-52/12	51.1.0	0.44	
	52/12-52/17	51.1.1	1.23	Transposition
	52/17-52/20	1.0.0	0.43	
	52/20-52/22	No Calc	0.47	River crossing
	52/22-52/24	No Calc	0.52	Entering Sundial Sub.
A	A/1-A/9	A.1.0	1.81	
	A/9-A/12	A.1.0	0.71	
B	B/1-B/5	1.0.0	0.78	New ROW
C	C/1-C/17	C.1.0	3.00	
D	D/1-D/17	D.1.0	2.86	
E	E/1-E/6	C.1.0	1.07	
	E/6-E/7	No Calc	0.28	Transition span

Segment	Calculation Section (tower to tower)	Calculation Number	Length Covered by Calculation (miles)	Comments
F	F/1-F/75	1.0.0	15.86	New ROW
G	G/1-G/8	1.0.0	1.39	New ROW
H	H/1-H/8	1.0.0	1.53	New ROW
I	I/1-1/13	1.0.0	2.77	New ROW
J	J/1-J/13	1.0.0	2.72	New ROW
K	K/1-K/94	1.0.0	22.80	New ROW
L	L/1-L/5	1.0.0	0.95	New ROW
	L/5-L/9	1.0.0	0.76	New ROW
M	M/1-M/11	1.0.0	2.39	New ROW
N	N/1-N/9	1.0.0	1.64	New ROW
O	O/1-O/83	1.0.0	19.47	New ROW
P	P/1-P/39	1.0.0	8.62	New ROW
Q	Q/1-Q/13	1.0.0	2.63	New ROW
R	R/1-R/10	1.0.0	1.93	New ROW
	R/10-R/19	R.1.0	1.75	
S	S/1-S/3	1.0.0	0.42	New ROW
T	T/1-T/3	1.0.0	0.31	New ROW
U	U/1-U/26	1.0.0	6.11	New ROW
V	V/1-V/27	1.0.0	5.96	New ROW
W	W/1-W/6	1.0.0	1.31	New ROW

[1] A transposition span is where the locations of the phase conductors (A, B, C) on the tower change; that is, instead of the A-phase being on the top, it is now on the bottom left and the other phases change accordingly. Such conductor location changes result in non-parallel conductors.
[2] A transition span is where the conductors go from one configuration to another, such as from a delta configuration to a flat configuration or from a single-circuit tower to one side of a double-circuit tower.

Table 6: Route Segments and Tower Numbers by Electrical Effects Calculation Number

Calculation Number	Segment	Calculation Section (tower to tower)	Length Covered by Calculation (miles)	Comments
1.0.0	1	1/1-1/28	6.42	New ROW
	3	3/1-3/38	7.82	New ROW
	5	5/1-5/10	1.93	New ROW
	7	7/1-7/10	2.05	New ROW
	8	8/1-8/9	1.61	New ROW
	10	10/1-10/34	7.93	New ROW
	11	11/1-11/21	5.00	New ROW
	12	12/1-12/20	4.96	New ROW
	14	14/1-14/7	1.50	New ROW
	15	15/1-15/9	1.86	New ROW
	18	18/1-18/32	7.17	New ROW
	23	23/1-23/7	1.29	New ROW
	26	26/1-26/35	6.54	New ROW
	28	28/1-28/27	5.94	New ROW
	30	30/1-30/31	6.01	New ROW
	35	35/1-35/15	2.52	New ROW
	40	40/1-40/11	2.02	New ROW
	43	43/1-43/9	1.69	New ROW
	45	45/3-45/6	0.32	New ROW
	49	49/1-49/7	1.23	New ROW
	50	50/1-50/5	0.67	New ROW
	52	52/17-52/20	0.43	New ROW
	B	B/1-B/5	0.78	New ROW
	F	F/1-F/75	15.86	New ROW
	G	G/1-G/8	1.39	New ROW
	H	H/1-H/8	1.53	New ROW
	I	I/1-1/13	2.77	New ROW
	J	J/1-J/13	2.72	New ROW
	K	K/1-K/94	22.80	New ROW
	L	L/1-L/5	0.95	New ROW

Calculation Number	**Segment**	**Calculation Section** (tower to tower)	**Length Covered by Calculation** (miles)	**Comments**
	L	L/5-L/9	0.76	New ROW
	M	M/1-M/11	2.39	New ROW
	N	N/1-N/9	1.64	New ROW
	O	O/1-O/83	19.47	New ROW
	P	P/1-P/39	8.62	New ROW
	Q	Q/1-Q/13	2.63	New ROW
	R	R/1-R/10	1.93	New ROW
	S	S/1-S/3	0.42	New ROW
	T	T/1-T/3	0.31	New ROW
	U	U/1-U/26	6.11	New ROW
	V	V/1-V/27	5.96	New ROW
	W	W/1-W/6	1.31	New ROW
2.1.0	2	2/1-2/7	1.64	
2.1.1	2	2/7-2/18	2.32	Transposition[1]
2.2.0	2	2/18-2/24	1.38	
2.2.1	2	2/24-2/27	0.46	Transposition
9.2.0	4	4/3-4/5	0.40	
	9	9/11-9/20	1.94	
	9	9/1-9/3	0.52	
	9	9/3-9/11	1.61	Configuration change
9.3.0	9	9/20-9/21	0.50	
	9	9/21-9/28	1.54	
9.3.1	9	9/28-9/82	12.62	Transposition
	25	25/1-25/7	1.35	
9.3.2	25	25/7-25/11	0.75	Transposition
25.2.0	25	25/11-25/18	1.64	Current change
	25	25/18-25/19	0.47	25.2.0 with 12.5' extra ROW; use 25.2.0
	25	25/19-25/72	11.00	
25.2.1	25	25/72-25/106	6.47	Transposition
25.3.0	25	25/106-25/110	0.63	
25.4.0	25	25/110-25/141	5.67	

Calculation Number	Segment	Calculation Section (tower to tower)	Length Covered by Calculation (miles)	Comments
25.5.0	25	25/141-25/151	1.71	
	25	25/151-25/152	0.18	
36A.1.0	36	36/1-36/2	0.22	
	36A	36A/1-36A/5	0.80	
36A.2.0	37	37/1-37/2	0.21	
	36A	36A/5-36A/6	0.23	
36B.1.0	36B	36B/2-36B/7	1.04	
37.2.0	37	37/2-37/4	0.46	
	38	38/1-38/5	0.66	
	39	39/1-39/20	4.05	
39.2.0	39	39/20-39/23	0.62	
39.3.0	39	39/23-39/27	0.68	
40.1.0	40	40/11-40/14	0.67	
	43	43/9-43/10	0.17	
	46	46/1-46/3	0.46	
	47	47/1-47/4	0.69	
	48	48/1-48/14	2.49	
40.1.1	48	48/1-48/14	2.49	Reverse current for Crossover Opt. 1
41.1.0	41	41/1-41/2	0.14	
	41	41/2-41/8	1.13	
	45	45/1-45/3	0.35	
	50	50/13-50/21	1.16	
49.1.0	49	49/7-49/10	0.69	
49.1.1	49	49/7-49/10	0.69	Phasing change for Central Alt. and all options
49.2.0	49	49/10-49/15	0.80	
49.2.1	49	49/10-49/15	0.80	Phasing change for Central Alt. and all options
50.1.0	50	50/21-50/26	0.80	
	50	50/5-50/13	1.46	
50.1.1	50	50/21-50/26	0.80	Phasing change for West Opt. 1 and Crossover Opt. 1

Calculation Number	Segment	Calculation Section (tower to tower)	Length Covered by Calculation (miles)	Comments
	50	50/5-50/13	1.46	Phasing change for West Opt. 1 and Crossover Opt. 1
51.1.0	51	51/1-51/11	2.07	
	52	52/1-52/2	0.13	
	52	52/9-52/12	0.44	
51.1.1	52	52/12-52/17	1.23	Transposition
52.2.0	52	52/2-52/9	1.48	
A.1.0	A	A/1-A/9	1.81	
	A	A/9-A/12	0.71	
C.1.0	C	C/1-C/17	3.00	
	E	E/1-E/6	1.07	
D.1.0	D	D/1-D/17	2.86	
R.1.0	R	R/10-R/19	1.75	
No Calc	2	2/27-2/28	0.24	Transition span[2]
No Calc	4	4/1-4/3	0.37	Transition spans
No Calc	52	52/20-52/22	0.47	Transition spans
No Calc	52	52/22-52/24	0.52	Transition spans
No Calc	36B	36B/1-36B2	0.18	Transition span
No Calc	36B	36B/7-36B/8	0.19	Transition span
No Calc	E	E/6-E/7	0.28	Transition span

[1] A transposition span is where the locations of the phase conductors (A, B, C) on the tower change; that is, instead of the A-phase being on the top, it is now on the bottom left and the other phases change accordingly. Such conductor location changes result in non-parallel conductors.
[2] A transition span is where the conductors go from one configuration to another, such as from a delta configuration to a flat configuration or from a single-circuit tower to one side of a double-circuit tower.

Table 7: Calculation 1.1.0 (New Right-of-Way)

Calculation 1.1.0: Electrical Sections						
Segment	Towers	Length		Segment	Towers	Length
New	New/All					

Calculation 1.1.0: Summary of Fields and Corona Effects							
	ROW Status	Average			Maximum		
Location		Left Edge	Right Edge	Peak On ROW	Left Edge	Right Edge	Peak On ROW
Electric Field, kV/m	No Action	2.3	2.3	5.3	2.3	2.3	8.8
	Proposed	2.3	2.3	5.3	2.3	2.3	8.8
Magnetic Field, mG	No Action	12	12	35	48	48	184
	Proposed	12	12	35	48	48	184
Audible Noise, dBA Foul weather L50	No Action	47.1	47.1	Not Applicable			
	Proposed	47.1	47.1				
Fair Weather RI, dB(uV/m) @ 100 ft from conductors	No Action	36	36	Not Applicable			
	Proposed	36	36				
Foul Weather TVI, dB(uV/m) @ 100 ft from conductors	No Action	21	21	Not Applicable			
	Proposed	21	21				

Figure 1: Calculation 1.1.0 – Electric Fields (New Right-of-Way)

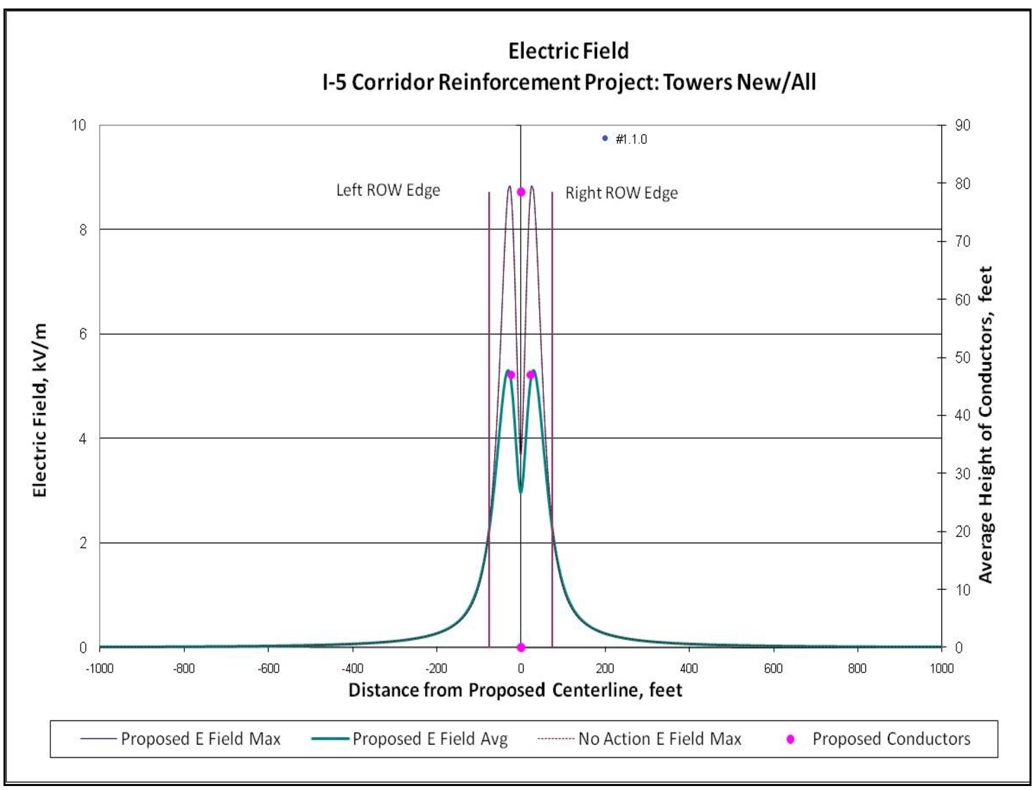

Figure 2: Calculation 1.1.0 – Magnetic Fields (New Right-of-Way)

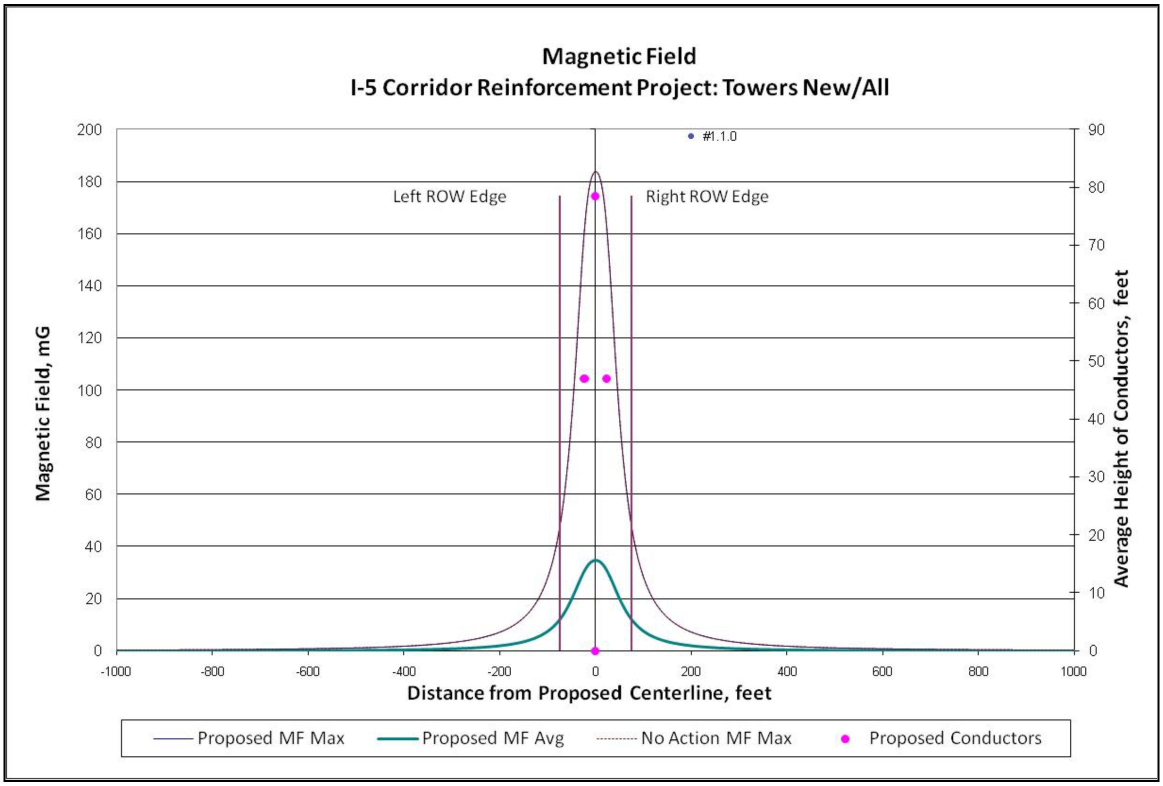

Figure 3: Calculation 1.1.0 – Audible Noise Levels (New Right-of-Way)

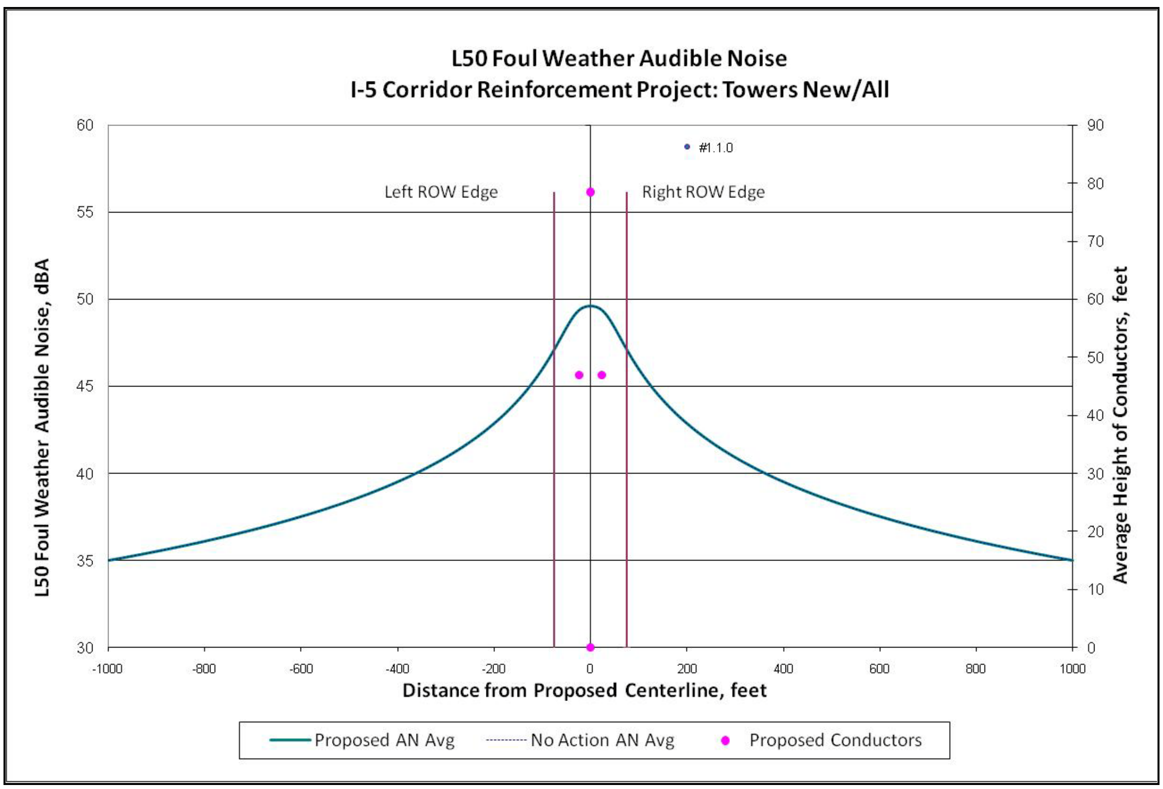

Table 8: Calculation 2.1.0

Calculation 2.1.0 : Electrical Sections						
Segment	Towers	Length		Segment	Towers	Length
2	2/1 - 2/7	1.64				

Calculation 2.1.0 : Summary of Fields and Corona Effects								
	ROW Status	Average			Maximum		
Location		Northeast Edge	Southwest Edge	Peak On ROW	Northeast Edge	Southwest Edge	Peak On ROW
Electric Field, kV/m	No Action	0.1	0.6	1.9	0.1	0.5	3.7
	Proposed	1.6	0.5	5.6	1.6	0.4	9.0
Magnetic Field, mG	No Action	1	5	19	4	17	107
	Proposed	9	1	36	35	5	187
Audible Noise, dBA Foul weather L50	No Action	34.9	39.0	Not Applicable			
	Proposed	46.7	44.0				
Fair Weather RI, dB(uV/m) @ 100 ft from conductors	No Action	19	27	Not Applicable			
	Proposed	36	28				
Foul Weather TVI, dB(uV/m) @ 100 ft from conductors	No Action	3	14	Not Applicable			
	Proposed	21	15				

Figure 4: Calculation 2.1.0 – Electric Fields

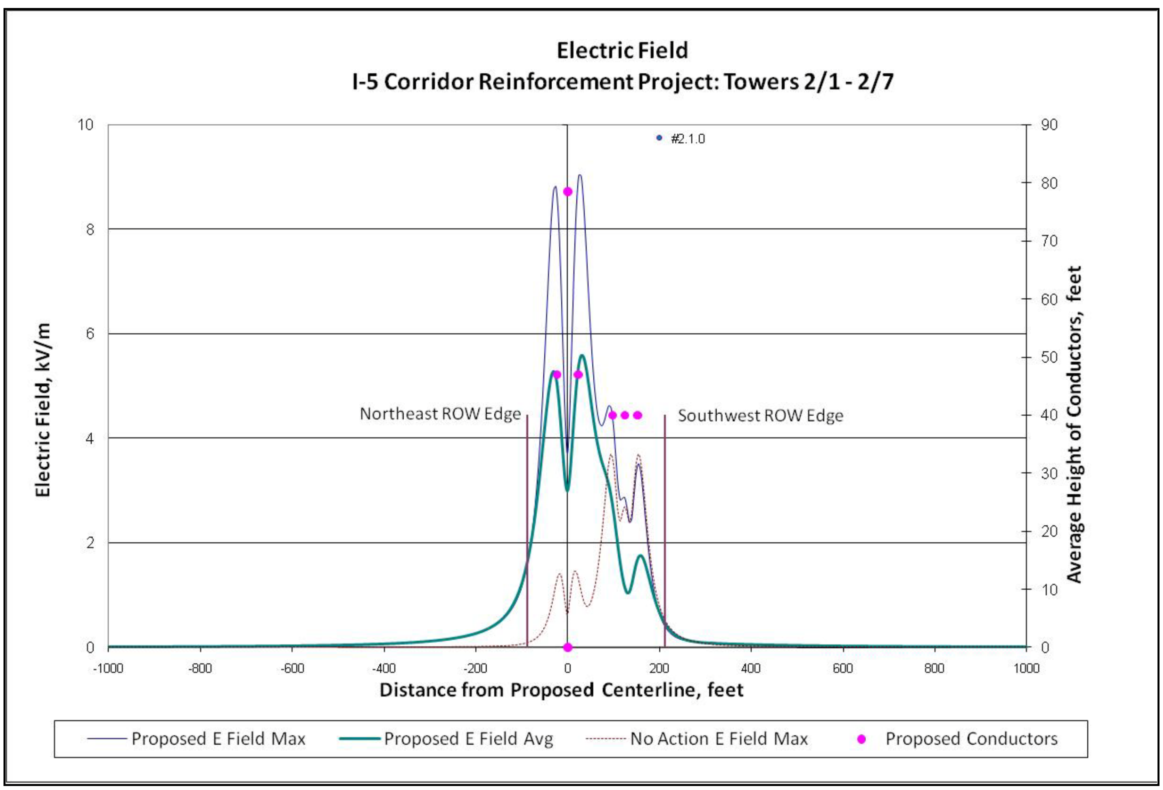

Figure 5: Calculation 2.1.0 – Magnetic Fields

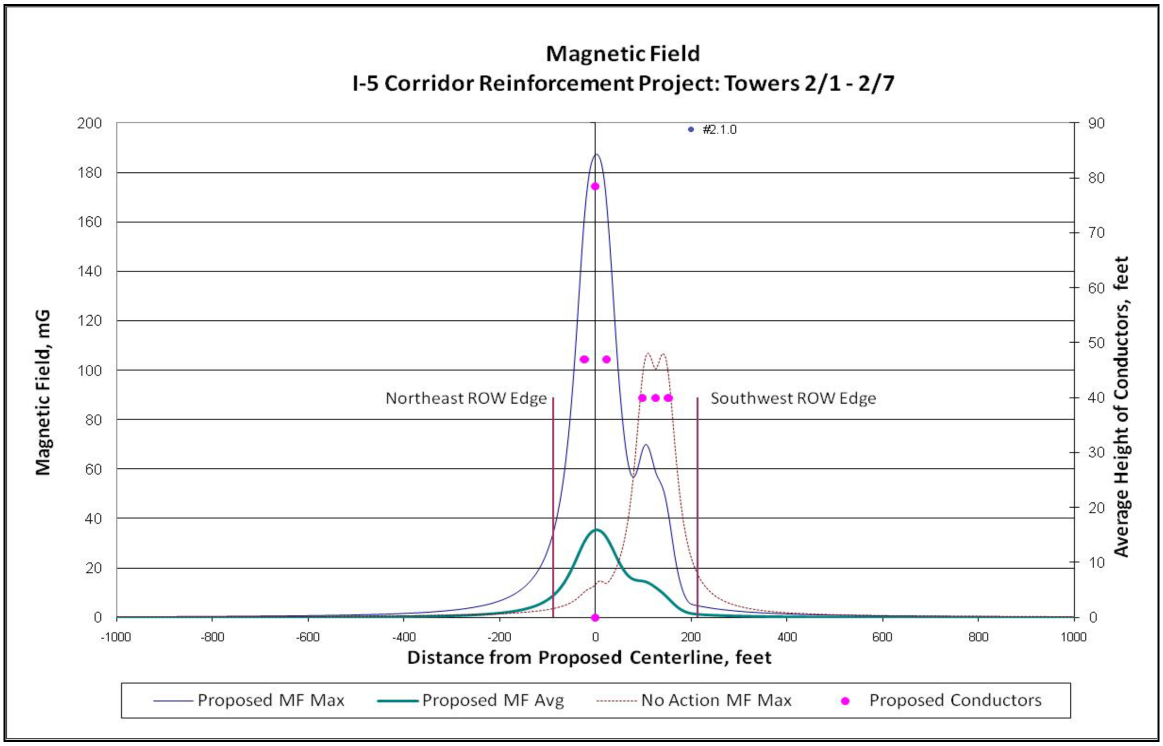

Figure 6: Calculation 2.1.0 – Audible Noise Levels

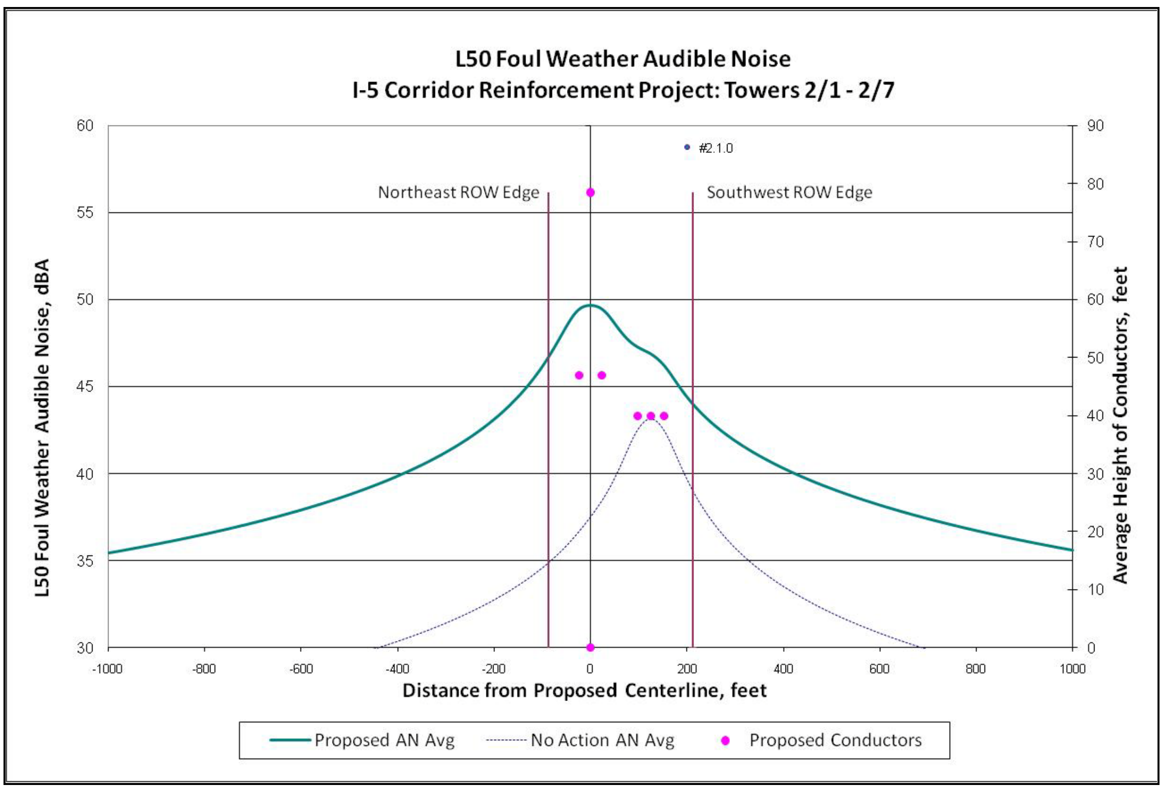

Table 9: Calculation 2.1.1

Calculation 2.1.1 : Electrical Sections						
Segment	Towers	Length		Segment	Towers	Length
2	2/7 - 2/18	1.64				

Calculation 2.1.1 : Summary of Fields and Corona Effects							
	ROW Status	Average			Maximum		
Location		Northeast Edge	Southwest Edge	Peak On ROW	Northeast Edge	Southwest Edge	Peak On ROW
Electric Field, kV/m	No Action	0.1	0.6	2.0	0.1	0.5	3.8
	Proposed	1.7	0.8	5.3	1.6	0.7	8.9
Magnetic Field, mG	No Action	1	5	19	4	17	107
	Proposed	10	3	34	37	11	182
Audible Noise, dBA Foul weather L50	No Action	34.9	39.0	Not Applicable			
	Proposed	46.9	44.4				
Fair Weather RI, dB(uV/m) @ 100 ft from conductors	No Action	19	27	Not Applicable			
	Proposed	36	28				
Foul Weather TVI, dB(uV/m) @ 100 ft from conductors	No Action	3	14	Not Applicable			
	Proposed	21	13				

Figure 7: Calculation 2.1.1 – Electric Fields

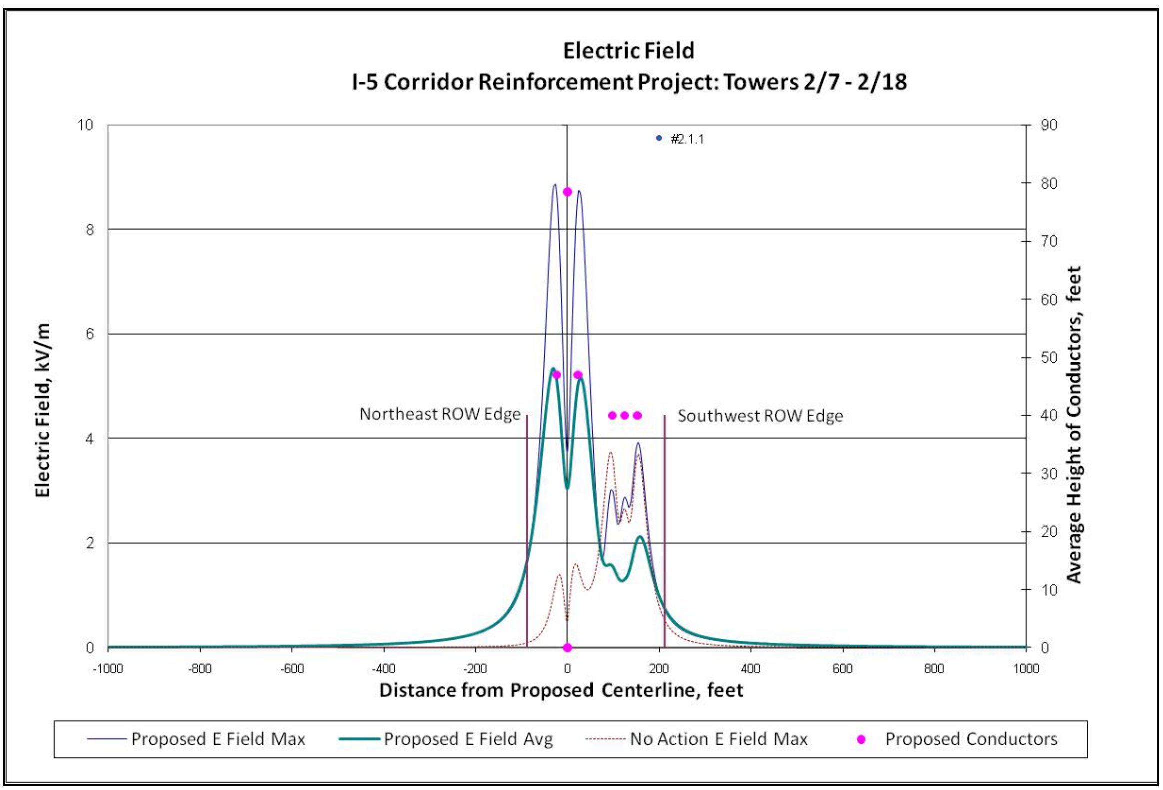

Figure 8: Calculation 2.1.1 – Magnetic Fields

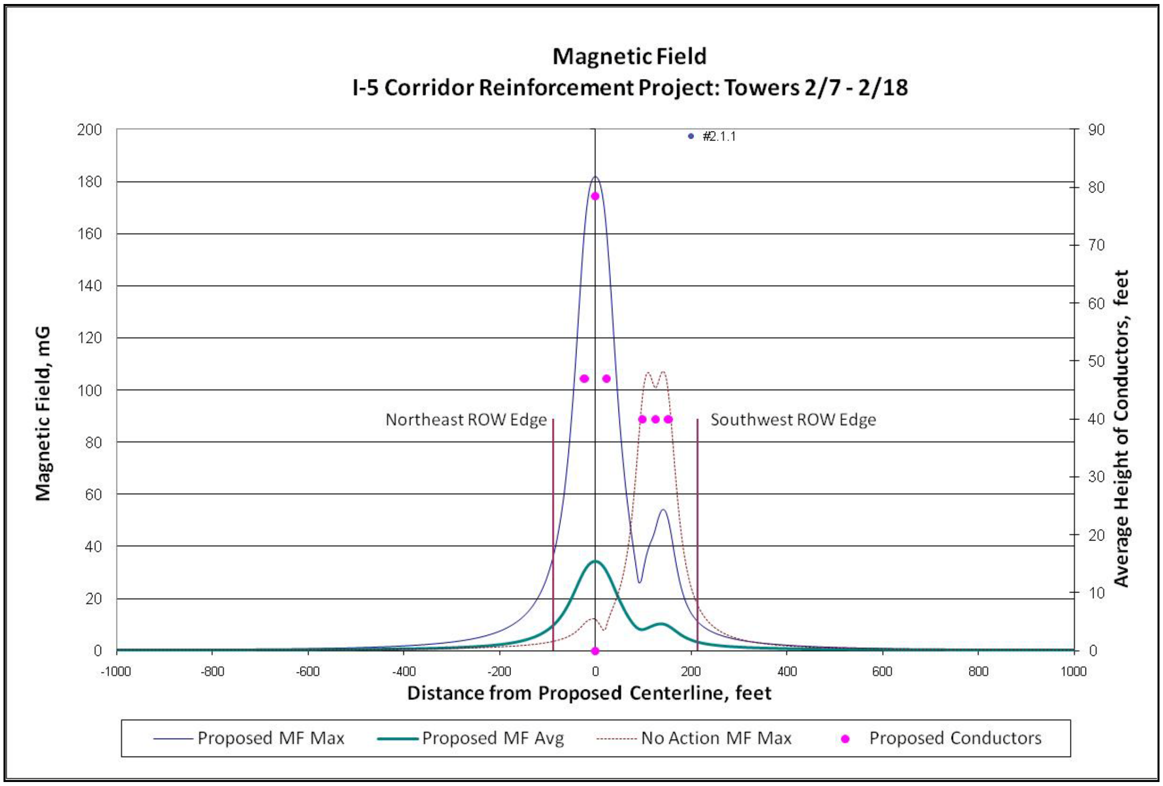

Figure 9: Calculation 2.1.1 – Audible Noise Levels

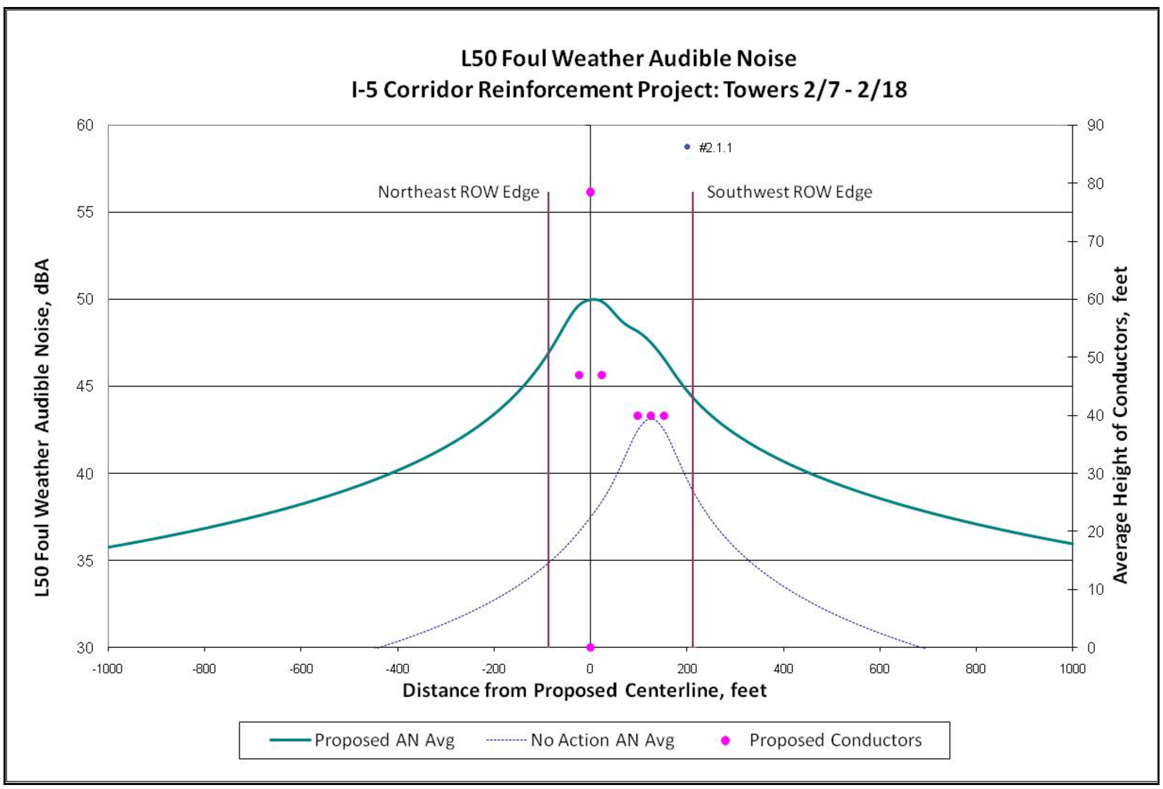

Table 10: Calculation 2.2.0

Calculation 2.2.0 : Electrical Sections						
Segment	Towers	Length		Segment	Towers	Length
2	2/18 - 2/24	1.38				

Calculation 2.2.0 : Summary of Fields and Corona Effects							
	ROW Status	Average			Maximum		
Location		Northeast Edge	Southwest Edge	Peak On ROW	Northeast Edge	Southwest Edge	Peak On ROW
Electric Field, kV/m	No Action	0.1	0.3	2.0	0.0	0.4	3.7
	Proposed	1.6	0.3	5.6	1.6	0.4	9.0
Magnetic Field, mG	No Action	2	1	36	4	3	153
	Proposed	9	1	38	34	4	193
Audible Noise, dBA Foul weather L50	No Action	34.9	35.3	Not Applicable			
	Proposed	46.7	41.4				
Fair Weather RI, dB(uV/m) @ 100 ft from conductors	No Action	27	18	Not Applicable			
	Proposed	36	24				
Foul Weather TVI, dB(uV/m) @ 100 ft from conductors	No Action	14	1	Not Applicable			
	Proposed	21	2				

Figure 10: Calculation 2.2.0 – Electric Fields

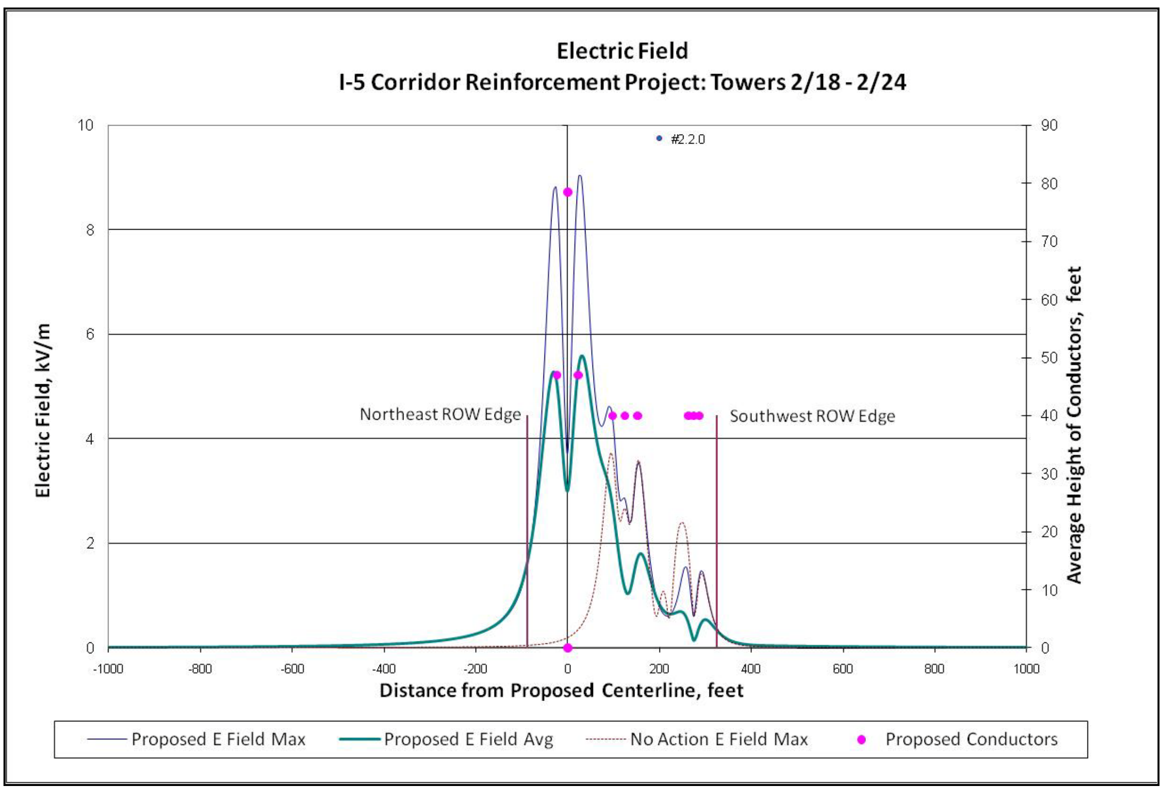

Figure 11: Calculation 2.2.0 – Magnetic Fields

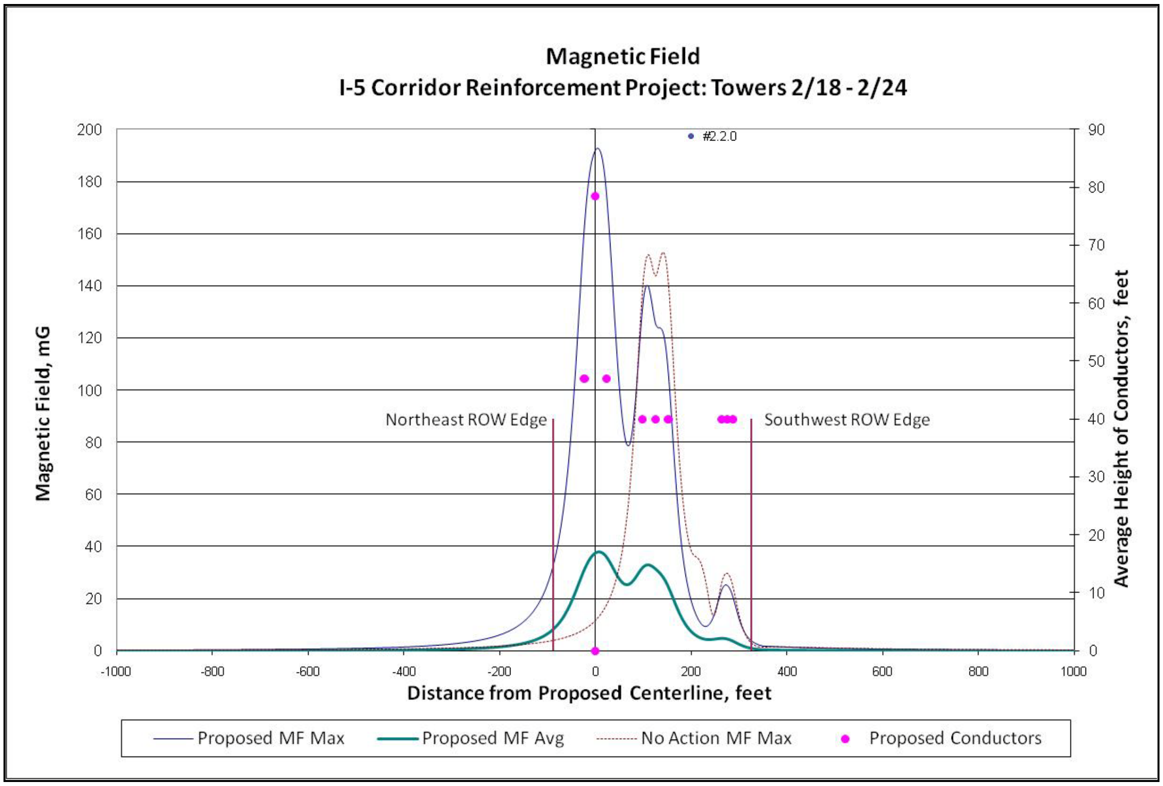

Figure 12: Calculation 2.2.0 – Audible Noise Levels

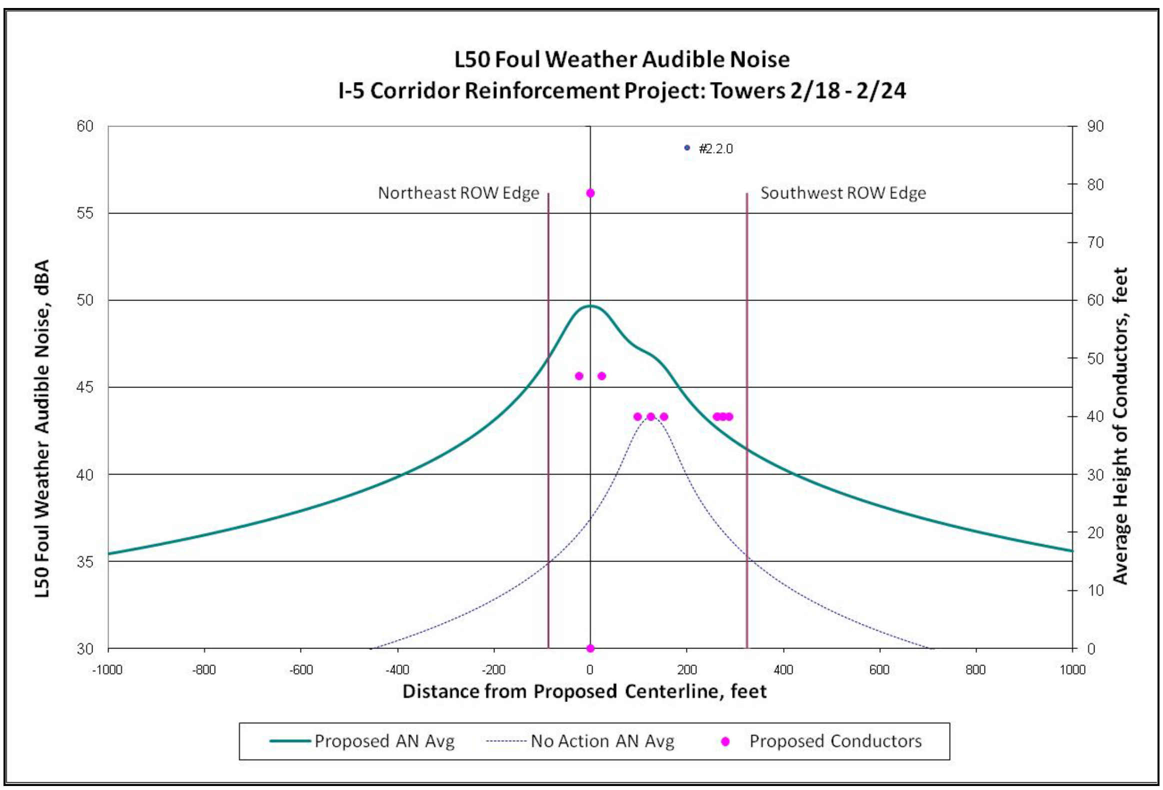

Table 11: Calculation 2.2.1

Calculation 2.2.1 : Electrical Sections						
Segment	Towers	Length		Segment	Towers	Length
2	2/24 - 2/27	0.46				

Calculation 2.2.1 : Summary of Fields and Corona Effects							
	ROW Status	Average			Maximum		
Location		Northeast Edge	Southwest Edge	Peak On ROW	Northeast Edge	Southwest Edge	Peak On ROW
Electric Field, kV/m	No Action	0.1	0.4	2.0	0.0	0.5	3.7
	Proposed	1.6	0.4	5.6	1.6	0.4	9.0
Magnetic Field, mG	No Action	2	2	36	4	8	152
	Proposed	9	2	38	33	5	193
Audible Noise, dBA Foul weather L50	No Action	34.9	35.3	Not Applicable			
	Proposed	46.7	41.5				
Fair Weather RI, dB(uV/m) @ 100 ft from conductors	No Action	27	18	Not Applicable			
	Proposed	36	24				
Foul Weather TVI, dB(uV/m) @ 100 ft from conductors	No Action	14	1	Not Applicable			
	Proposed	21	2				

Figure 13: Calculation 2.2.1 – Electric Fields

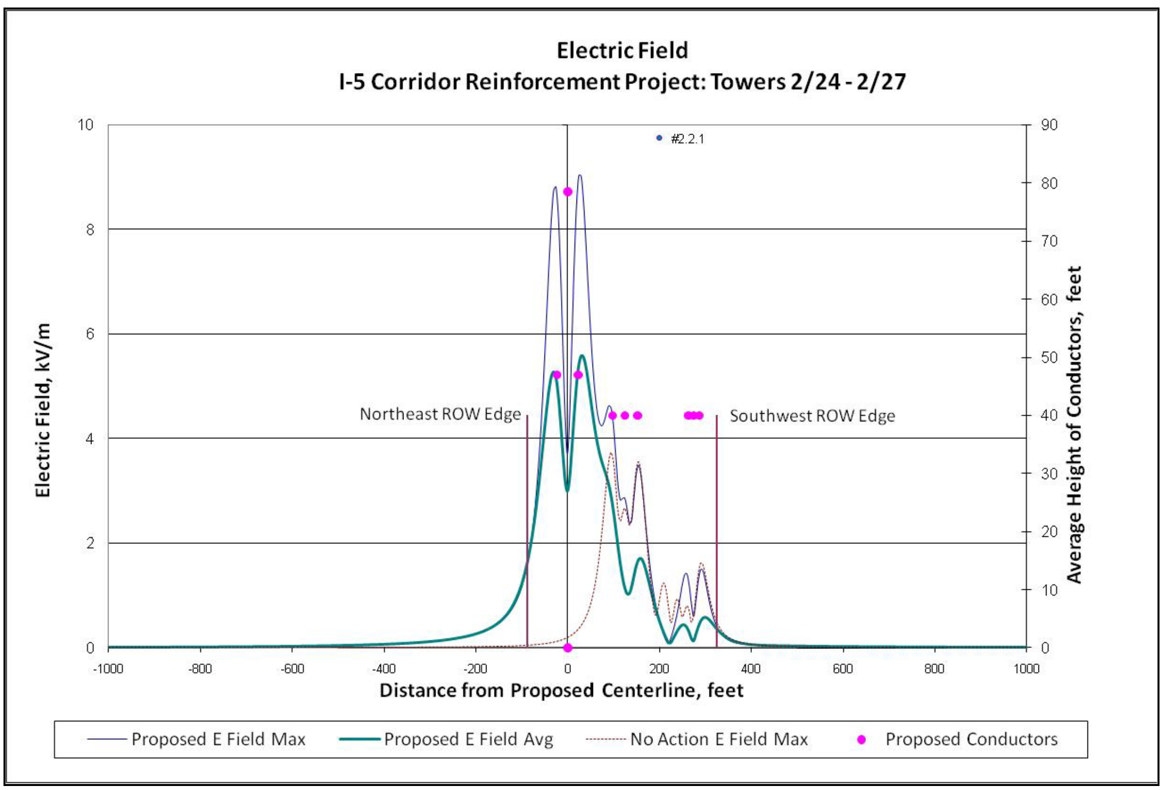

Figure 14: Calculation 2.2.1 – Magnetic Fields

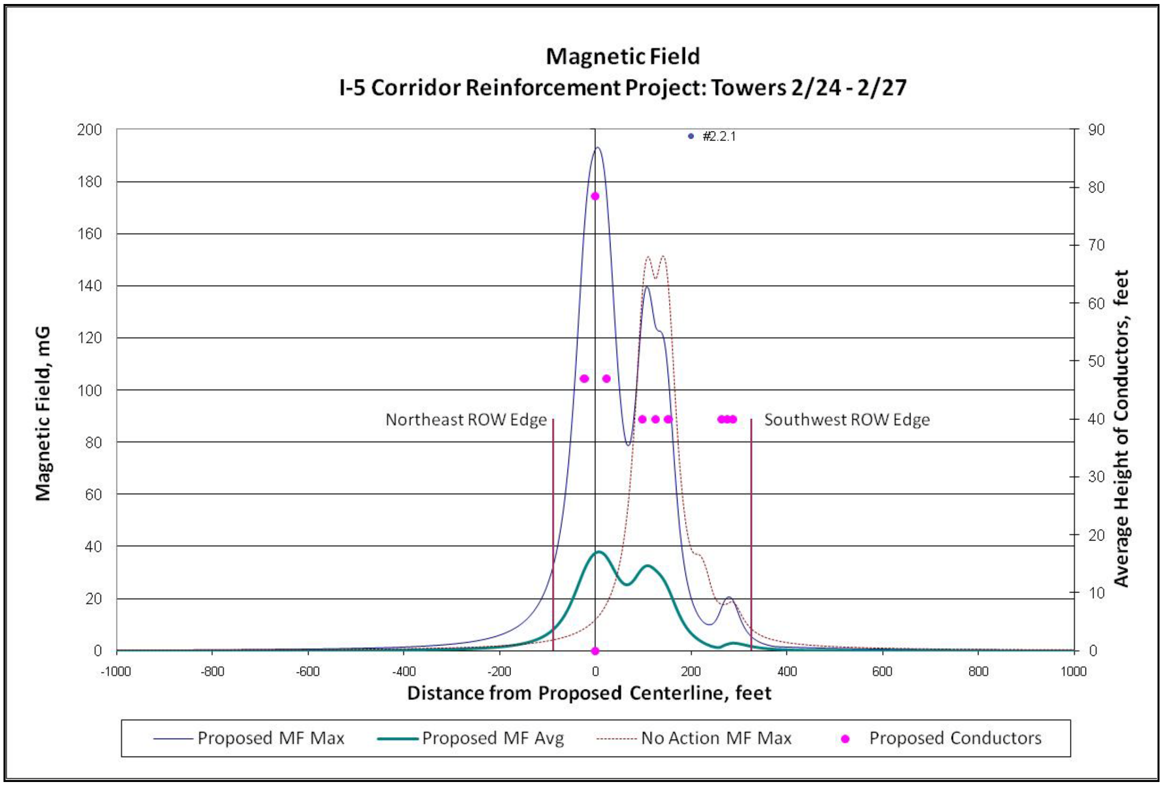

Figure 15: Calculation 2.2.1 – Audible Noise Levels

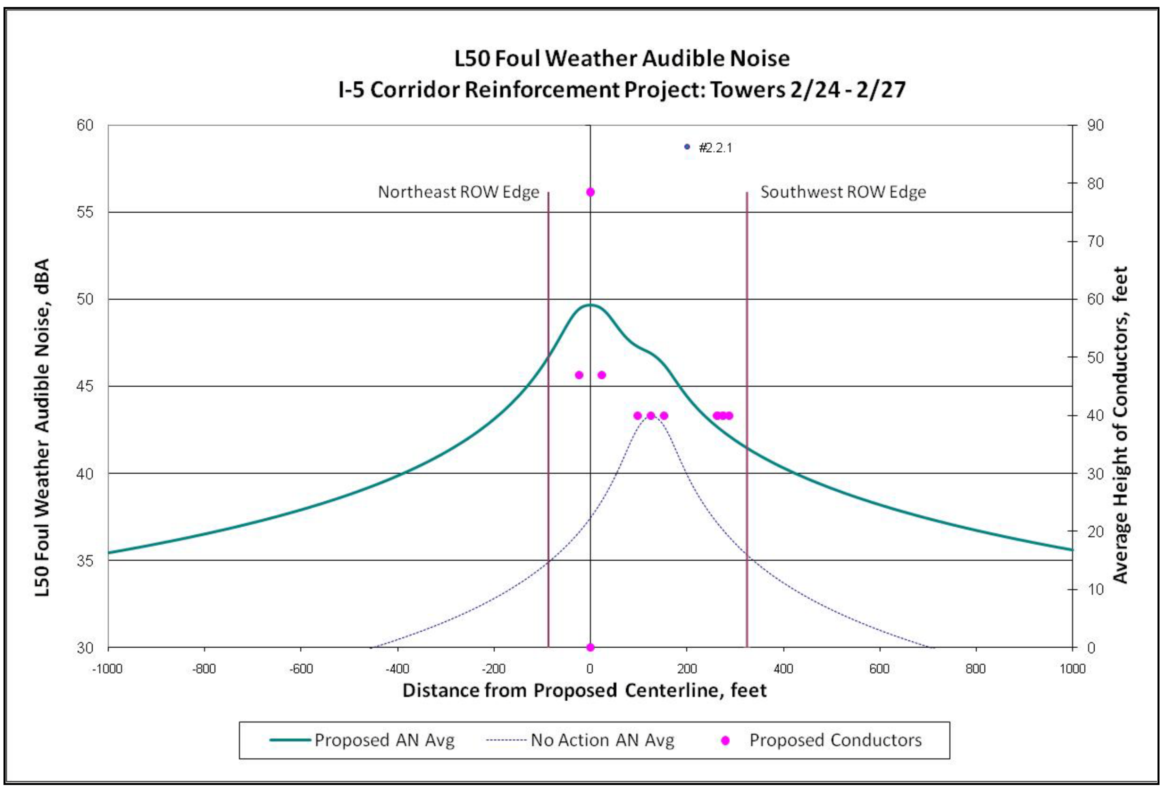

Table 12: Calculation 9.2.0

Calculation 9.2.0 : Electrical Sections						
Segment	Towers	Length		Segment	Towers	Length
4	4/3 - 4/5	0.40		9	9/3 - 9/11	1.61
9	9/1 - 9/3	0.52		9	9/11 - 9/20	1.94

Calculation 9.2.0 : Summary of Fields and Corona Effects							
	ROW Status	Average			Maximum		
Location		Northeast Edge	Southwest Edge	Peak On ROW	Northeast Edge	Southwest Edge	Peak On ROW
Electric Field, kV/m	No Action	0.2	1.2	2.0	0.2	1.3	3.7
	Proposed	2.2	1.0	5.5	2.3	1.1	8.8
Magnetic Field, mG	No Action	1	5	11	5	25	77
	Proposed	12	2	34	46	8	180
Audible Noise, dBA Foul weather L50	No Action	35.5	40.5	Not Applicable			
	Proposed	47.2	45.0				
Fair Weather RI, dB(uV/m) @ 100 ft from conductors	No Action	20	27	Not Applicable			
	Proposed	36	29				
Foul Weather TVI, dB(uV/m) @ 100 ft from conductors	No Action	4	14	Not Applicable			
	Proposed	21	16				

Figure 16: Calculation 9.2.0 – Electric Fields

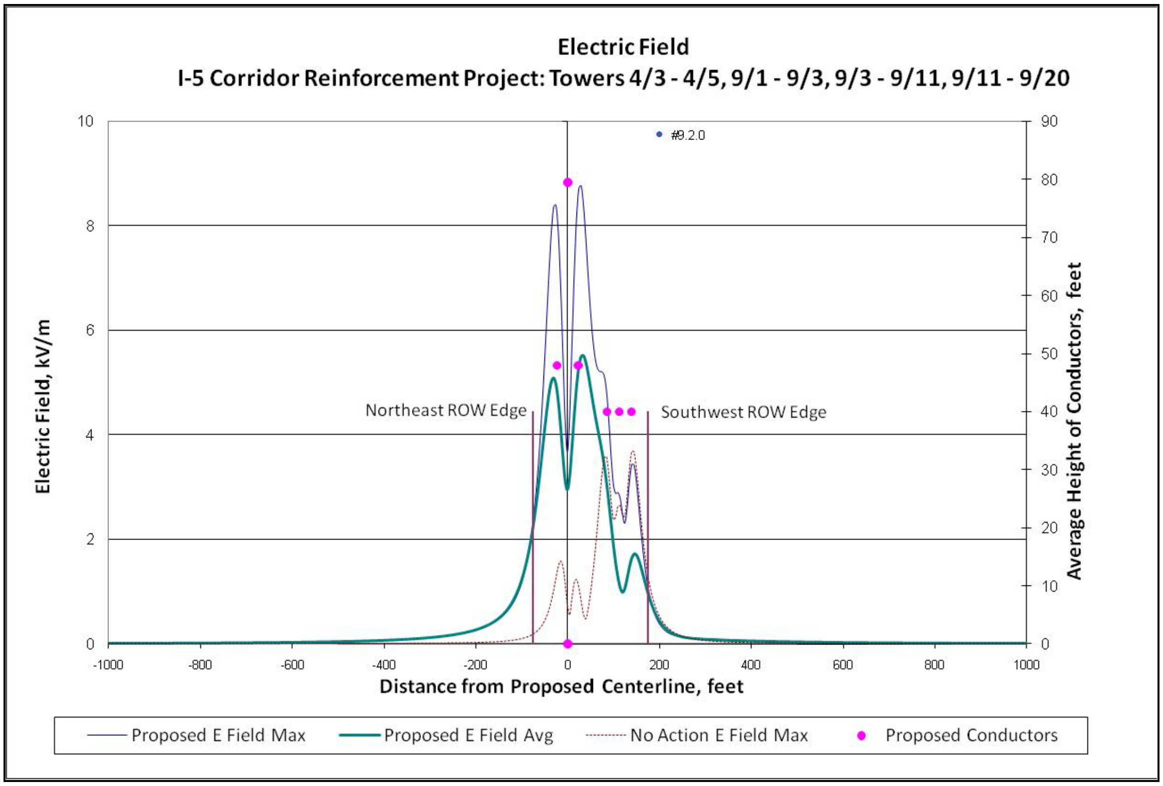

Figure 17: Calculation 9.2.0 – Magnetic Fields

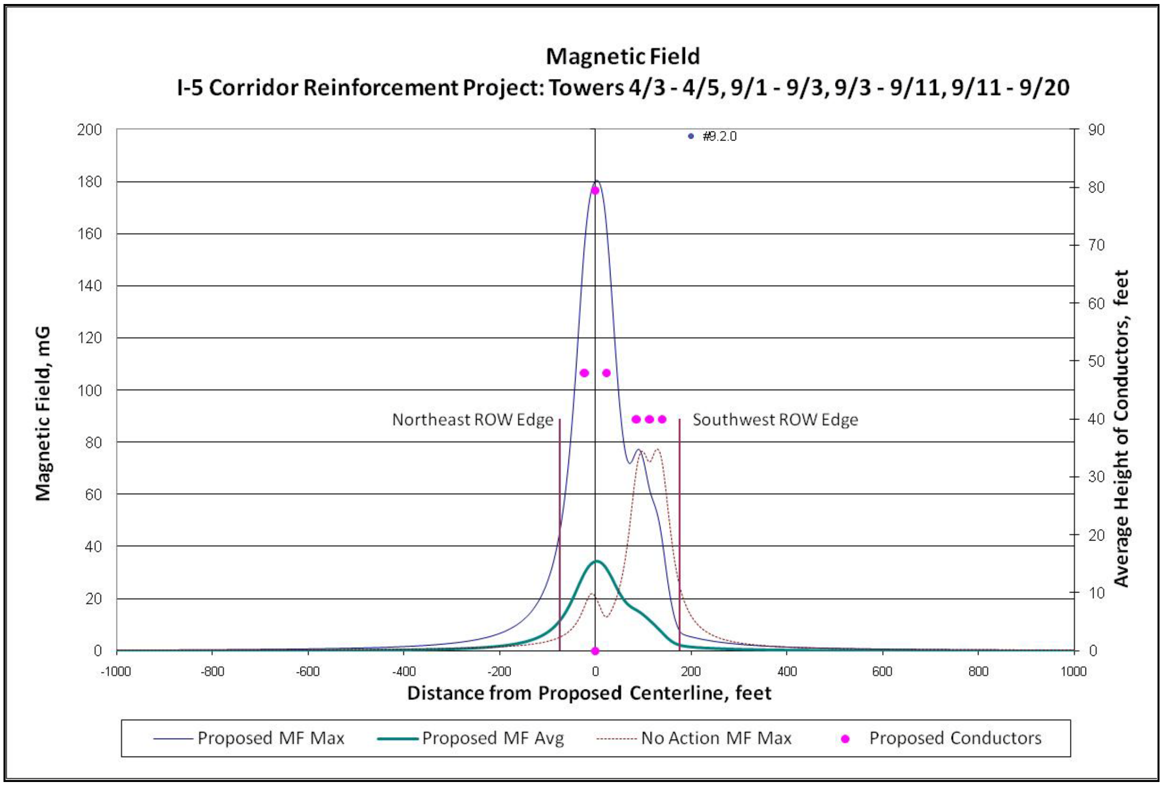

Figure 18: Calculation 9.2.0 – Audible Noise Levels

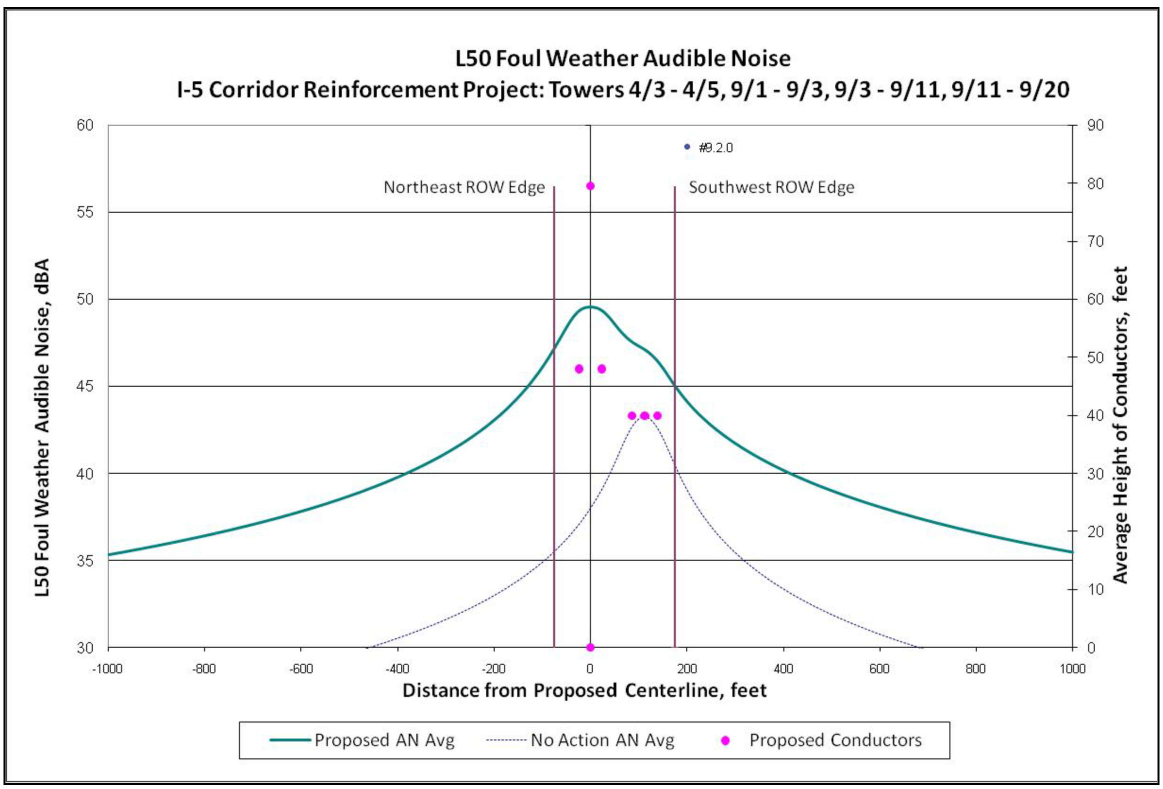

Table 13: Calculation 9.3.0

Calculation 9.3.0 : Electrical Sections						
Segment	Towers	Length		Segment	Towers	Length
9	9/20 - 9/21	0.50				
9	9/21 - 9/28	1.54				

Calculation 9.3.0 : Summary of Fields and Corona Effects							
	ROW Status	Average			Maximum		
Location		Northeast Edge	Southwest Edge	Peak On ROW	Northeast Edge	Southwest Edge	Peak On ROW
Electric Field, kV/m	No Action	0.1	0.6	1.9	0.0	0.5	3.7
	Proposed	1.9	0.5	5.6	1.8	0.4	9.0
Magnetic Field, mG	No Action	1	3	11	2	13	78
	Proposed	10	1	35	39	4	187
Audible Noise, dBA Foul weather L50	No Action	34.8	39.0	Not Applicable			
	Proposed	46.9	43.9				
Fair Weather RI, dB(uV/m) @ 100 ft from conductors	No Action	27	27	Not Applicable			
	Proposed	36	28				
Foul Weather TVI, dB(uV/m) @ 100 ft from conductors	No Action	14	14	Not Applicable			
	Proposed	21	15				

Figure 19: Calculation 9.3.0 – Electric Fields

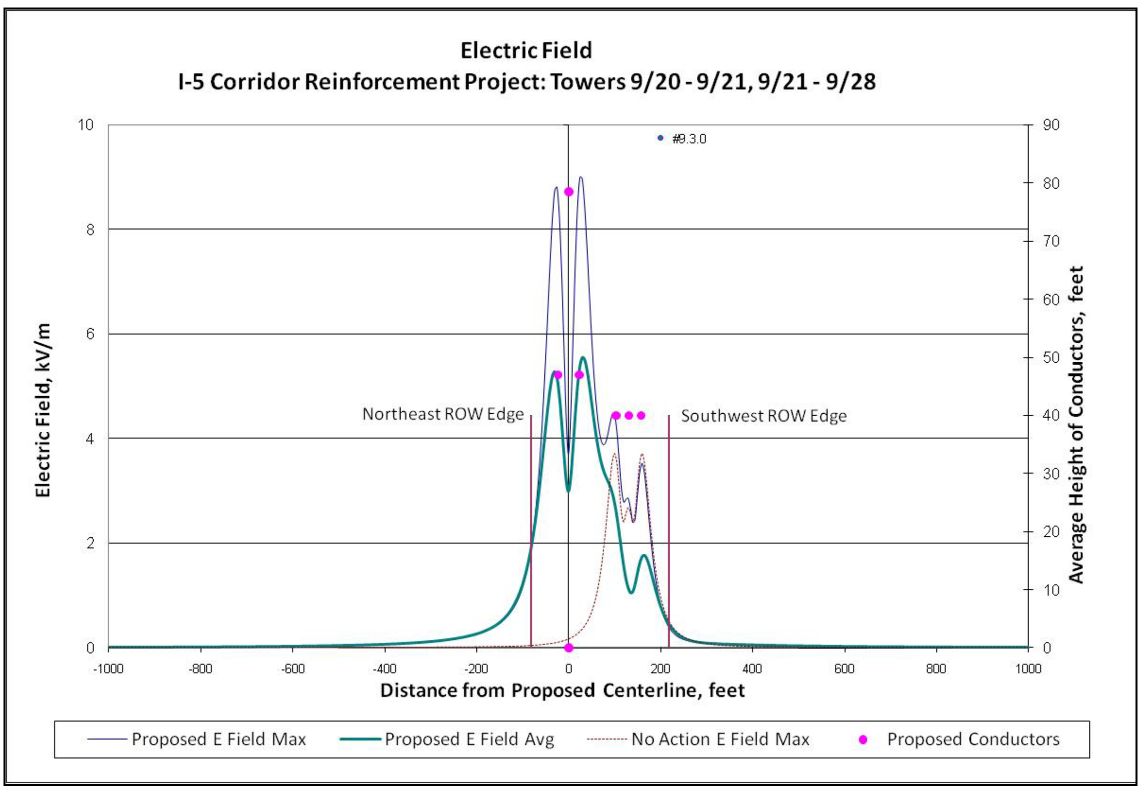

Figure 20: Calculation 9.3.0 – Magnetic Fields

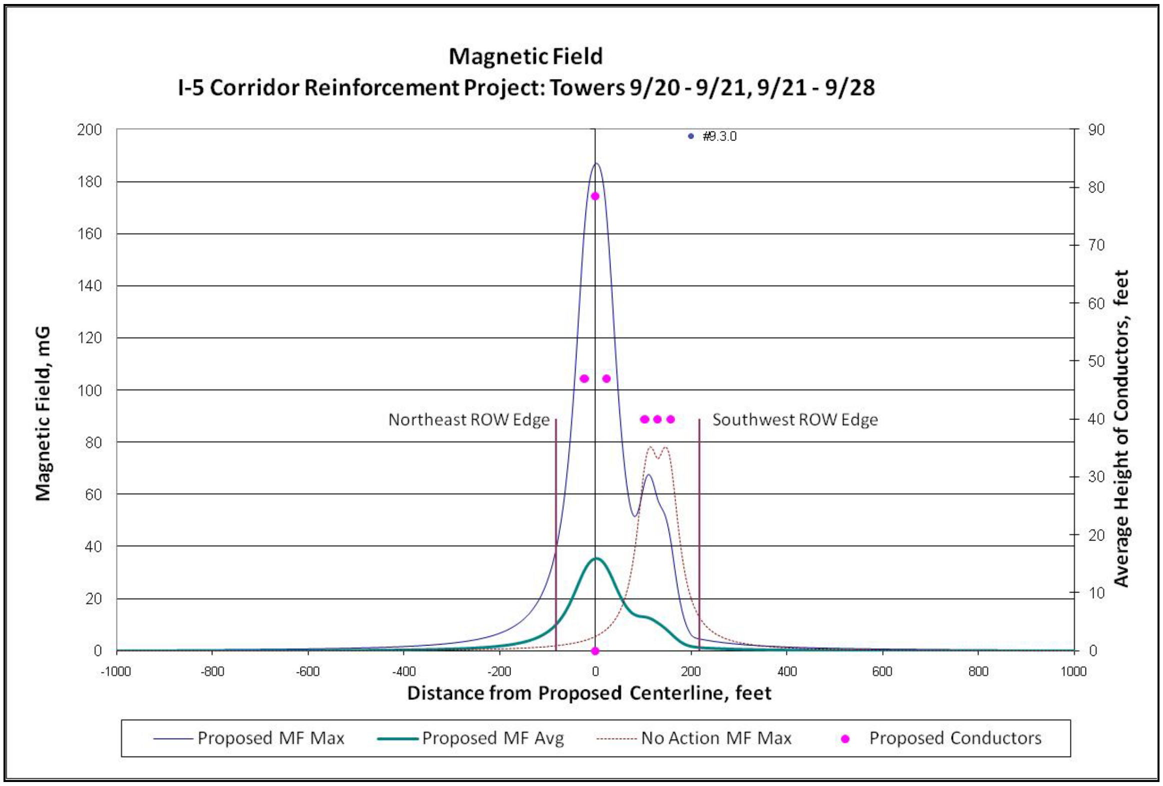

Figure 21: Calculation 9.3.0 – Audible Noise Levels

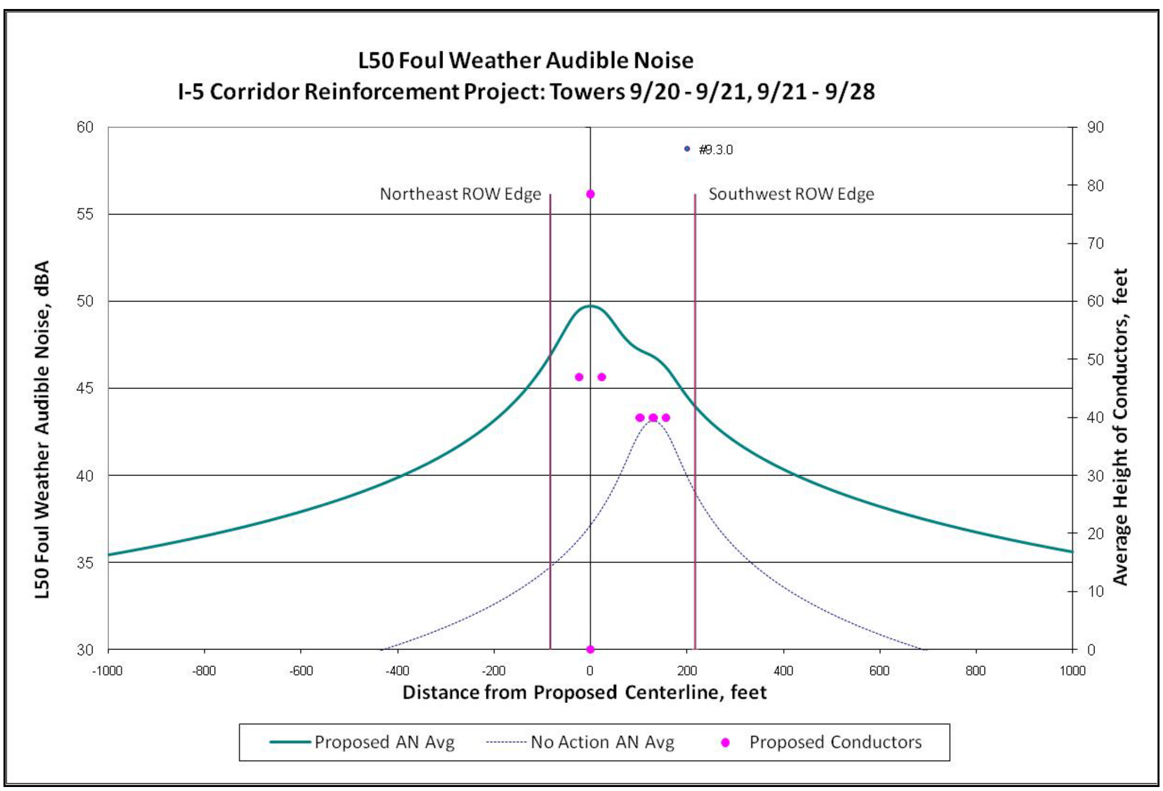

Table 14: Calculation 9.3.1

Calculation 9.3.1 : Electrical Sections						
Segment	Towers	Length		Segment	Towers	Length
9	9/28 - 9/82	12.62				
25	25/1 - 25/7	1.35				

Calculation 9.3.1 : Summary of Fields and Corona Effects							
	ROW Status	Average			Maximum		
Location		Northeast Edge	Southwest Edge	Peak On ROW	Northeast Edge	Southwest Edge	Peak On ROW
Electric Field, kV/m	No Action	0.1	0.6	1.9	0.0	0.5	3.7
	Proposed	1.9	0.7	5.3	1.9	0.7	8.9
Magnetic Field, mG	No Action	1	3	11	2	13	78
	Proposed	11	3	34	41	11	182
Audible Noise, dBA Foul weather L50	No Action	34.8	39.0	Not Applicable			
	Proposed	47.1	44.3				
Fair Weather RI, dB(uV/m) @ 100 ft from conductors	No Action	27	27	Not Applicable			
	Proposed	36	28				
Foul Weather TVI, dB(uV/m) @ 100 ft from conductors	No Action	14	14	Not Applicable			
	Proposed	21	13				

Figure 22: Calculation 9.3.1 – Electric Fields

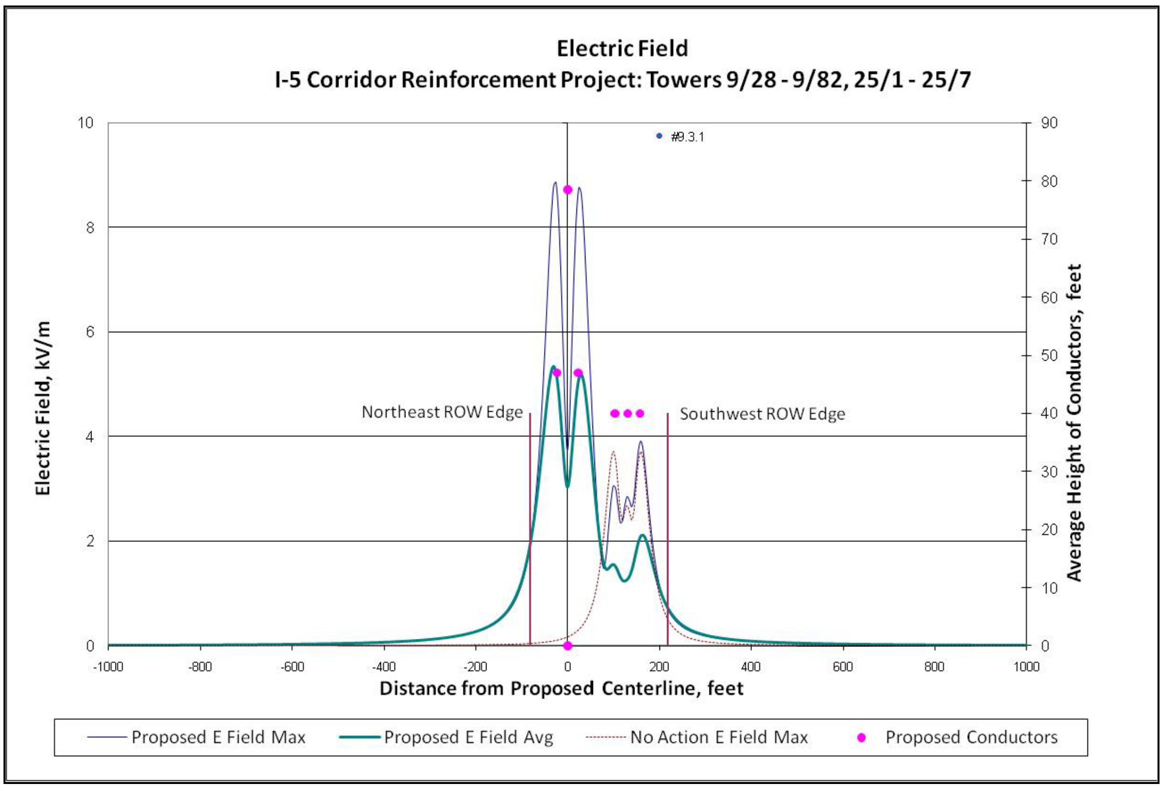

Figure 23: Calculation 9.3.1 – Magnetic Fields

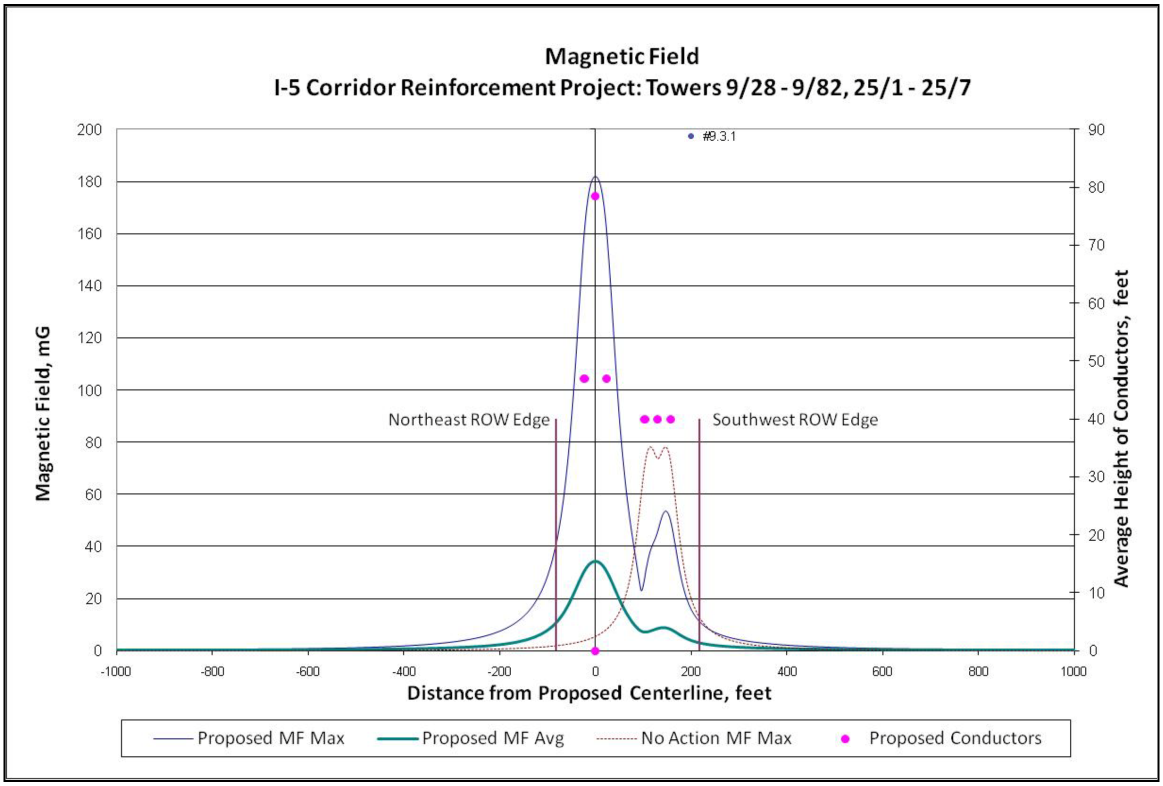

Figure 24: Calculation 9.3.1 – Audible Noise Levels

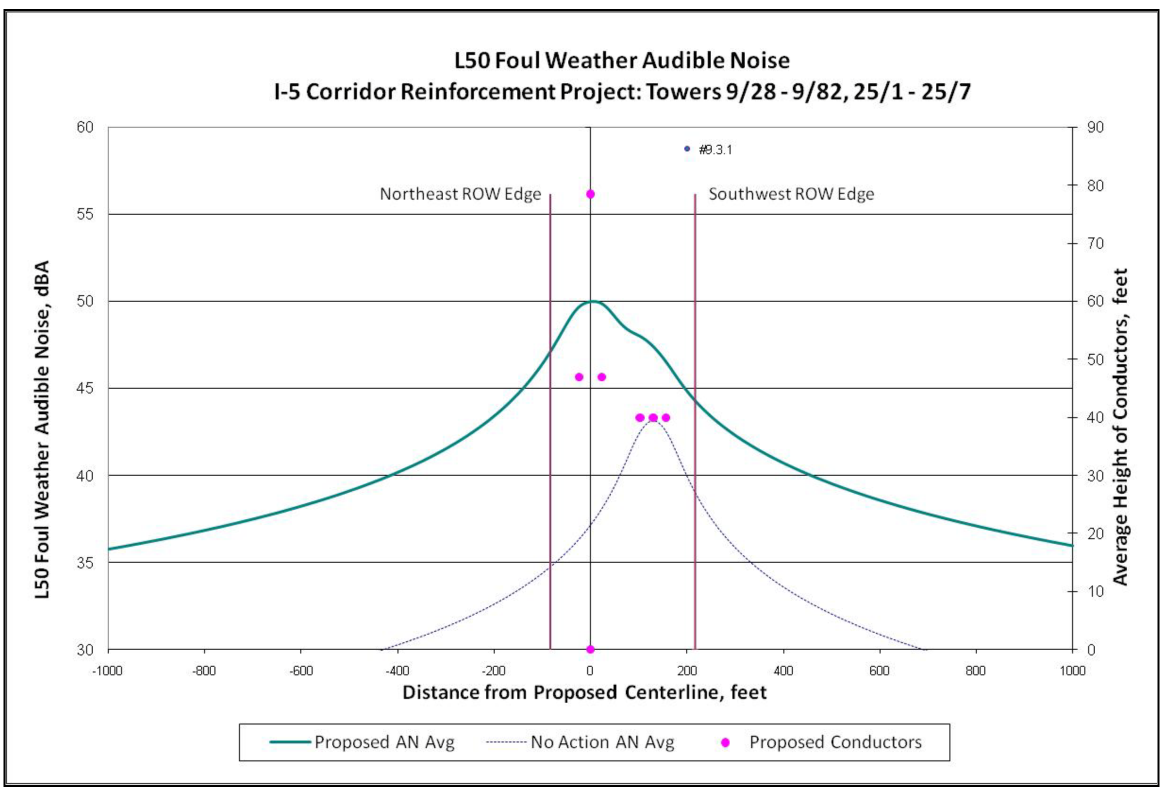

Table 15: Calculation 9.3.2

Calculation 9.3.2 : Electrical Sections						
Segment	Towers	Length		Segment	Towers	Length
25	25/7 - 25/11	0.75				

Calculation 9.3.2 : Summary of Fields and Corona Effects							
	ROW Status	Average			Maximum		
Location		Northeast Edge	Southwest Edge	Peak On ROW	Northeast Edge	Southwest Edge	Peak On ROW
Electric Field, kV/m	No Action	0.1	0.6	1.9	0.0	0.5	3.7
	Proposed	1.6	0.6	5.3	1.6	0.5	8.8
Magnetic Field, mG	No Action	1	3	11	2	13	78
	Proposed	10	3	34	36	12	183
Audible Noise, dBA Foul weather L50	No Action	34.8	39.0	Not Applicable			
	Proposed	47.0	44.5				
Fair Weather RI, dB(uV/m) @ 100 ft from conductors	No Action	27	27	Not Applicable			
	Proposed	36	28				
Foul Weather TVI, dB(uV/m) @ 100 ft from conductors	No Action	14	14	Not Applicable			
	Proposed	21	15				

Figure 25: Calculation 9.3.2 – Electric Fields

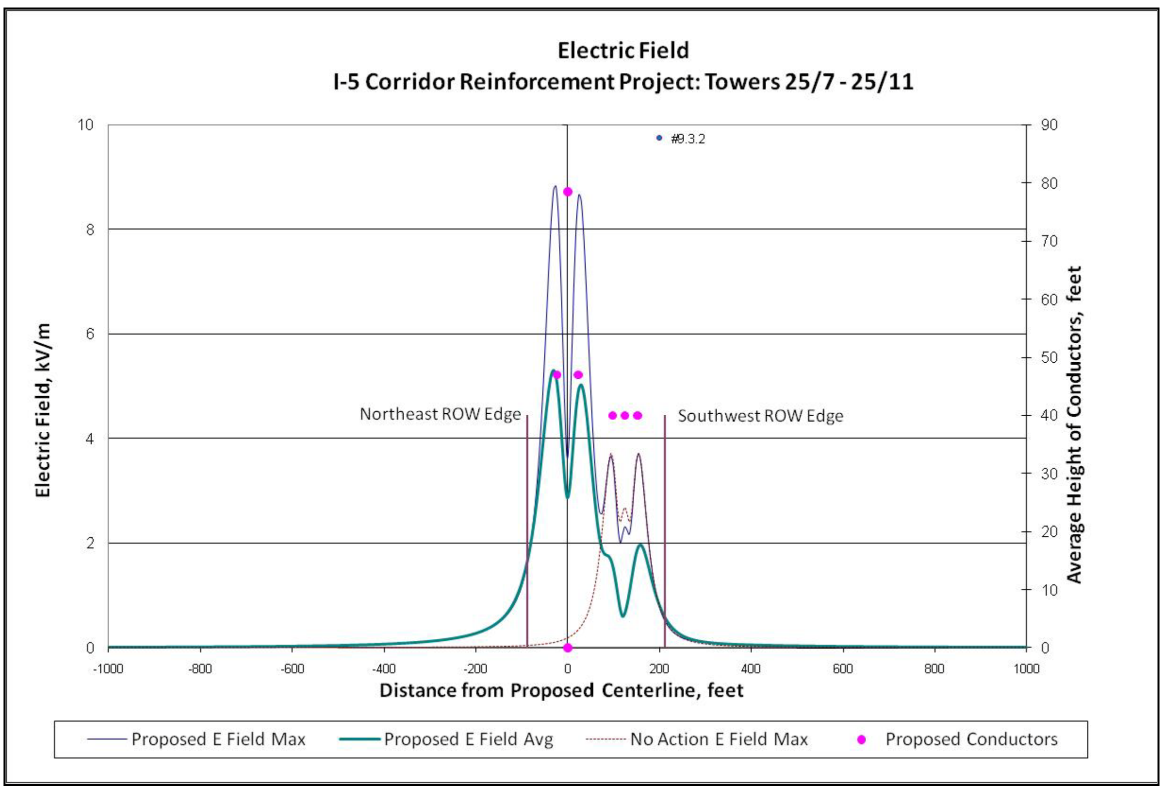

Figure 26: Calculation 9.3.2 – Magnetic Fields

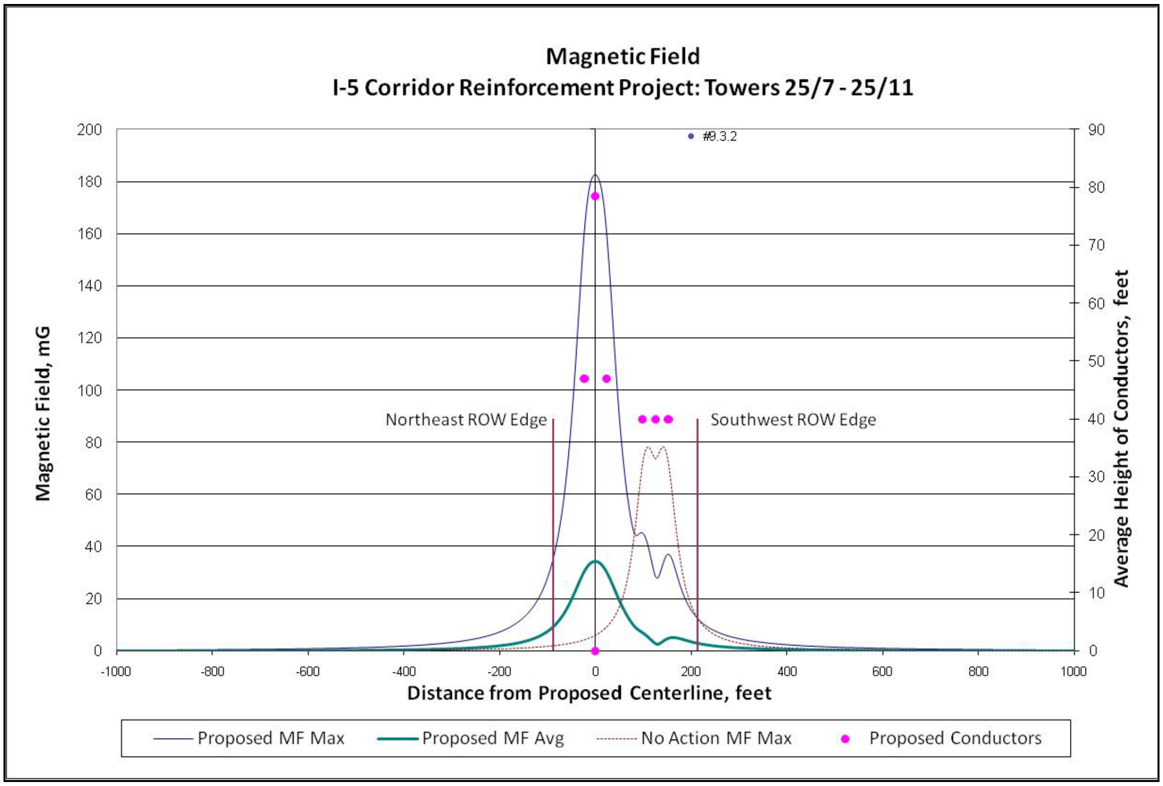

Figure 27: Calculation 9.3.2 – Audible Noise Levels

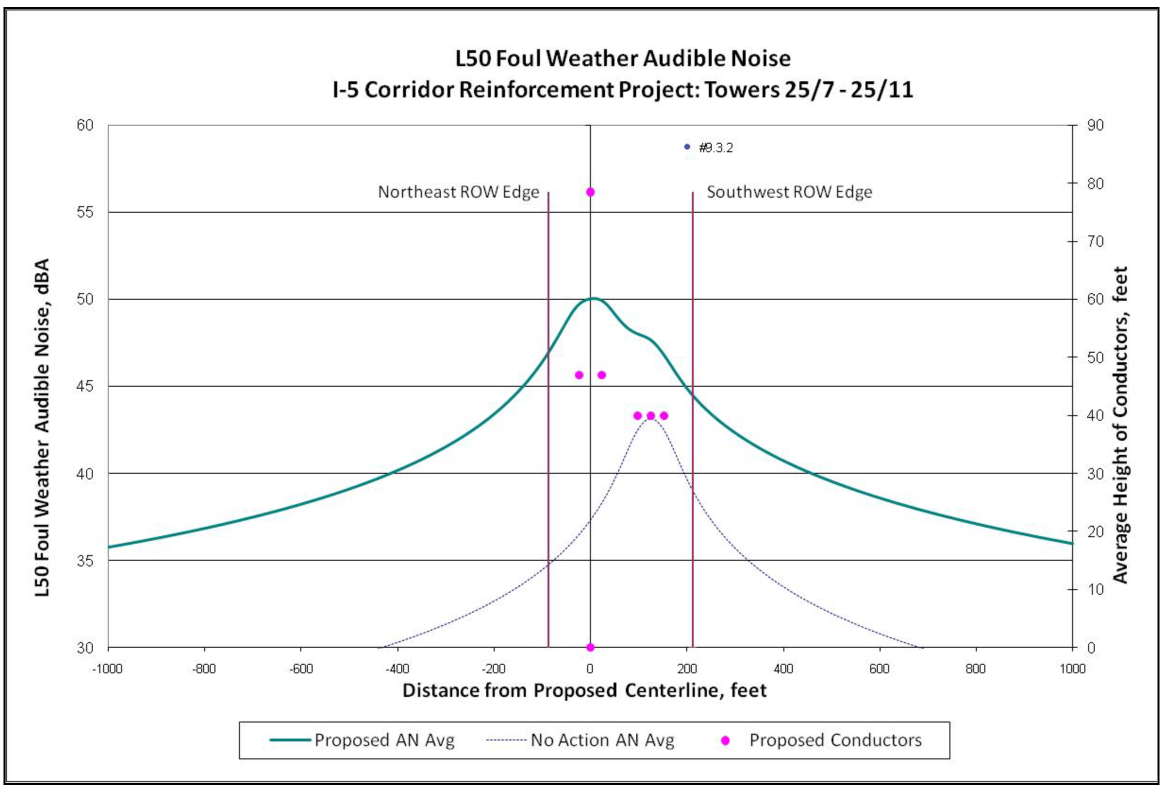

Table 16: Calculation 25.2.0

Calculation 25.2.0 : Electrical Sections						
Segment	Towers	Length		Segment	Towers	Length
25	25/11 - 25/18	1.64				
25	25/19 - 25/72	11.00				

Calculation 25.2.0 : Summary of Fields and Corona Effects							
	ROW Status	Average			Maximum		
Location		Northeast Edge	Southwest Edge	Peak On ROW	Northeast Edge	Southwest Edge	Peak On ROW
Electric Field, kV/m	No Action	0.1	1.2	1.9	0.1	1.3	3.7
	Proposed	2.3	1.2	5.3	2.3	1.3	8.8
Magnetic Field, mG	No Action	2	15	35	8	76	242
	Proposed	12	14	33	49	71	196
Audible Noise, dBA Foul weather L50	No Action	35.4	40.4	Not Applicable			
	Proposed	47.6	45.7				
Fair Weather RI, dB(uV/m) @ 100 ft from conductors	No Action	27	27	Not Applicable			
	Proposed	36	29				
Foul Weather TVI, dB(uV/m) @ 100 ft from conductors	No Action	14	14	Not Applicable			
	Proposed	21	16				

Figure 28: Calculation 25.2.0 – Electric Fields

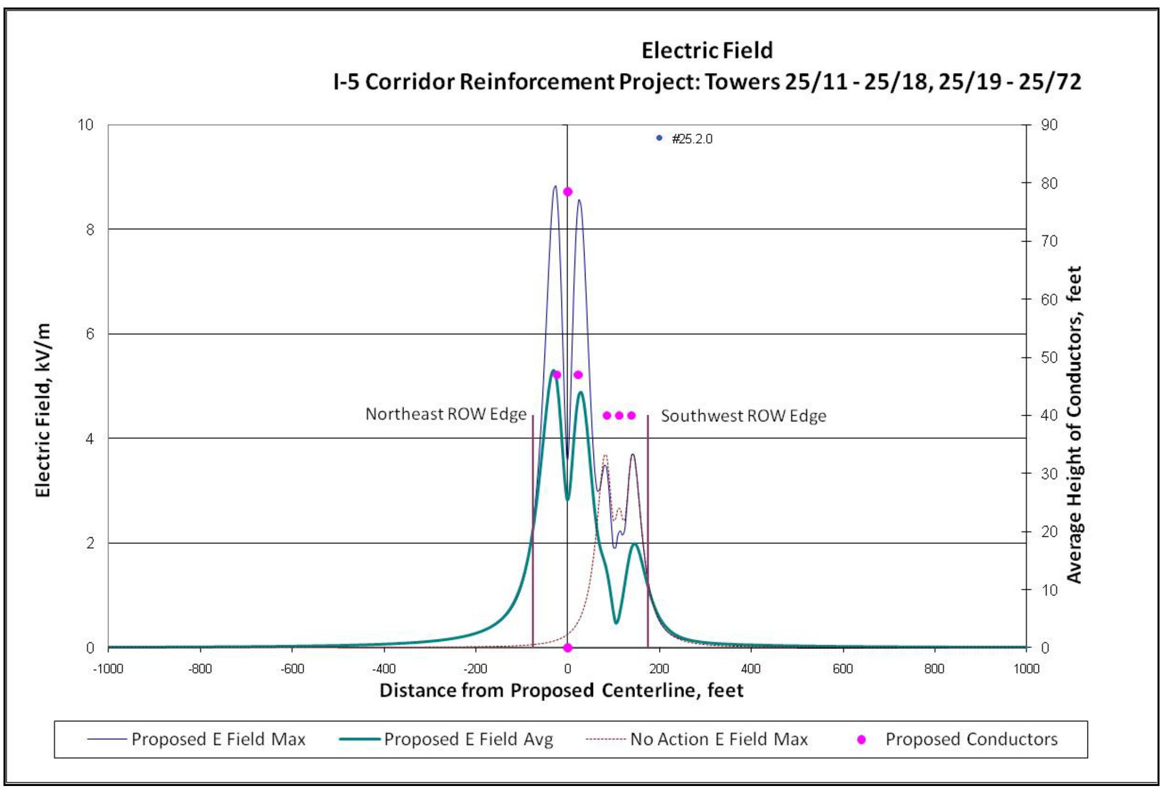

Figure 29: Calculation 25.2.0 – Magnetic Fields

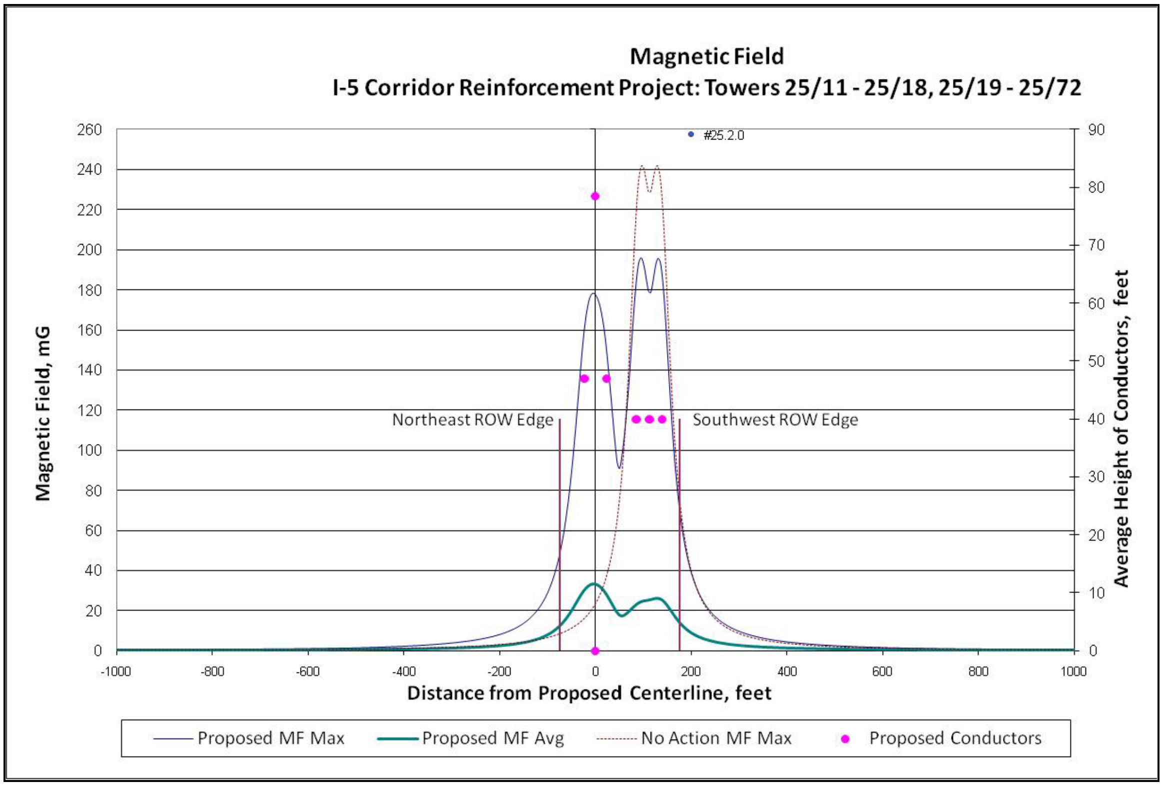

Figure 30: Calculation 25.2.0 – Audible Noise Levels

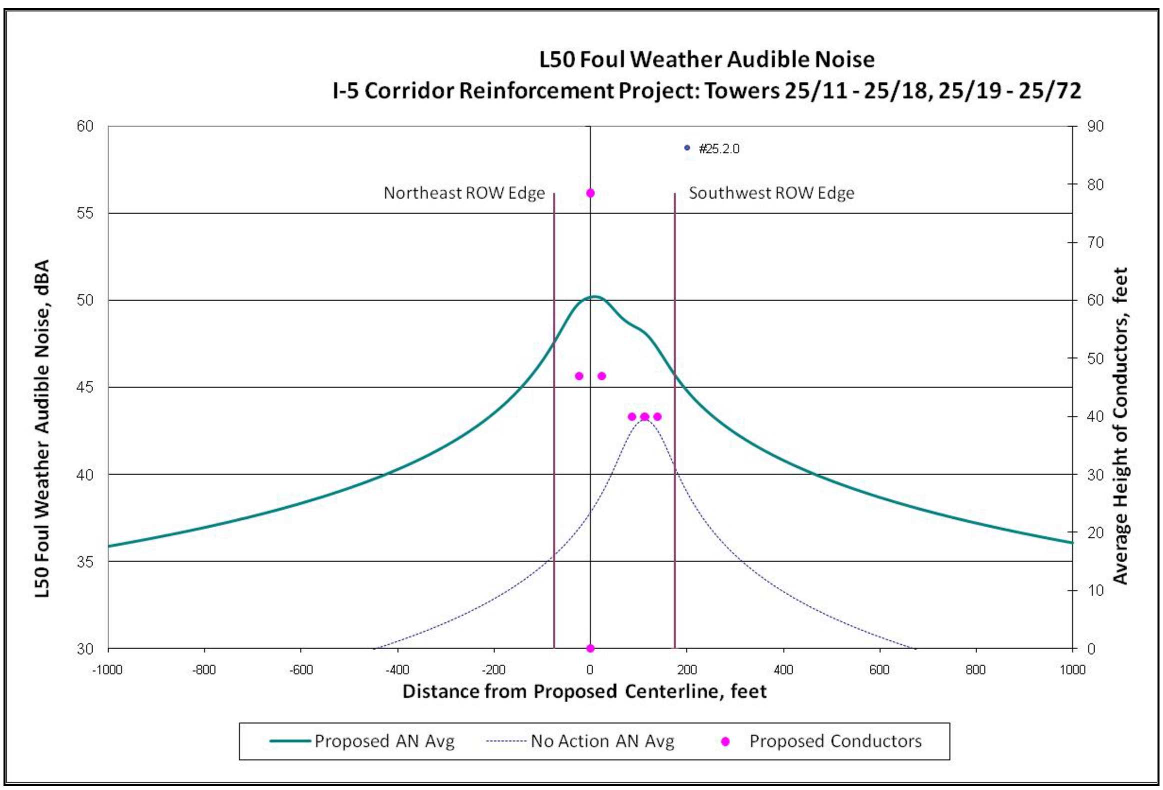

Table 17: Calculation 25.2.1

Calculation 25.2.1 : Electrical Sections						
Segment	Towers	Length		Segment	Towers	Length
25	25/72 - 25/106	6.47				

Calculation 25.2.1 : Summary of Fields and Corona Effects							
	ROW Status	Average			Maximum		
Location		Northeast Edge	Southwest Edge	Peak On ROW	Northeast Edge	Southwest Edge	Peak On ROW
Electric Field, kV/m	No Action	0.1	1.2	1.9	0.1	1.3	3.7
	Proposed	2.2	1.0	5.5	2.3	1.1	8.8
Magnetic Field, mG	No Action	2	15	35	8	76	242
	Proposed	11	11	38	41	58	240
Audible Noise, dBA Foul weather L50	No Action	35.4	40.4	Not Applicable			
	Proposed	47.2	45.0				
Fair Weather RI, dB(uV/m) @ 100 ft from conductors	No Action	27	27	Not Applicable			
	Proposed	36	29				
Foul Weather TVI, dB(uV/m) @ 100 ft from conductors	No Action	14	14	Not Applicable			
	Proposed	21	16				

Figure 31: Calculation 25.2.1 – Electric Fields

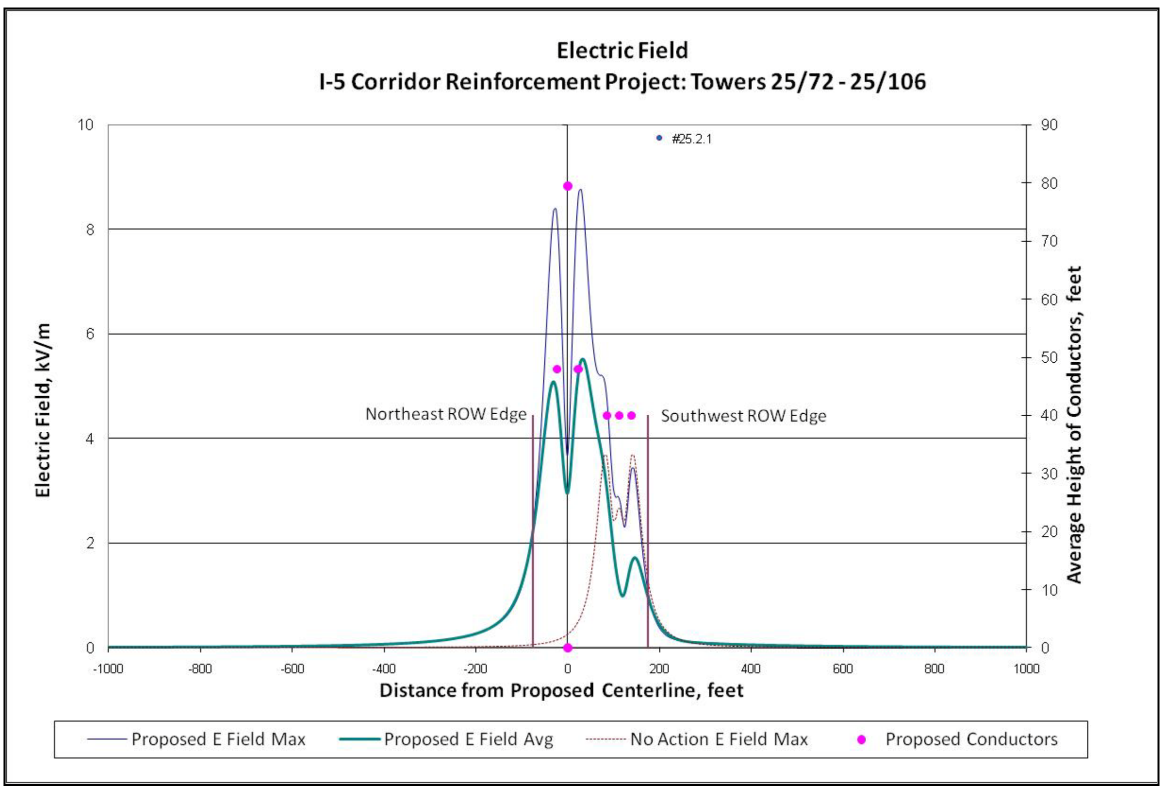

Figure 32: Calculation 25.2.1 – Magnetic Fields

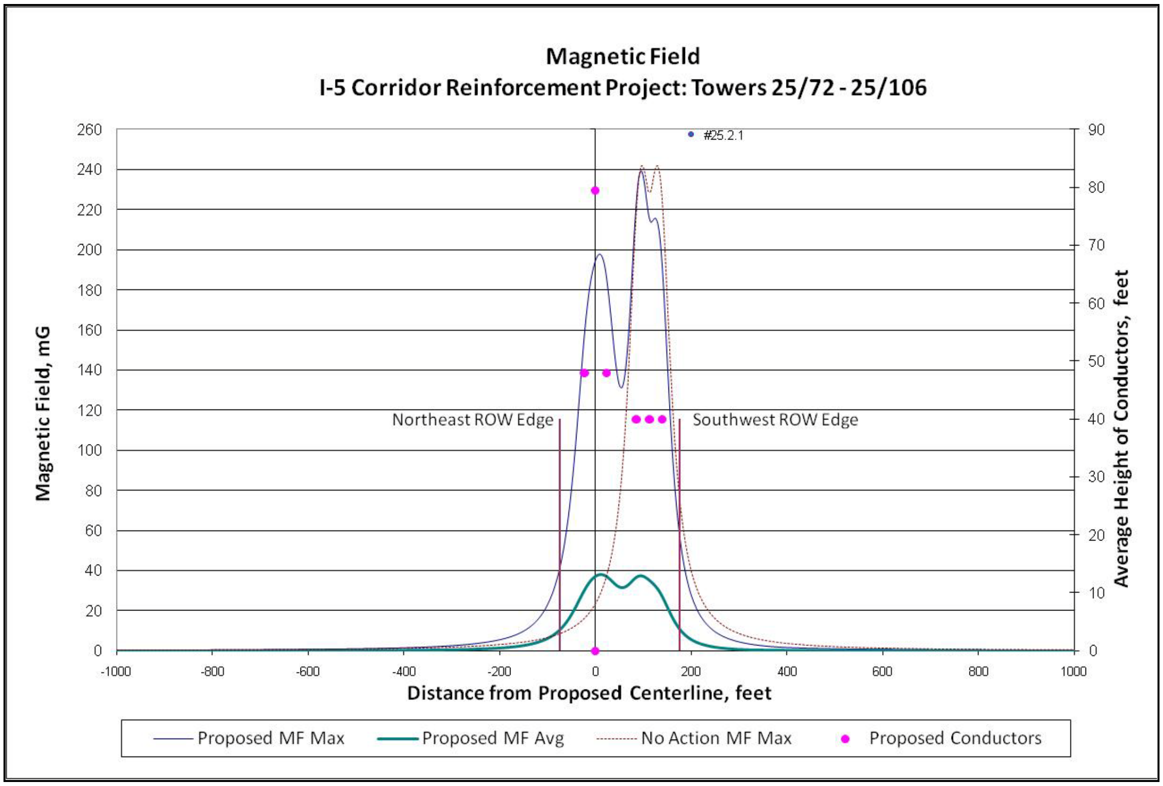

Figure 33: Calculation 25.2.1 – Audible Noise Levels

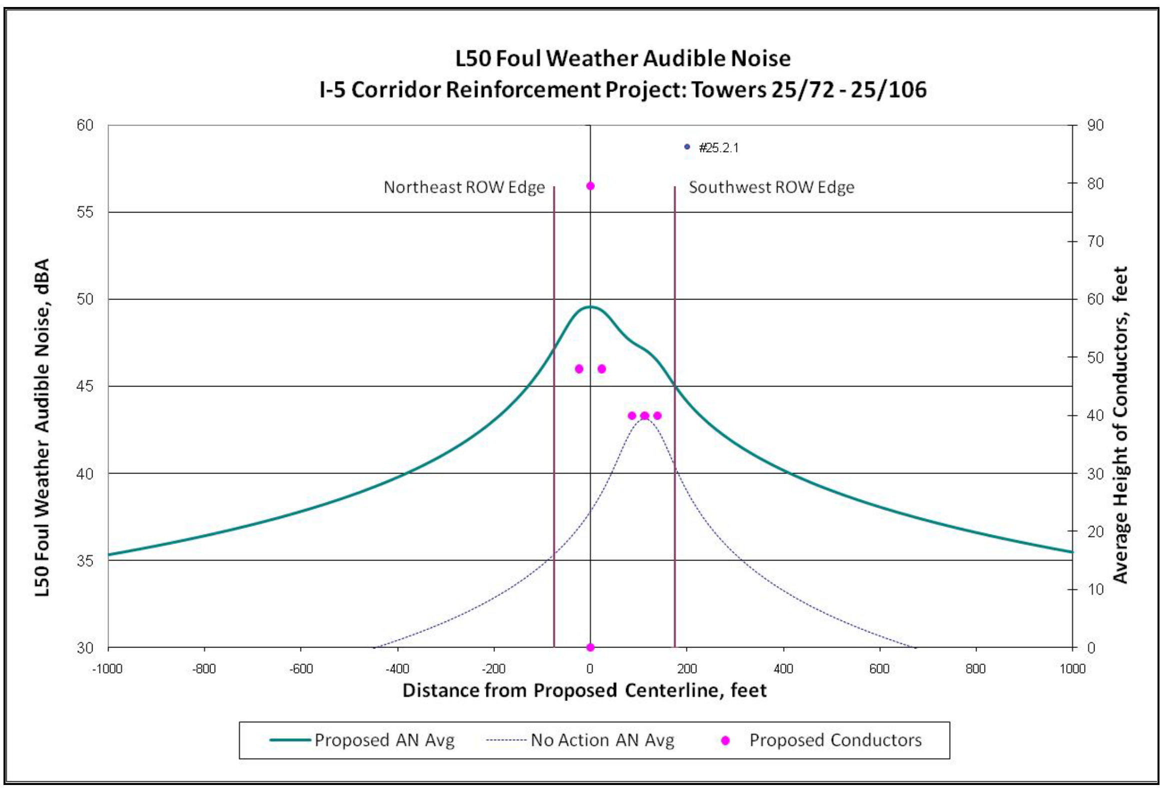

Table 18: Calculation 25.3.0

Calculation 25.3.0: Electrical Sections						
Segment	Towers	Length		Segment	Towers	Length
25	25/106 - 25/110	0.63				

Calculation 25.3.0: Summary of Fields and Corona Effects							
	ROW Status	Average			Maximum		
Location		Northwest Edge	Southeast Edge	Peak On ROW	Northwest Edge	Southeast Edge	Peak On ROW
Electric Field, kV/m	No Action	0.0	0.7	1.2	0.0	0.9	2.4
	Proposed	0.9	0.6	5.3	0.9	0.8	8.8
Magnetic Field, mG	No Action	0	5	5	1	40	52
	Proposed	6	3	35	22	25	184
Audible Noise, dBA Foul weather L50	No Action	11.7	20.0	Not Applicable			
	Proposed	45.5	43.2				
Fair Weather RI, dB(uV/m) @ 100 ft from conductors	No Action	10	10	Not Applicable			
	Proposed	36	27				
Foul Weather TVI, dB(uV/m) @ 100 ft from conductors	No Action	-7	-7	Not Applicable			
	Proposed	21	8				

Figure 34: Calculation 25.3.0 – Electric Fields

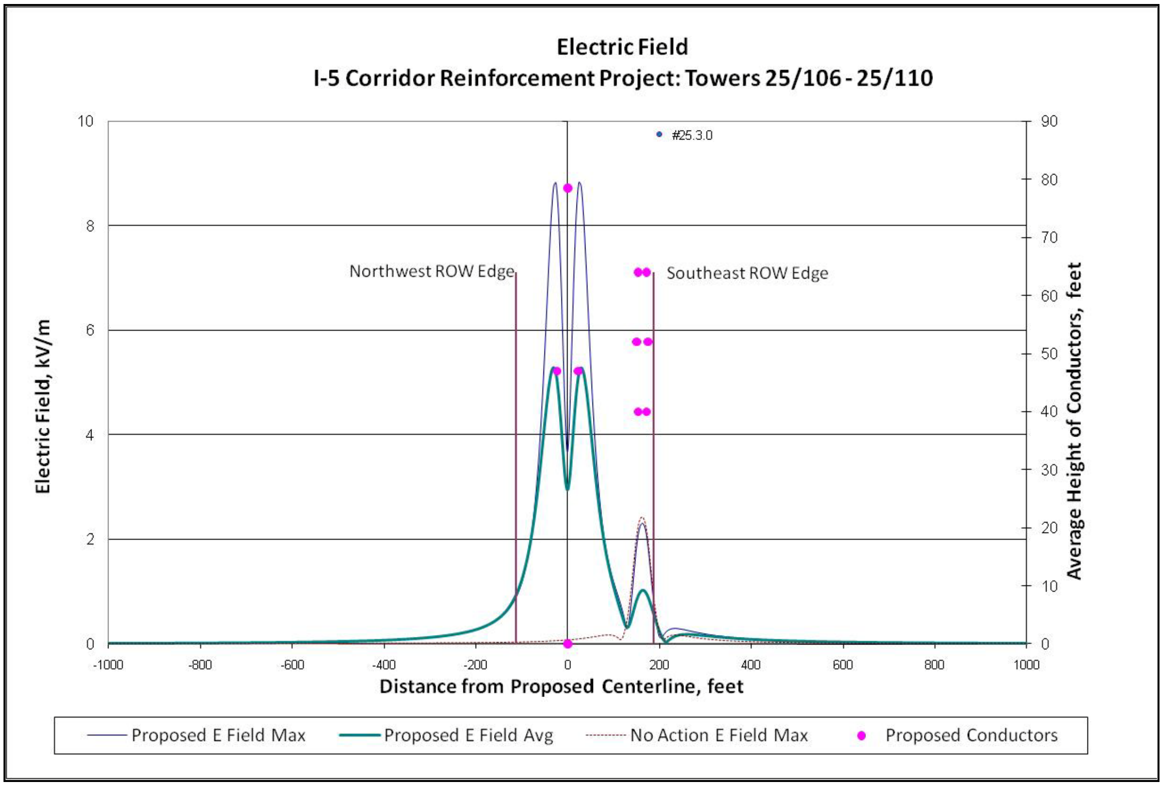

Figure 35: Calculation 25.3.0 – Magnetic Fields

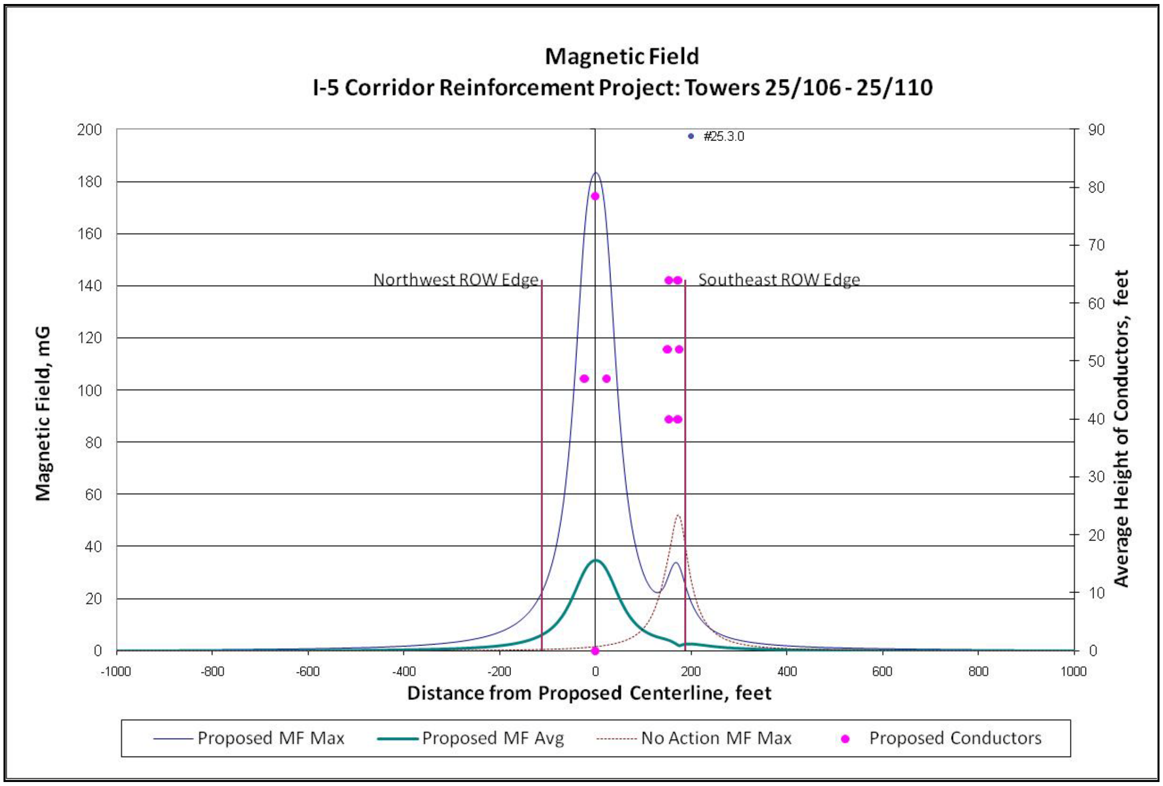

Figure 36: Calculation 25.3.0 – Audible Noise Levels

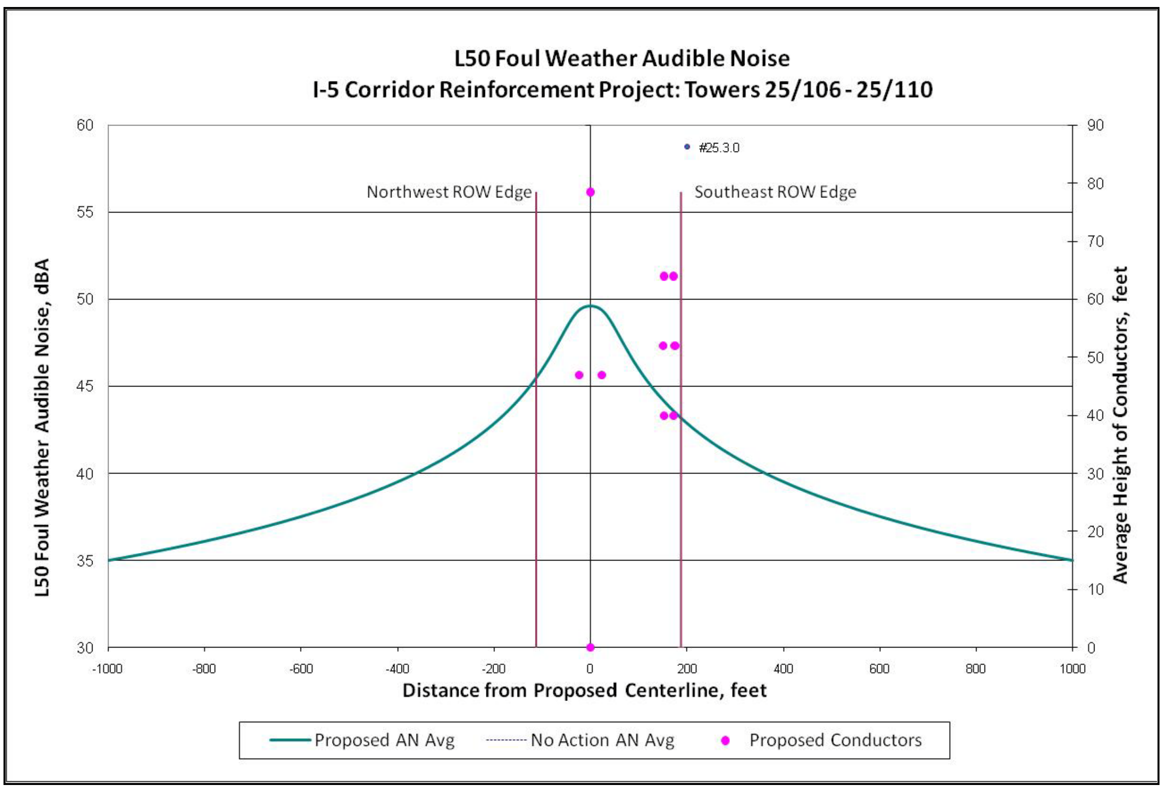

Table 19: Calculation 25.4.0

Calculation 25.4.0: Electrical Sections						
Segment	Towers	Length		Segment	Towers	Length
25	25/110 - 25/141	5.67				

Calculation 25.4.0: Summary of Fields and Corona Effects							
	ROW Status	Average			Maximum		
Location		Northwest Edge	Southeast Edge	Peak On ROW	Northwest Edge	Southeast Edge	Peak On ROW
Electric Field, kV/m	No Action	0.2	0.8	2.9	0.2	1.0	5.3
	Proposed	2.2	0.7	5.5	2.3	0.9	8.7
Magnetic Field, mG	No Action	5	5	49	9	32	136
	Proposed	14	4	32	50	22	170
Audible Noise, dBA Foul weather L50	No Action	48.4	49.3	Not Applicable			
	Proposed	50.7	51.3				
Fair Weather RI, dB(uV/m) @ 100 ft from conductors	No Action	37	30	Not Applicable			
	Proposed	36	34				
Foul Weather TVI, dB(uV/m) @ 100 ft from conductors	No Action	23	14	Not Applicable			
	Proposed	21	18				

Figure 37: Calculation 25.4.0 – Electric Fields

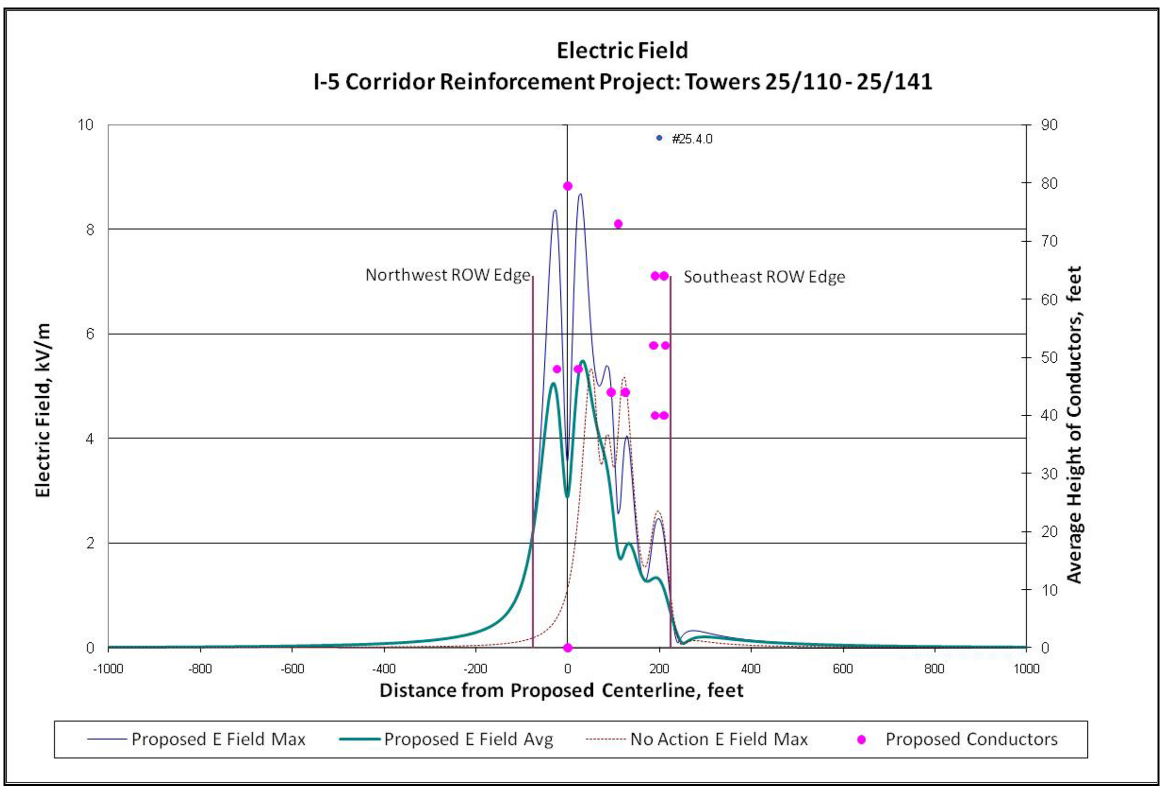

Figure 38: Calculation 25.4.0 – Magnetic Fields

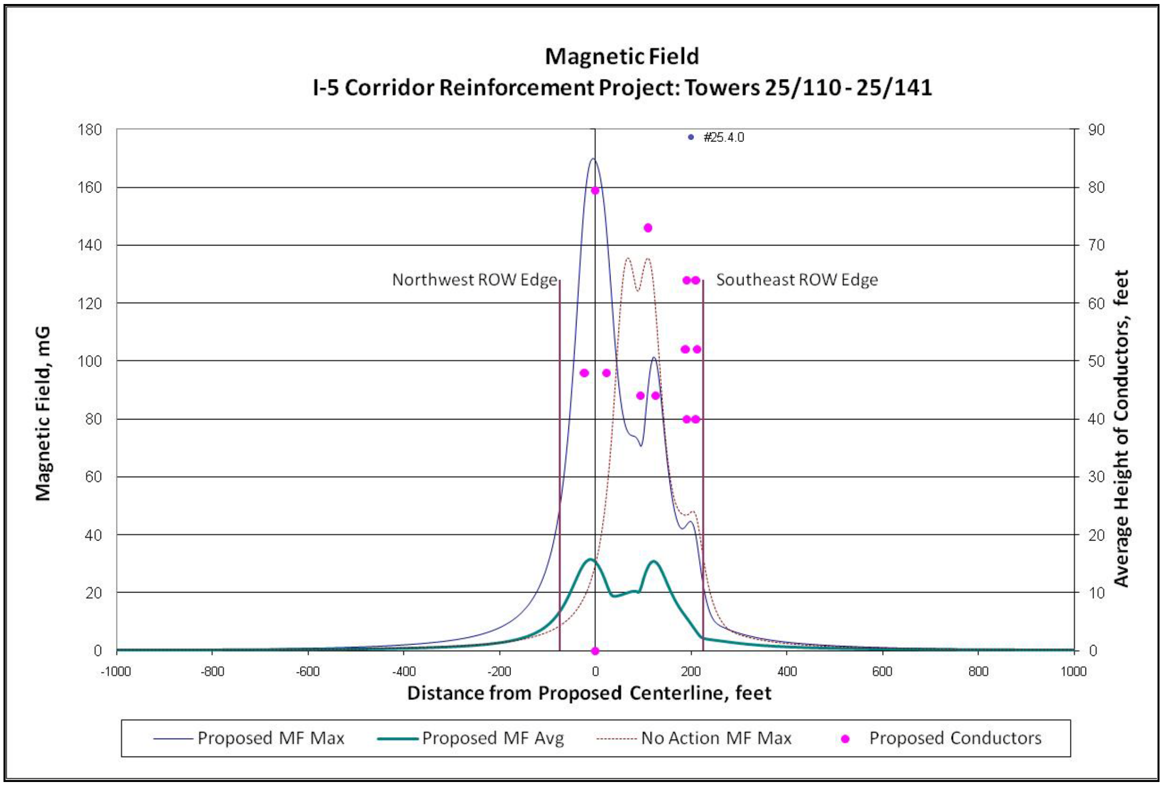

Figure 39: Calculation 25.4.0 – Audible Noise Levels

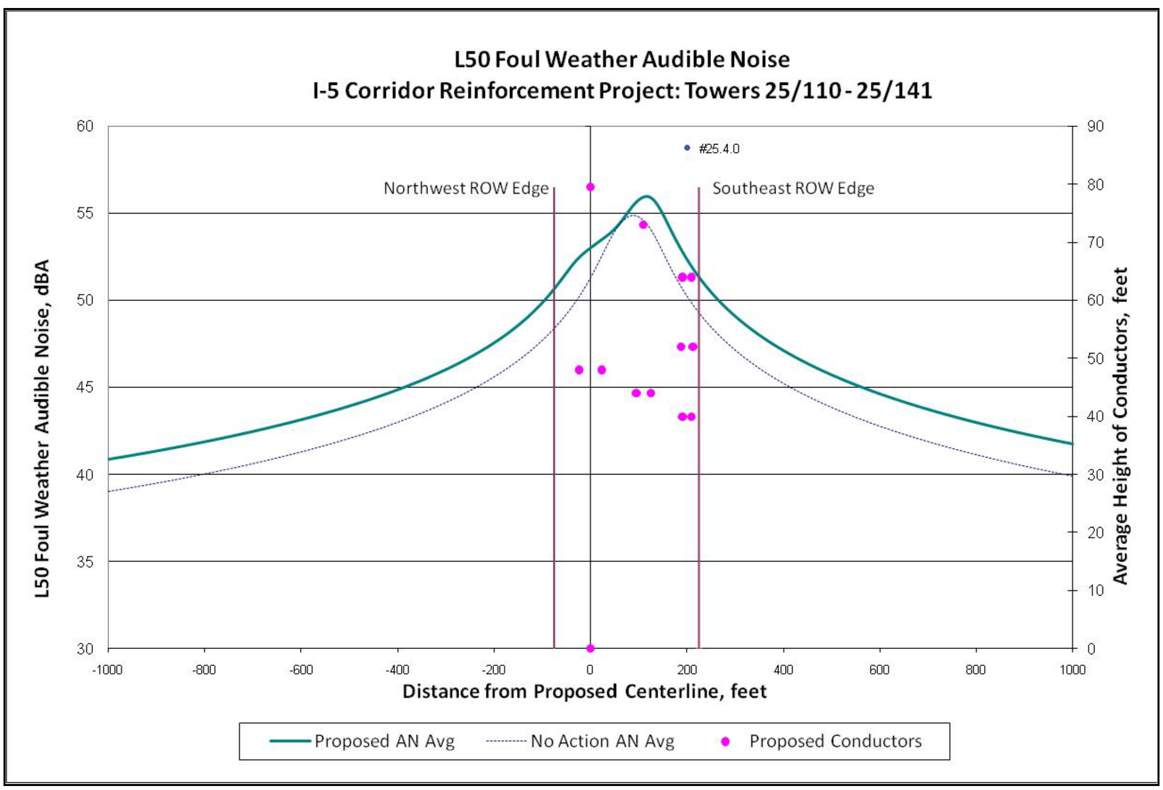

Table 20: Calculation 25.5.0

Calculation 25.5.0 : Electrical Sections						
Segment	Towers	Length		Segment	Towers	Length
25	25/141 - 25/151	1.71				
25	25/151 - 25/152	0.18				

Calculation 25.5.0 : Summary of Fields and Corona Effects							
	ROW Status	Average			Maximum		
Location		Northwest Edge	Southeast Edge	Peak On ROW	Northwest Edge	Southeast Edge	Peak On ROW
Electric Field, kV/m	No Action	0.3	0.6	2.9	0.2	0.9	5.4
	Proposed	2.2	0.6	5.8	2.3	0.9	8.8
Magnetic Field, mG	No Action	5	3	49	9	26	136
	Proposed	15	5	46	51	15	158
Audible Noise, dBA Foul weather L50	No Action	48.4	49.3	Not Applicable			
	Proposed	49.8	49.6				
Fair Weather RI, dB(uV/m) @ 100 ft from conductors	No Action	37	30	Not Applicable			
	Proposed	36	30				
Foul Weather TVI, dB(uV/m) @ 100 ft from conductors	No Action	23	14	Not Applicable			
	Proposed	21	15				

Figure 40: Calculation 25.5.0 – Electric Fields

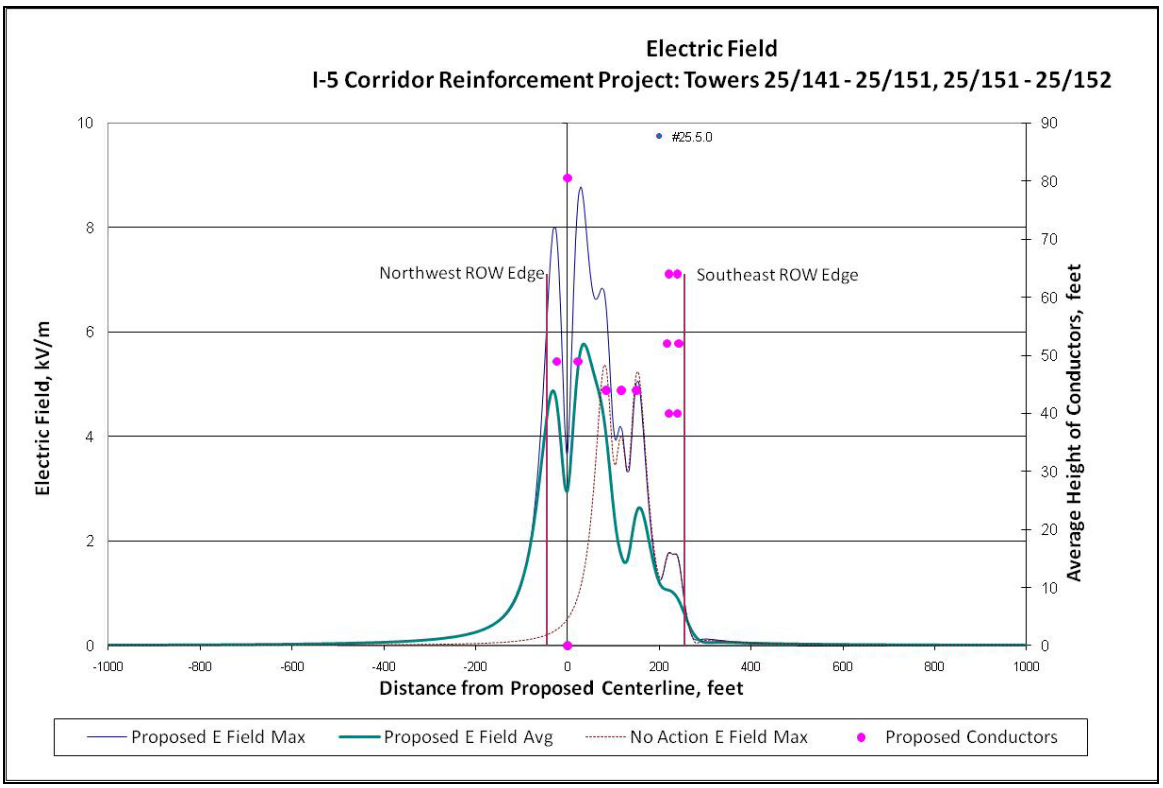

Figure 41: Calculation 25.5.0 – Magnetic Fields

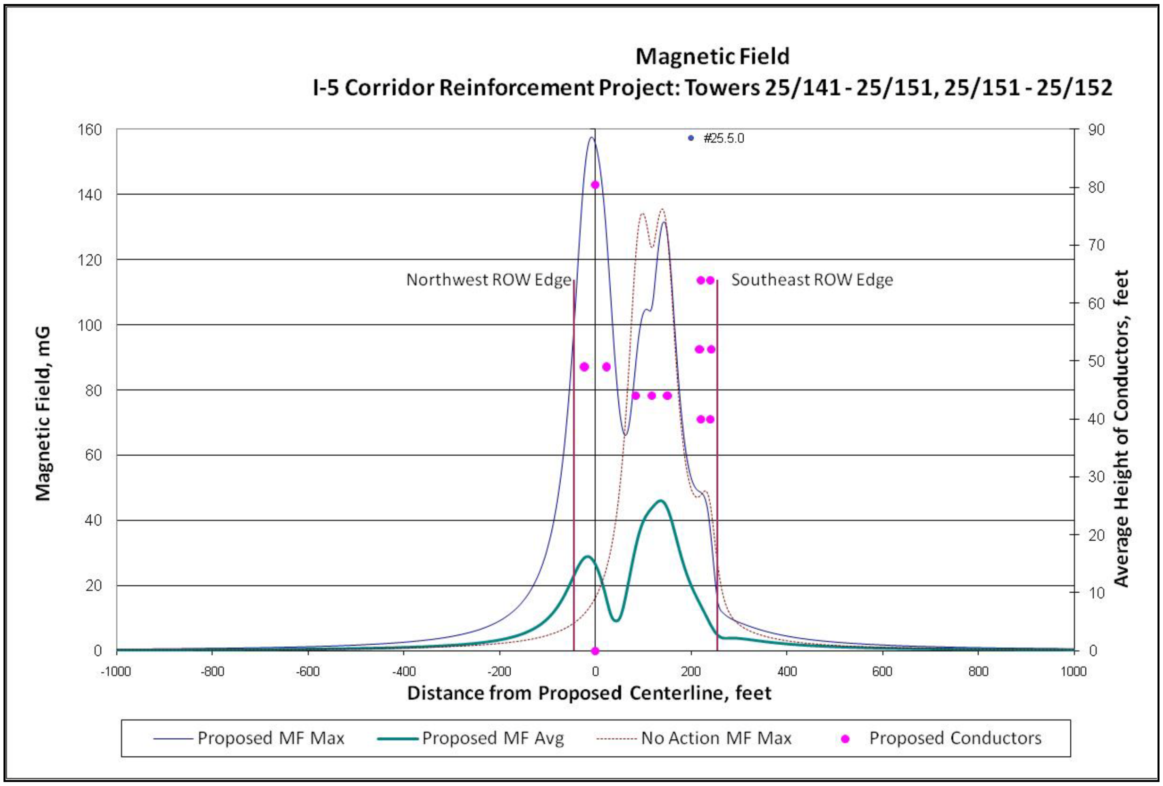

Figure 42: Calculation 25.5.0 – Audible Noise Levels

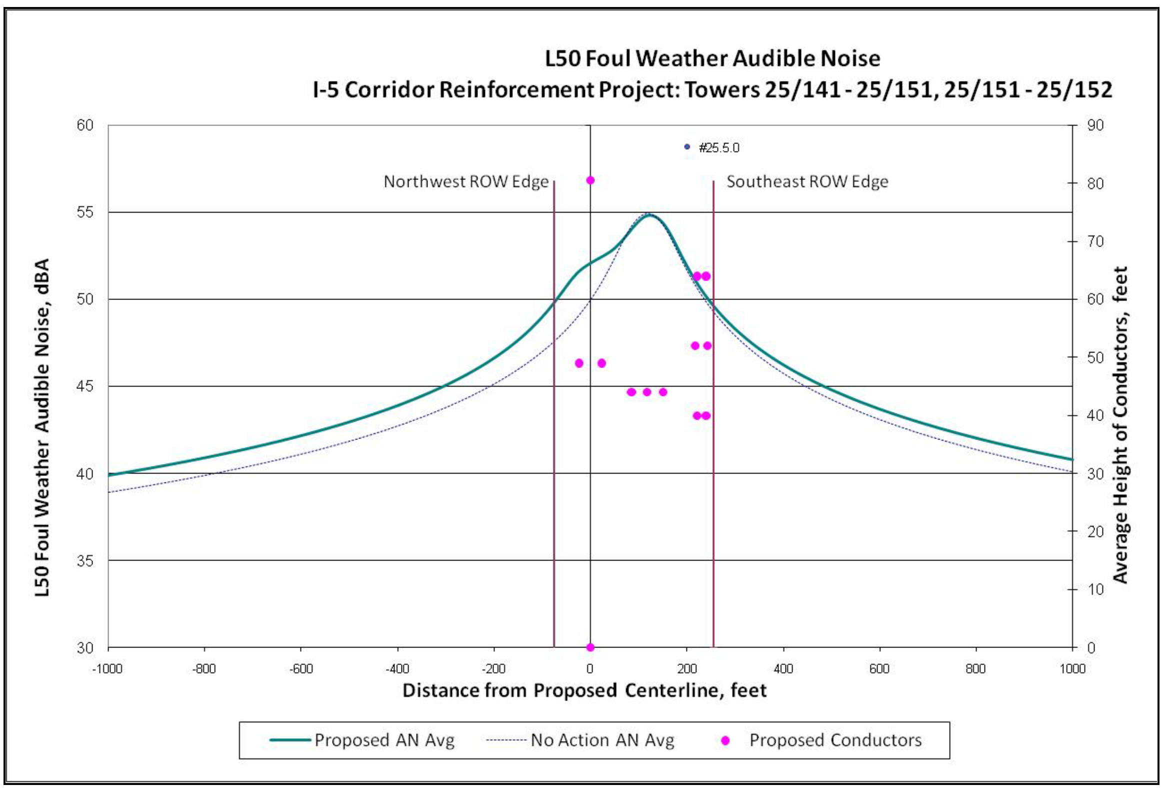

Table 21: Calculation 36A.1.0

Calculation 36A.1.0: Electrical Sections						
Segment	Towers	Length		Segment	Towers	Length
36	36/1 - 36/2	0.22				
36A	36A/1 - 36A/5	0.80				

Calculation 36A.1.0: Summary of Fields and Corona Effects							
	ROW Status	Average			Maximum		
Location		North Edge	South Edge	Peak On ROW	North Edge	South Edge	Peak On ROW
Electric Field, kV/m	No Action	0.3	0.6	2.9	0.2	0.9	5.4
	Proposed	2.2	0.6	5.8	2.3	0.9	8.8
Magnetic Field, mG	No Action	5	4	49	9	15	136
	Proposed	15	6	46	51	12	158
Audible Noise, dBA Foul weather L50	No Action	48.4	49.3	Not Applicable			
	Proposed	49.8	49.6				
Fair Weather RI, dB(uV/m) @ 100 ft from conductors	No Action	37	30	Not Applicable			
	Proposed	36	30				
Foul Weather TVI, dB(uV/m) @ 100 ft from conductors	No Action	23	14	Not Applicable			
	Proposed	21	15				

Figure 43: Calculation 36A.1.0 – Electric Fields

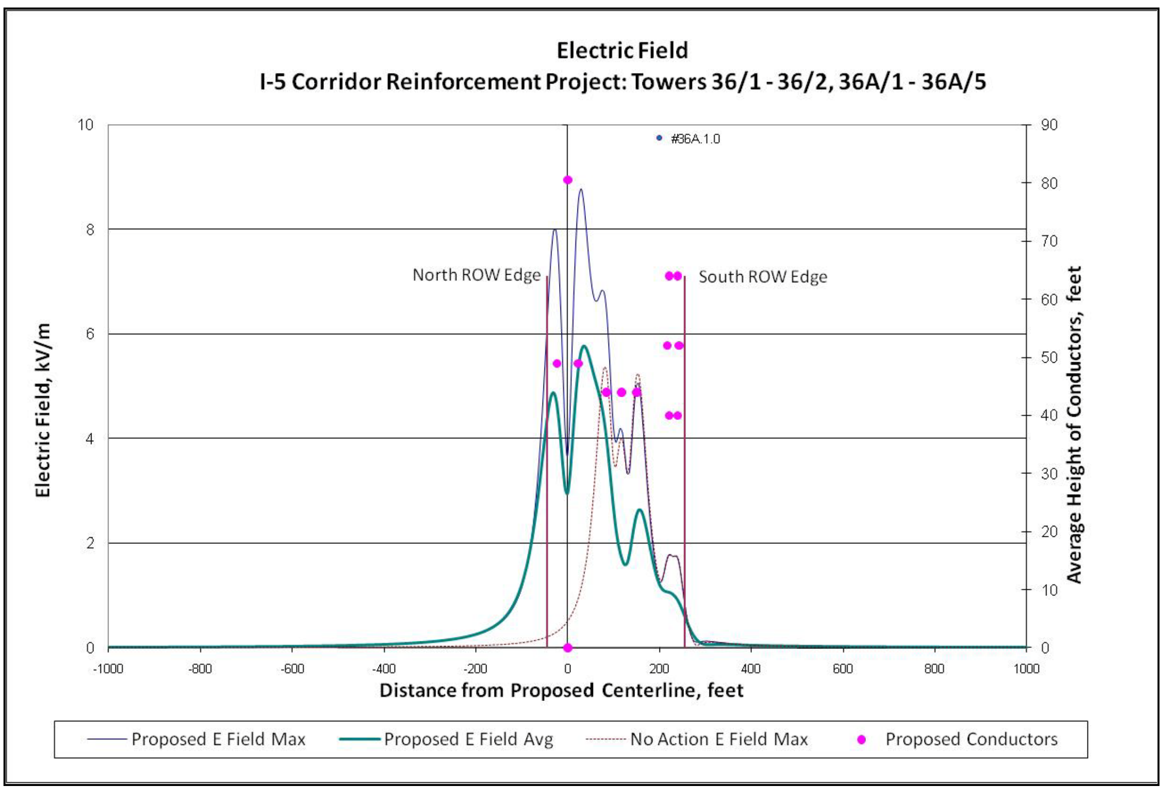

Figure 44: Calculation 36A.1.0 – Magnetic Fields

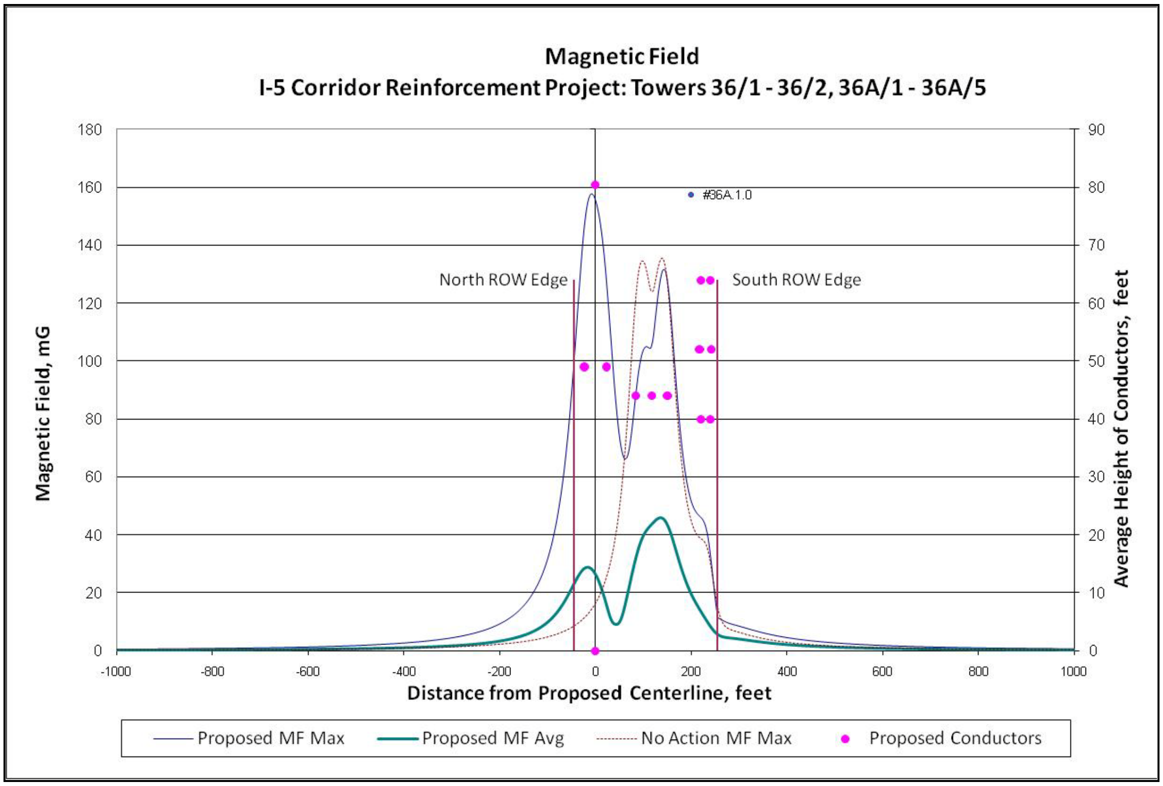

Figure 45: Calculation 36A.1.0 – Audible Noise Levels

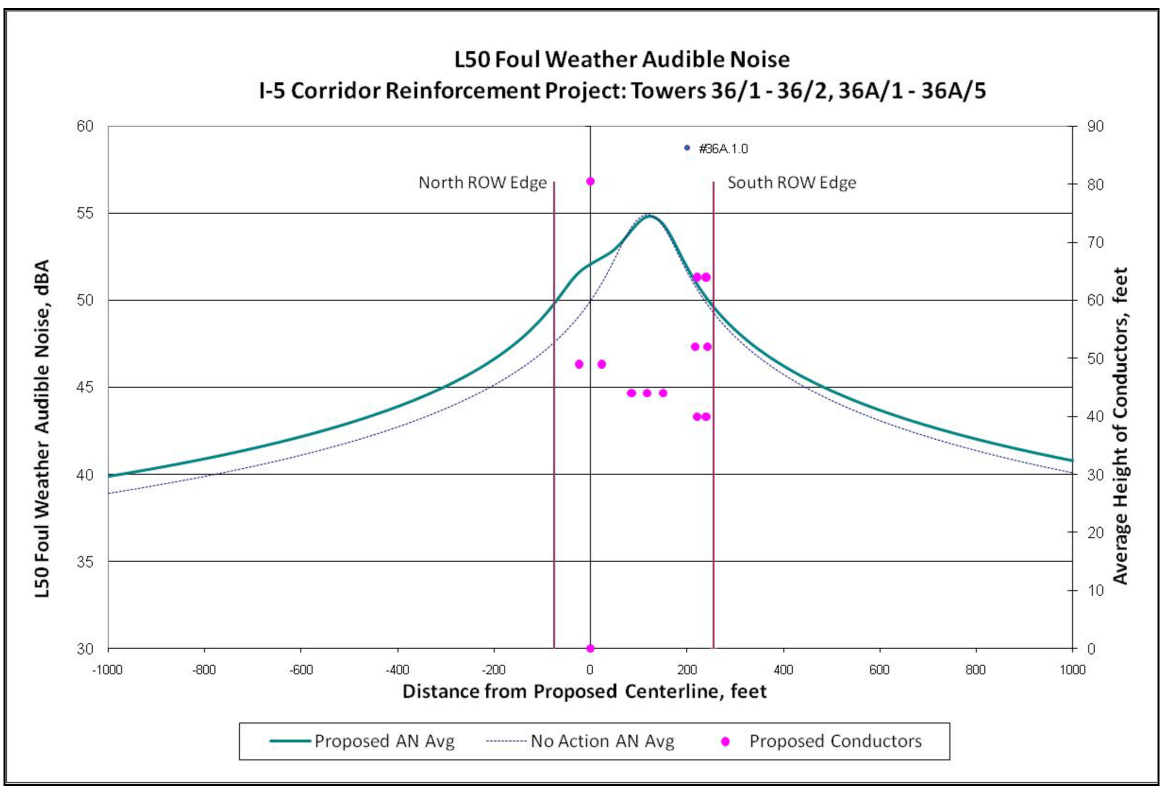

Table 22: Calculation 36A.2.0

Calculation 36A.2.0: Electrical Sections						
Segment	Towers	Length		Segment	Towers	Length
36A	36A/5 - 36A/6	0.23				
37	37/1 - 37/2	0.21				

Calculation 36A.2.0: Summary of Fields and Corona Effects							
	ROW Status	Average			Maximum		
Location		North Edge	South Edge	Peak On ROW	North Edge	South Edge	Peak On ROW
Electric Field, kV/m	No Action	0.3	0.6	2.9	0.2	0.9	5.4
	Proposed	2.2	0.6	5.5	2.3	0.9	8.7
Magnetic Field, mG	No Action	5	4	49	9	15	136
	Proposed	13	4	32	50	15	170
Audible Noise, dBA Foul weather L50	No Action	48.4	49.3	Not Applicable			
	Proposed	50.7	51.3				
Fair Weather RI, dB(uV/m) @ 100 ft from conductors	No Action	37	30	Not Applicable			
	Proposed	36	34				
Foul Weather TVI, dB(uV/m) @ 100 ft from conductors	No Action	23	14	Not Applicable			
	Proposed	21	18				

Figure 46: Calculation 36A.2.0 – Electric Fields

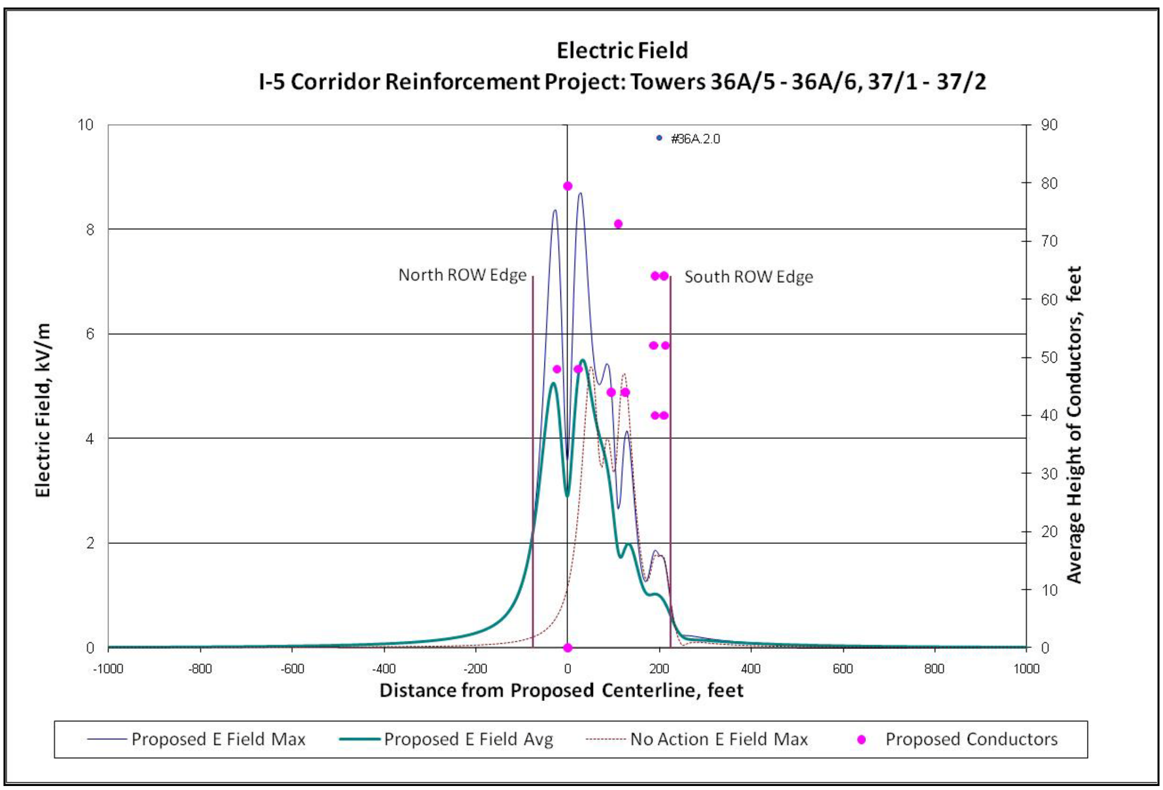

Figure 47: Calculation 36A.2.0 – Magnetic Fields

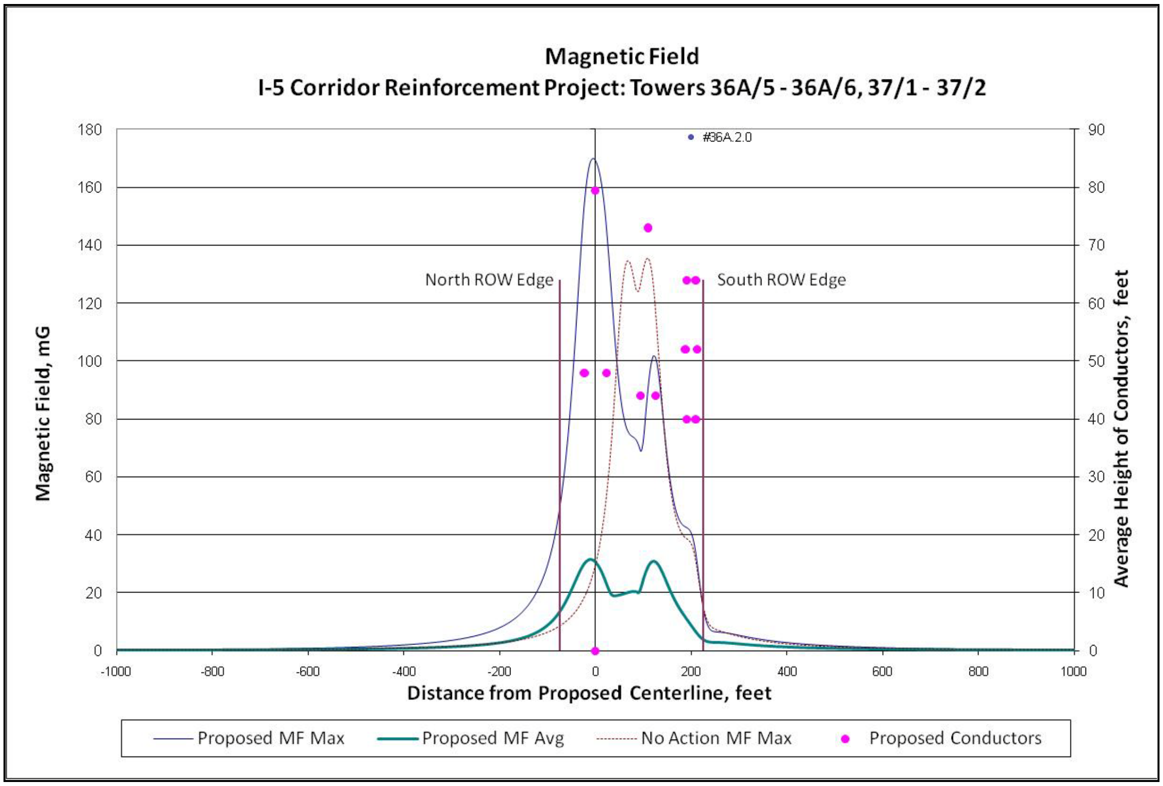

Figure 48: Calculation 36A.2.0 – Audible Noise Levels

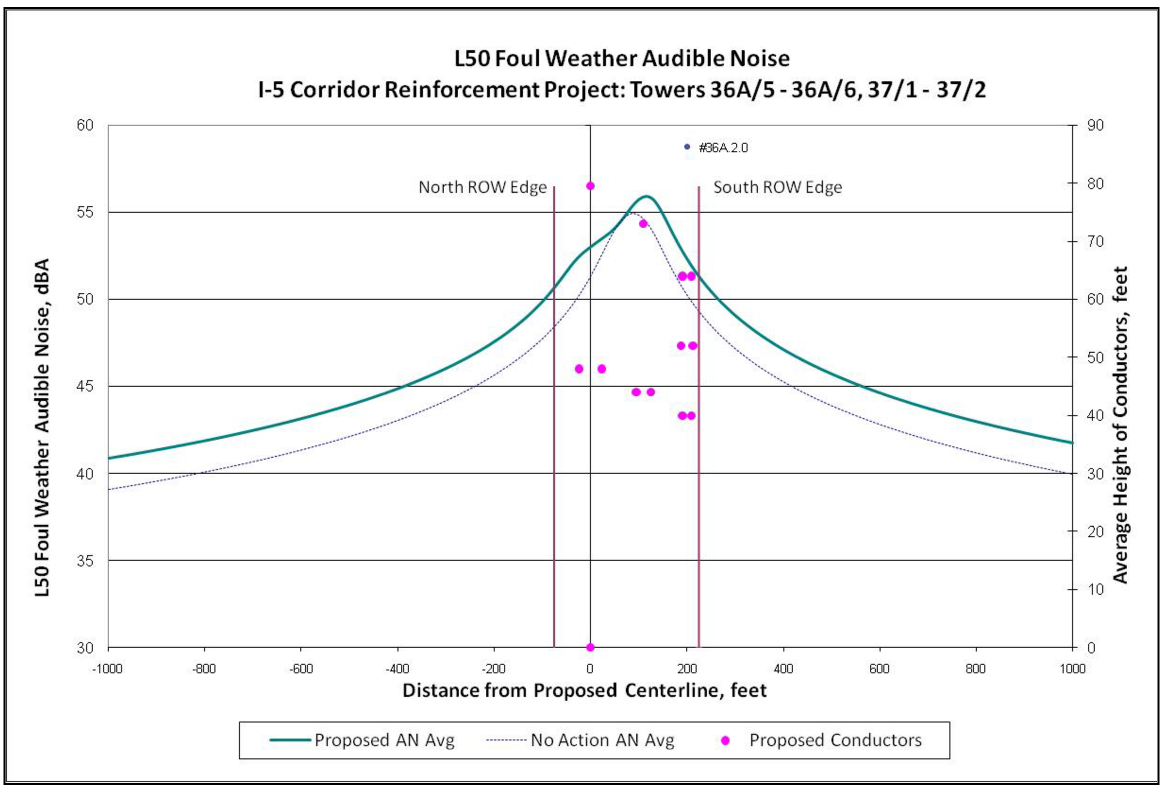

Table 23: Calculation 36B.1.0

Calculation 36B.1.0: Electrical Sections						
Segment	Towers	Length		Segment	Towers	Length
36B	36B/2 - 36B/7	1.04				

Calculation 36B.1.0: Summary of Fields and Corona Effects							
	ROW Status	Average			Maximum		
Location		North Edge	South Edge	Peak On ROW	North Edge	South Edge	Peak On ROW
Electric Field, kV/m	No Action	0.1	0.0	2.9	0.0	0.1	5.4
	Proposed	0.1	0.5	5.3	0.1	0.5	8.9
Magnetic Field, mG	No Action	2	1	49	4	2	136
	Proposed	3	5	46	5	14	181
Audible Noise, dBA Foul weather L50	No Action	46.6	44.5	Not Applicable			
	Proposed	47.2	47.3				
Fair Weather RI, dB(uV/m) @ 100 ft from conductors	No Action	37	30	Not Applicable			
	Proposed	37	36				
Foul Weather TVI, dB(uV/m) @ 100 ft from conductors	No Action	23	14	Not Applicable			
	Proposed	23	21				

Figure 49: Calculation 36B.1.0 – Electric Fields

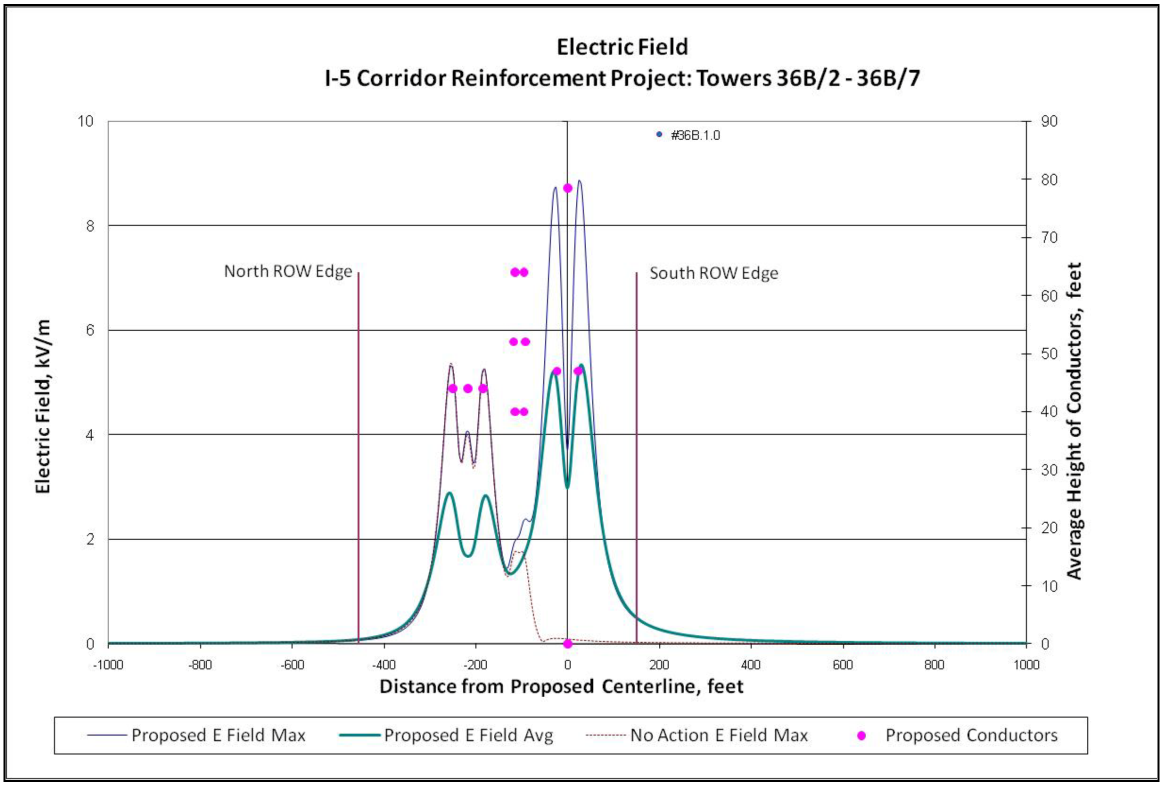

Figure 50: Calculation 36B.1.0 – Magnetic Fields

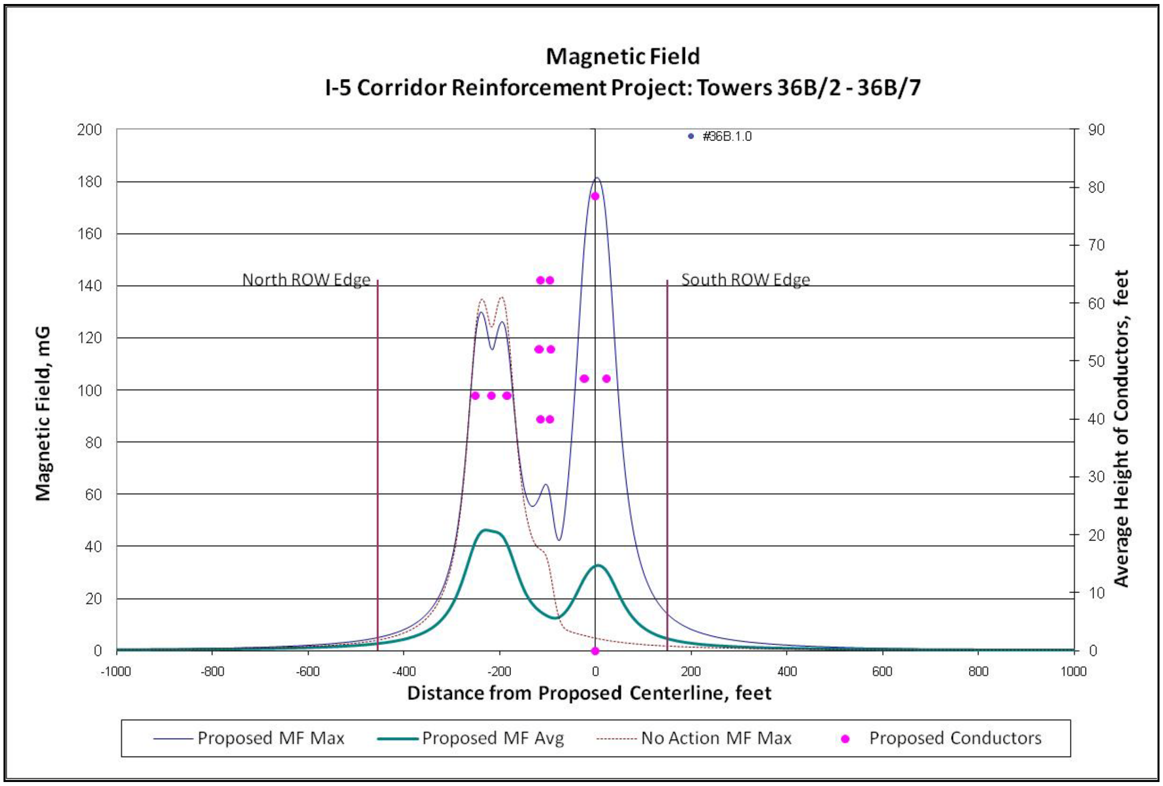

Figure 51: Calculation 36B.1.0 – Audible Noise Levels

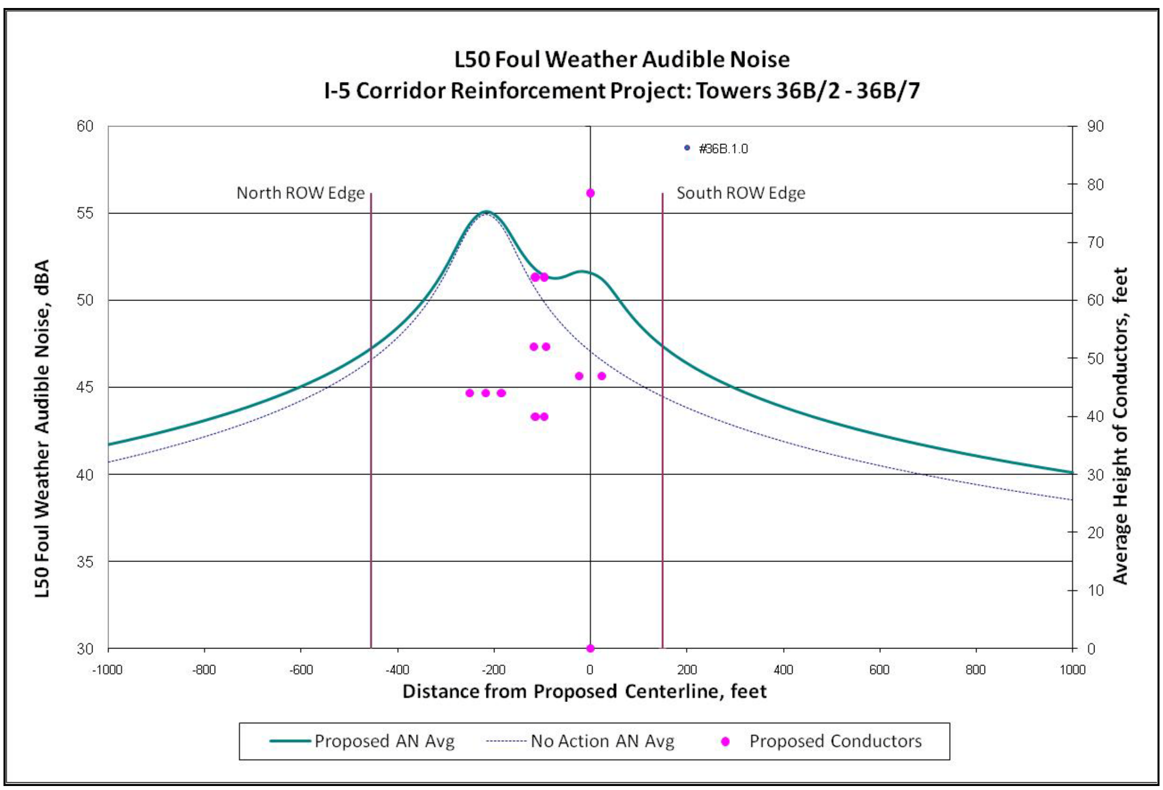

Table 24: Calculation 37.2.0

Calculation 37.2.0: Electrical Sections						
Segment	Towers	Length		Segment	Towers	Length
37	37/2 - 37/4	0.46		39	39/1 - 39/20	4.05
38	38/1 - 38/5	0.66				

Calculation 37.2.0: Summary of Fields and Corona Effects							
	ROW Status	Average			Maximum		
Location		North Edge	South Edge	Peak On ROW	North Edge	South Edge	Peak On ROW
Electric Field, kV/m	No Action	0.1	1.1	2.9	0.1	1.1	5.3
	Proposed	1.4	1.0	5.7	1.3	1.0	8.8
Magnetic Field, mG	No Action	3	16	49	5	30	136
	Proposed	11	17	46	35	36	158
Audible Noise, dBA Foul weather L50	No Action	47.1	51.3	Not Applicable			
	Proposed	49.1	51.5				
Fair Weather RI, dB(uV/m) @ 100 ft from conductors	No Action	37	37	Not Applicable			
	Proposed	36	38				
Foul Weather TVI, dB(uV/m) @ 100 ft from conductors	No Action	23	23	Not Applicable			
	Proposed	21	24				

Figure 52: Calculation 37.2.0 – Electric Fields

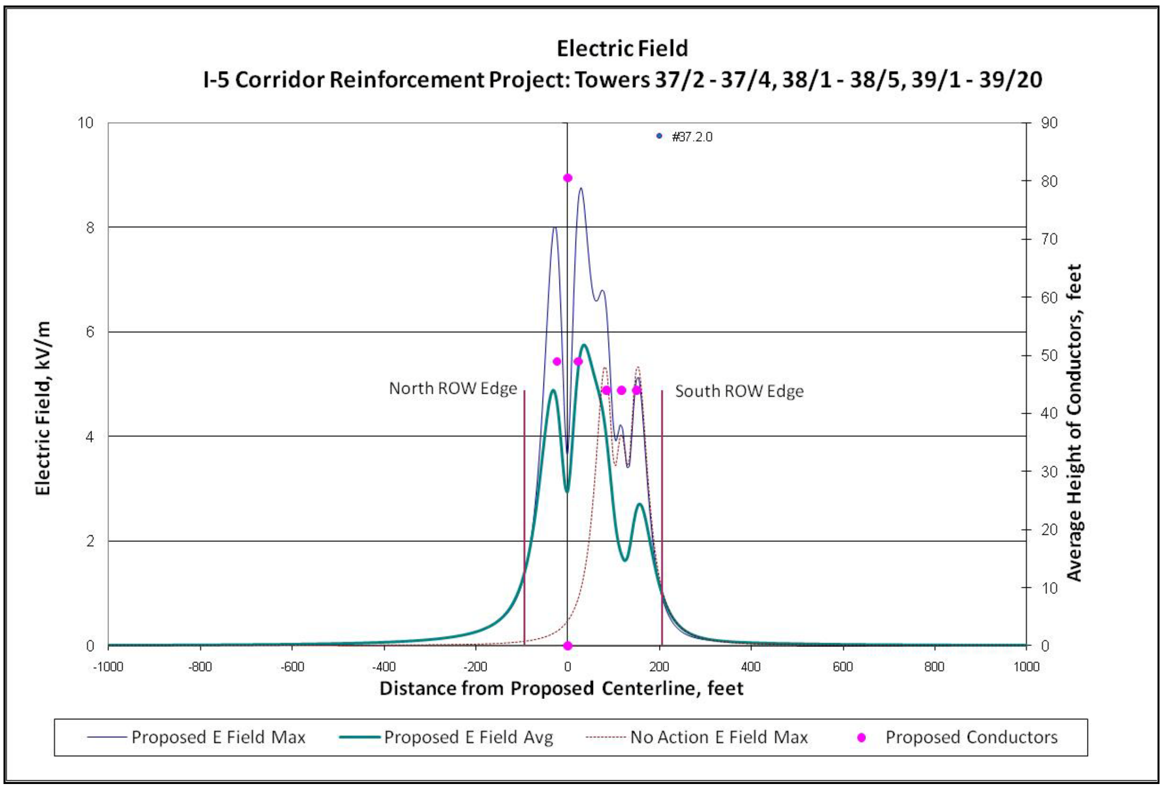

Figure 53: Calculation 37.2.0 – Magnetic Fields

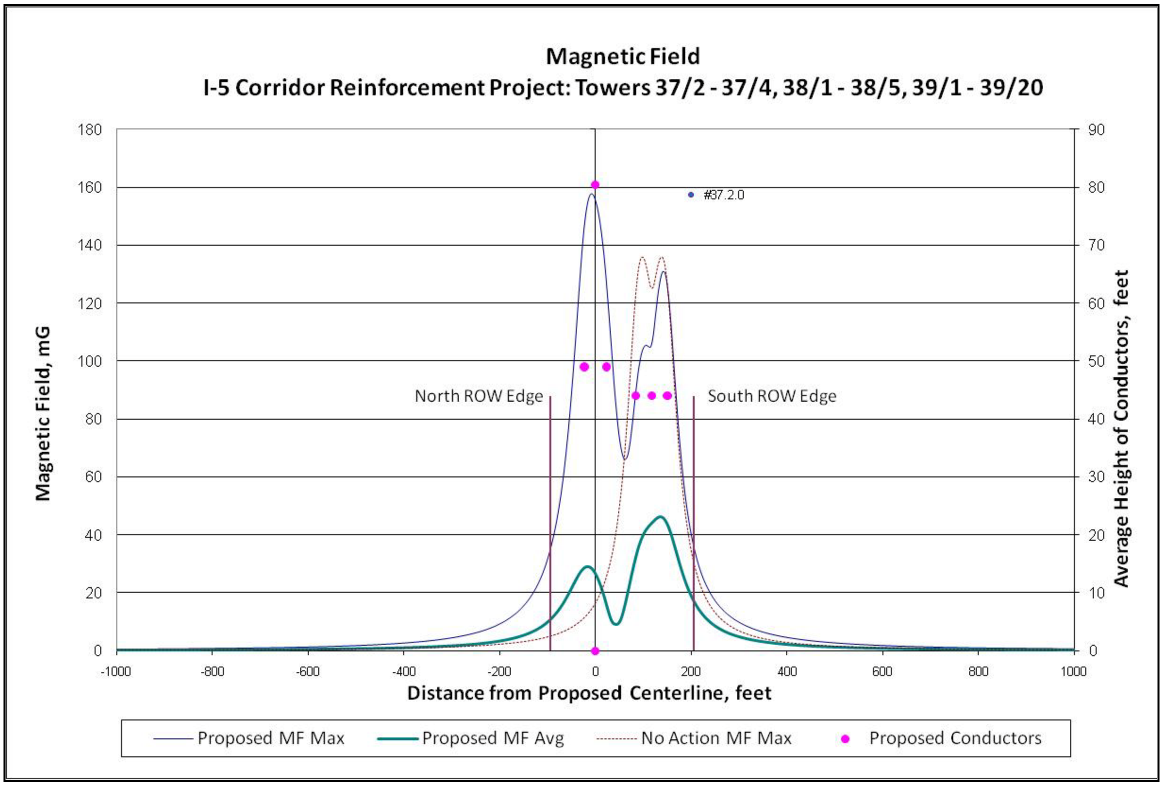

Figure 54: Calculation 37.2.0 – Audible Noise Levels

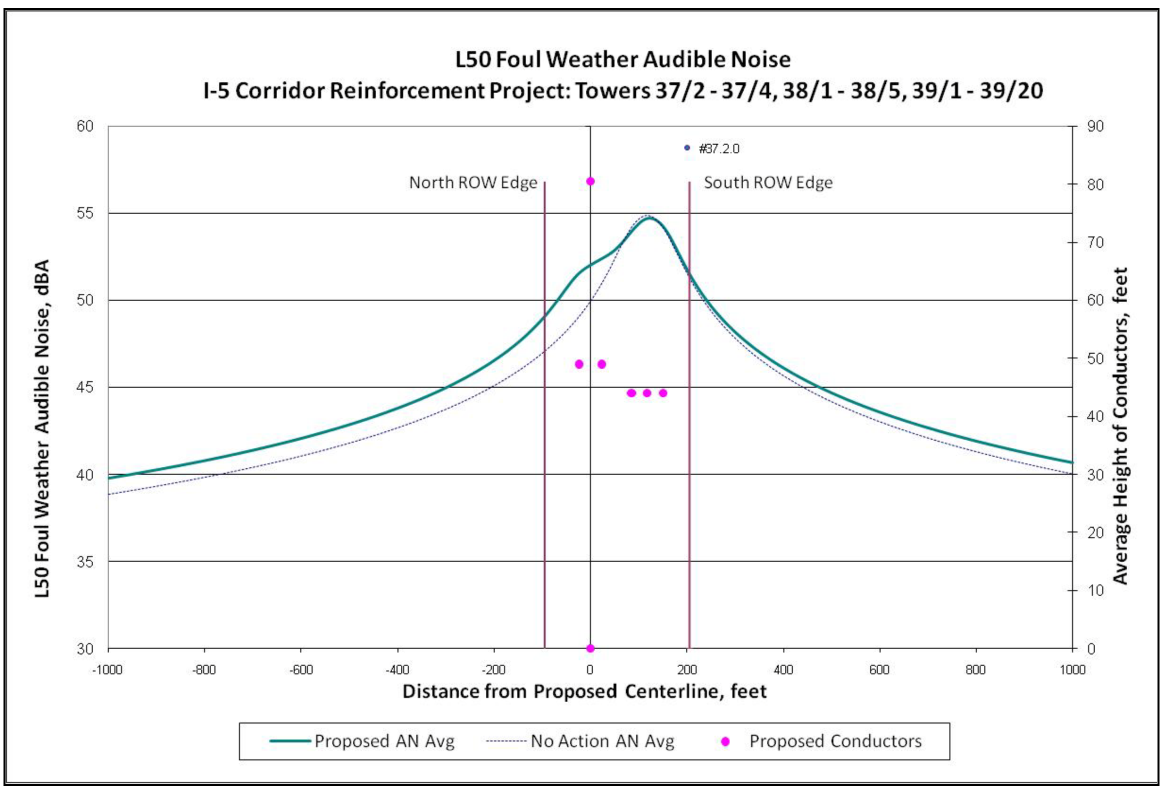

Table 25: Calculation 39.2.0

Calculation 39.2.0: Electrical Sections						
Segment	Towers	Length		Segment	Towers	Length
39	39/20 - 39/23	0.62				

Calculation 39.2.0: Summary of Fields and Corona Effects							
	ROW Status	Average			Maximum		
Location		North Edge	South Edge	Peak On ROW	North Edge	South Edge	Peak On ROW
Electric Field, kV/m	No Action	0.1	0.1	2.9	0.1	0.1	5.3
	Proposed	0.1	2.2	5.7	0.1	2.3	8.8
Magnetic Field, mG	No Action	3	4	49	5	6	136
	Proposed	4	15	46	7	51	158
Audible Noise, dBA Foul weather L50	No Action	47.1	47.6	Not Applicable			
	Proposed	47.5	49.8				
Fair Weather RI, dB(uV/m) @ 100 ft from conductors	No Action	37	37	Not Applicable			
	Proposed	38	36				
Foul Weather TVI, dB(uV/m) @ 100 ft from conductors	No Action	23	23	Not Applicable			
	Proposed	24	21				

Figure 55: Calculation 39.2.0 – Electric Fields

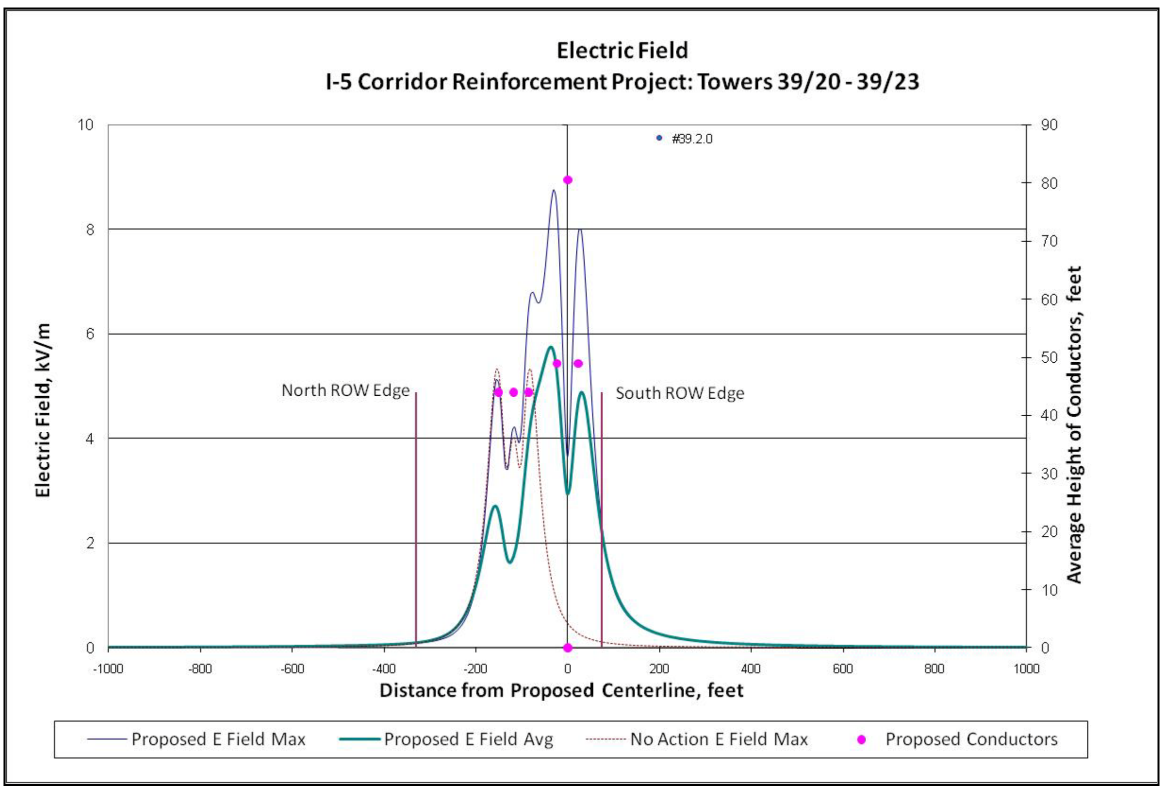

Figure 56: Calculation 39.2.0 – Magnetic Fields

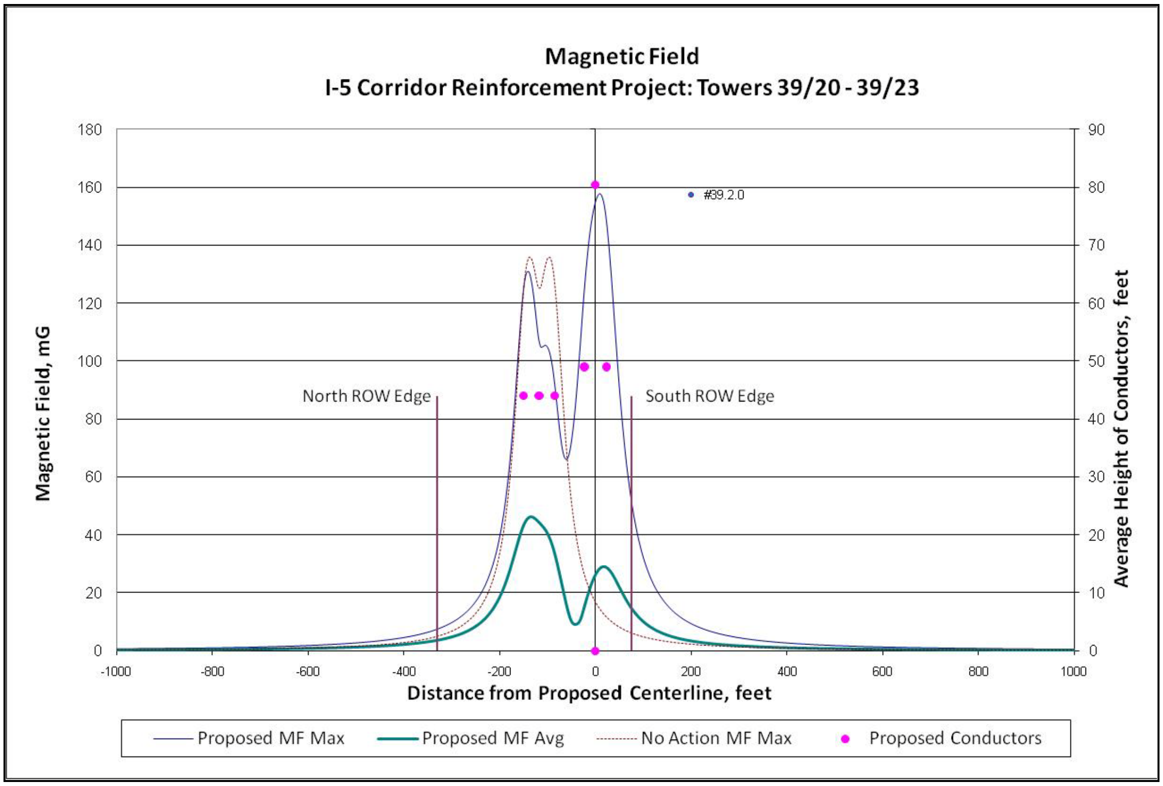

Figure 57: Calculation 39.2.0 – Audible Noise Levels

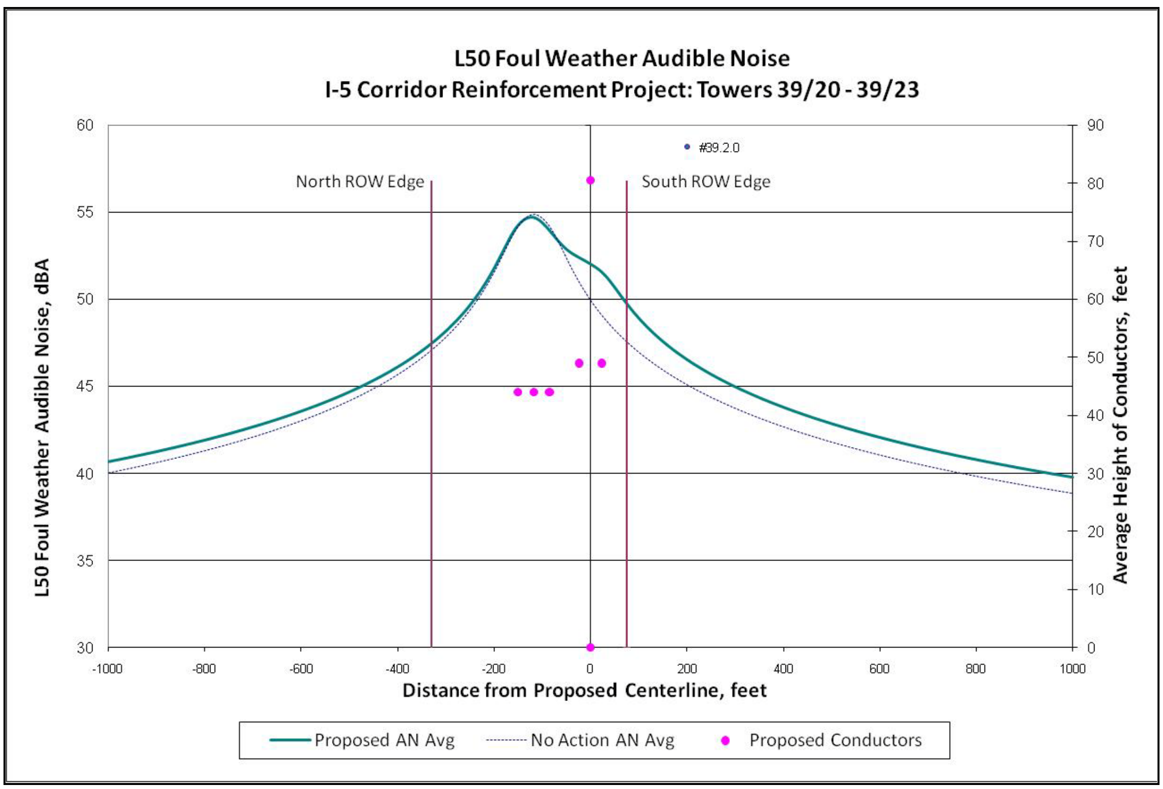

Table 26: Calculation 39.3.0

Calculation 39.3.0: Electrical Sections						
Segment	Towers	Length		Segment	Towers	Length
39	39/23 - 39/27	0.68				

Calculation 39.3.0: Summary of Fields and Corona Effects							
	ROW Status	Average			Maximum		
Location		North Edge	South Edge	Peak On ROW	North Edge	South Edge	Peak On ROW
Electric Field, kV/m	No Action	1.2	0.1	2.9	0.1	1.2	5.4
	Proposed	1.2	2.3	5.4	1.2	2.4	8.9
Magnetic Field, mG	No Action	16	2	51	31	6	142
	Proposed	16	13	49	32	49	174
Audible Noise, dBA Foul weather L50	No Action	51.4	45.6	Not Applicable			
	Proposed	51.7	49.5				
Fair Weather RI, dB(uV/m) @ 100 ft from conductors	No Action	37	29	Not Applicable			
	Proposed	37	36				
Foul Weather TVI, dB(uV/m) @ 100 ft from conductors	No Action	23	12	Not Applicable			
	Proposed	23	21				

Figure 58: Calculation 39.3.0 – Electric Fields

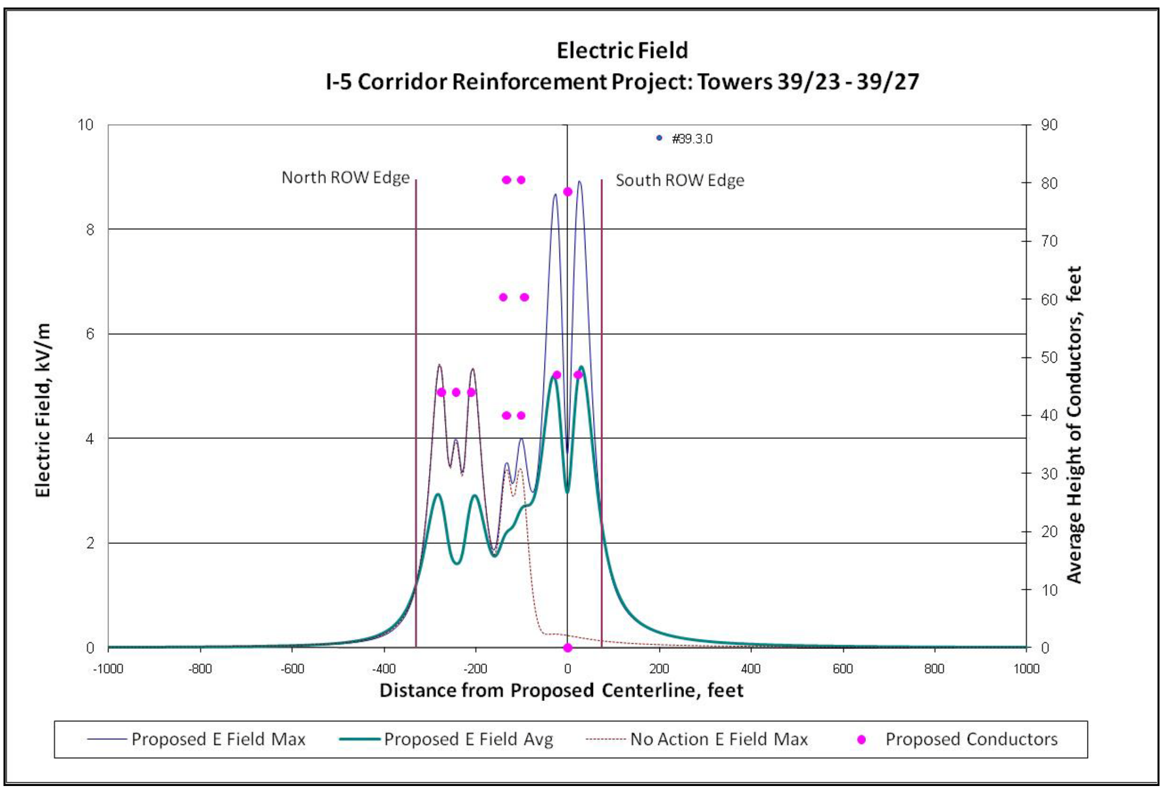

Figure 59: Calculation 39.3.0 – Magnetic Fields

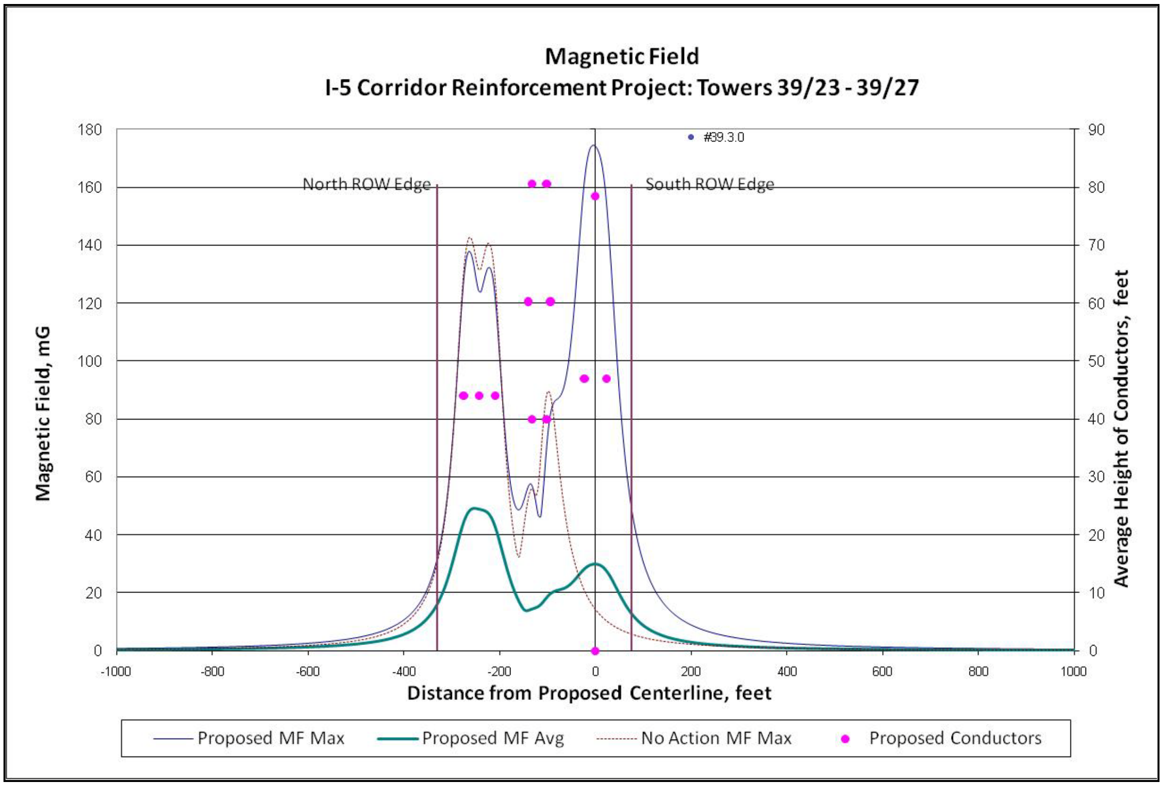

Figure 60: Calculation 39.3.0 – Audible Noise Levels

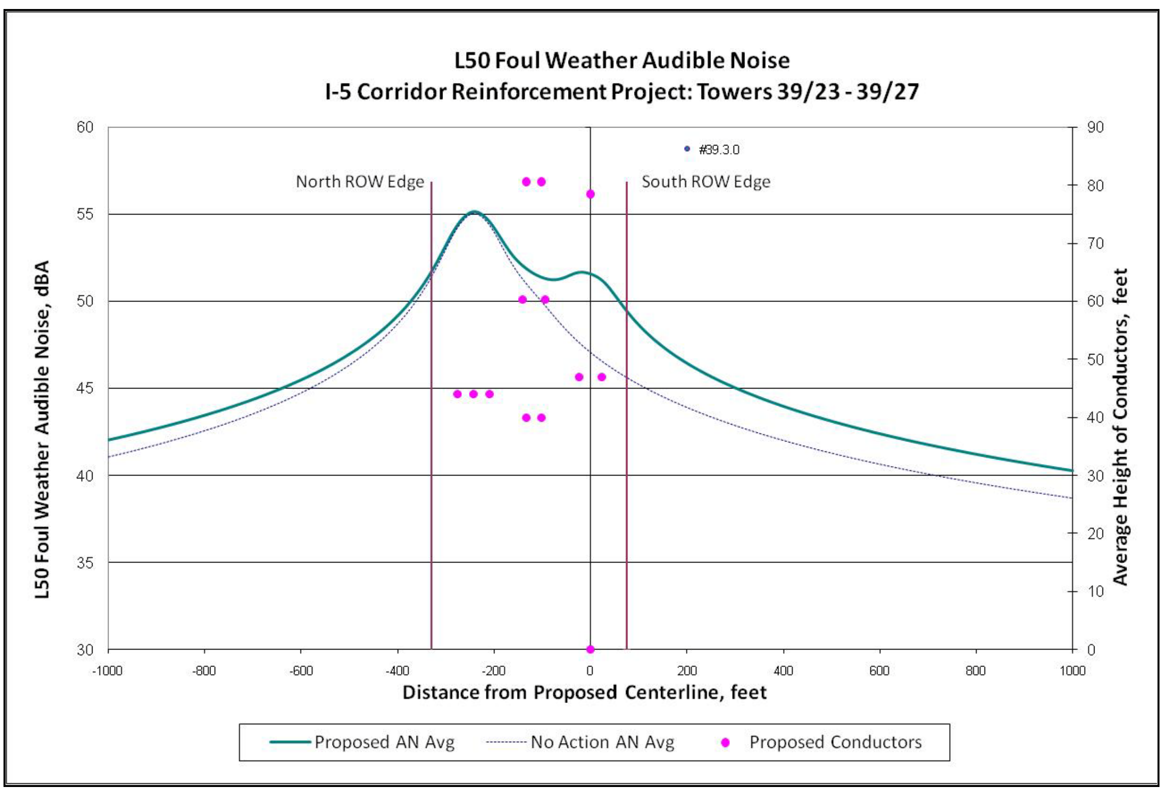

Table 27: Calculation 40.1.0

Calculation 40.1.0: Electrical Sections						
Segment	Towers	Length		Segment	Towers	Length
40	40/11 - 40/14	0.68		47	47/1 - 47/4	
43	43/9 - 43/10			48	48/1 - 48/14	
46	46/1 - 46/3					

Calculation 40.1.0: Summary of Fields and Corona Effects							
	ROW Status	Average			Maximum		
Location		North Edge	South Edge	Peak On ROW	North Edge	South Edge	Peak On ROW
Electric Field, kV/m	No Action	0.6	0.6	2.3	0.5	0.5	4.0
	Proposed	0.5	0.8	5.6	0.4	0.8	8.9
Magnetic Field, mG	No Action	4	3	19	13	13	94
	Proposed	6	13	28	19	50	139
Audible Noise, dBA Foul weather L50	No Action	39.8	39.8	Not Applicable			
	Proposed	43.8	47.1				
Fair Weather RI, dB(uV/m) @ 100 ft from conductors	No Action	26	26	Not Applicable			
	Proposed	30	40				
Foul Weather TVI, dB(uV/m) @ 100 ft from conductors	No Action	13	13	Not Applicable			
	Proposed	14	20				

Figure 61: Calculation 40.1.0 – Electric Fields

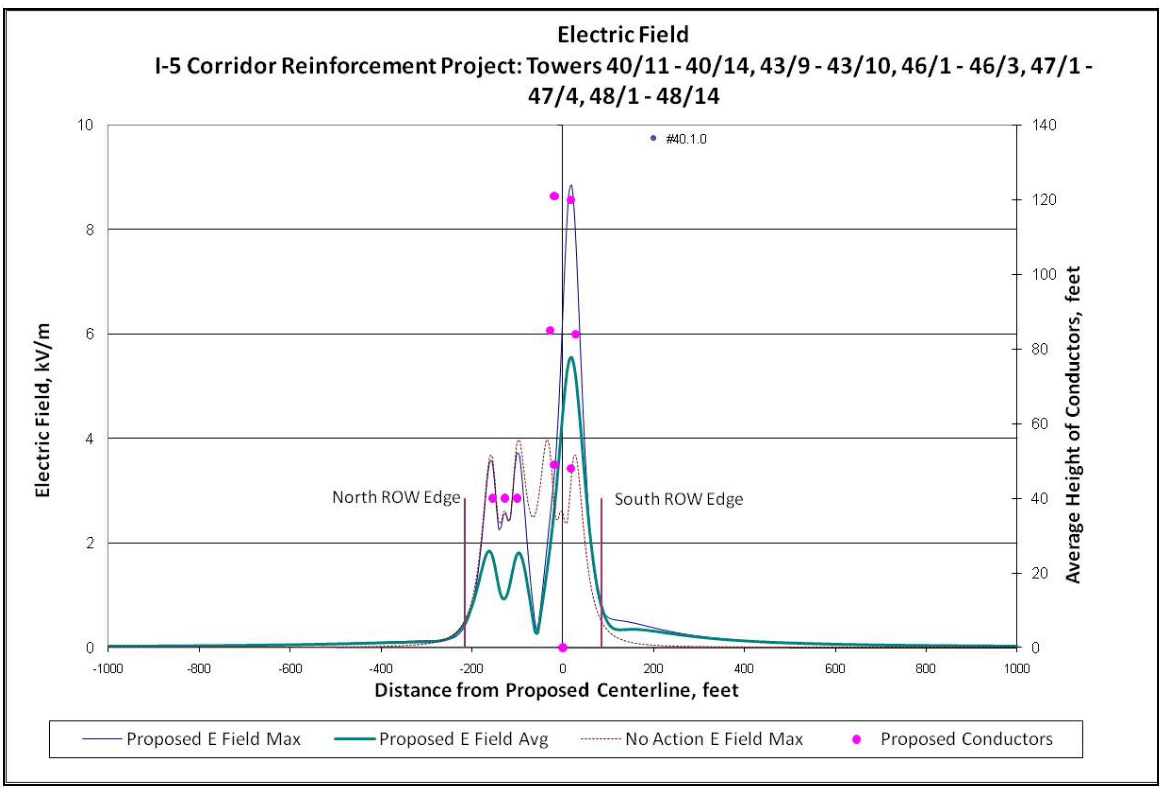

Figure 62: Calculation 40.1.0 – Magnetic Fields

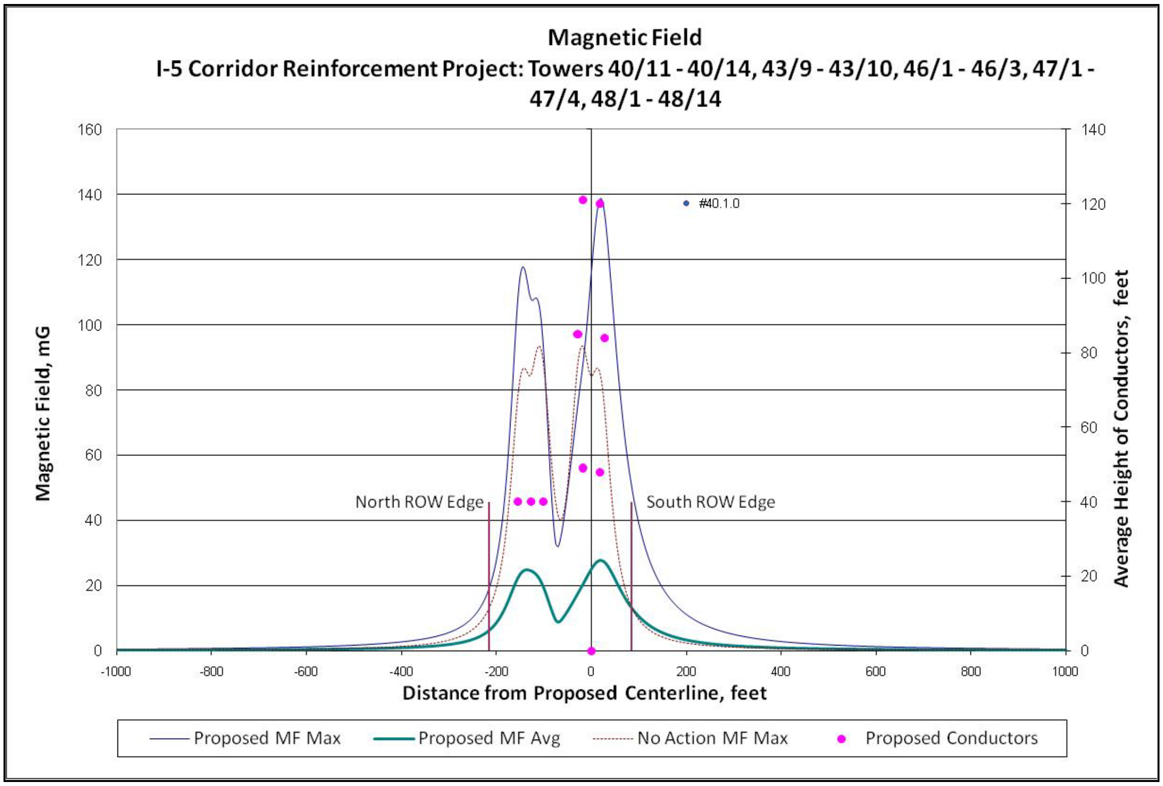

Figure 63: Calculation 40.1.0 – Audible Noise Levels

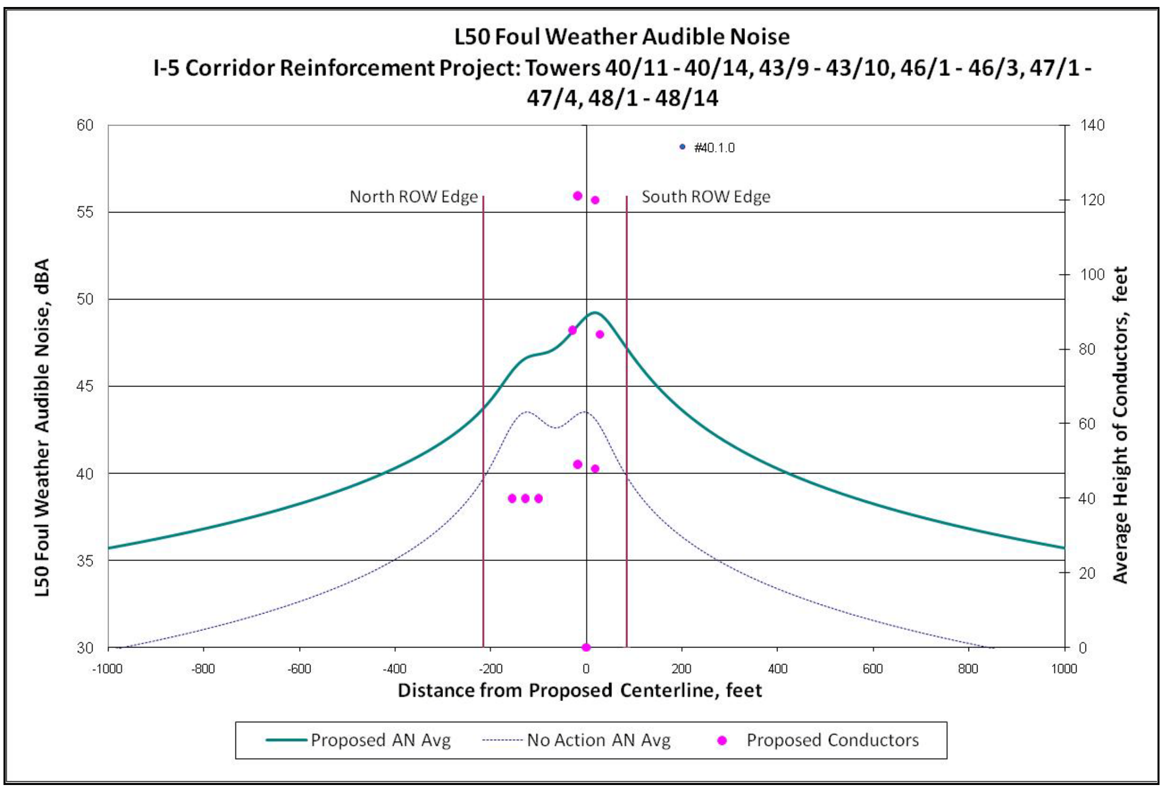

Table 28: Calculation 41.1.0

Calculation 41.1.0: Electrical Sections						
Segment	Towers	Length		Segment	Towers	Length
41	41/1 - 41/2	0.14		45	45/1 - 45/3	0.35
41	41/2 - 41/8	1.13		50	50/13 - 50/21	1.16

Calculation 41.1.0: Summary of Fields and Corona Effects							
	ROW Status	Average			Maximum		
Location		Northeast Edge	Southwest Edge	Peak On ROW	Northeast Edge	Southwest Edge	Peak On ROW
Electric Field, kV/m	No Action	0.1	0.1	0.8	0.1	0.1	1.6
	Proposed	0.1	1.3	5.6	0.4	1.2	8.8
Magnetic Field, mG	No Action	1	1	3	4	6	35
	Proposed	8	14	25	31	55	130
Audible Noise, dBA Foul weather L50	No Action	18.4	18.4	Not Applicable			
	Proposed	45.5	47.2				
Fair Weather RI, dB(uV/m) @ 100 ft from conductors	No Action	10	10	Not Applicable			
	Proposed	35	40				
Foul Weather TVI, dB(uV/m) @ 100 ft from conductors	No Action	-7	-7	Not Applicable			
	Proposed	16	20				

Figure 64: Calculation 41.1.0 – Electric Fields

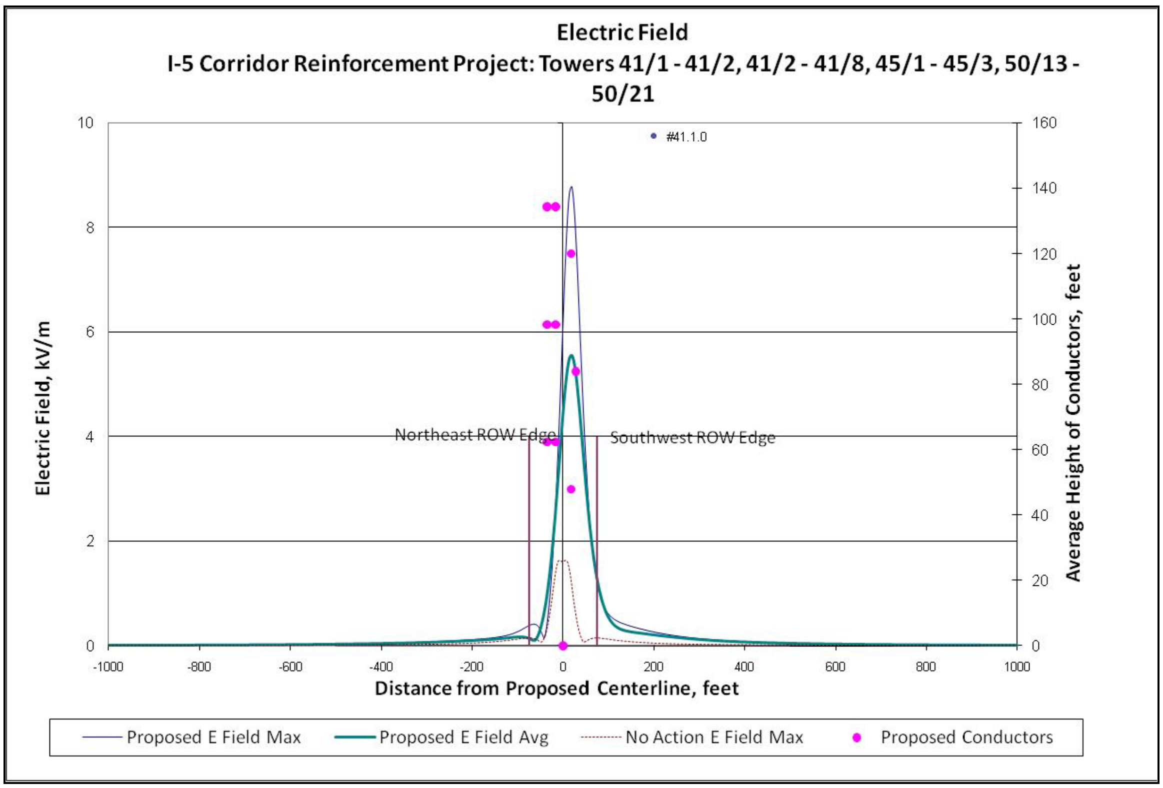

Figure 65: Calculation 41.1.0 – Magnetic Fields

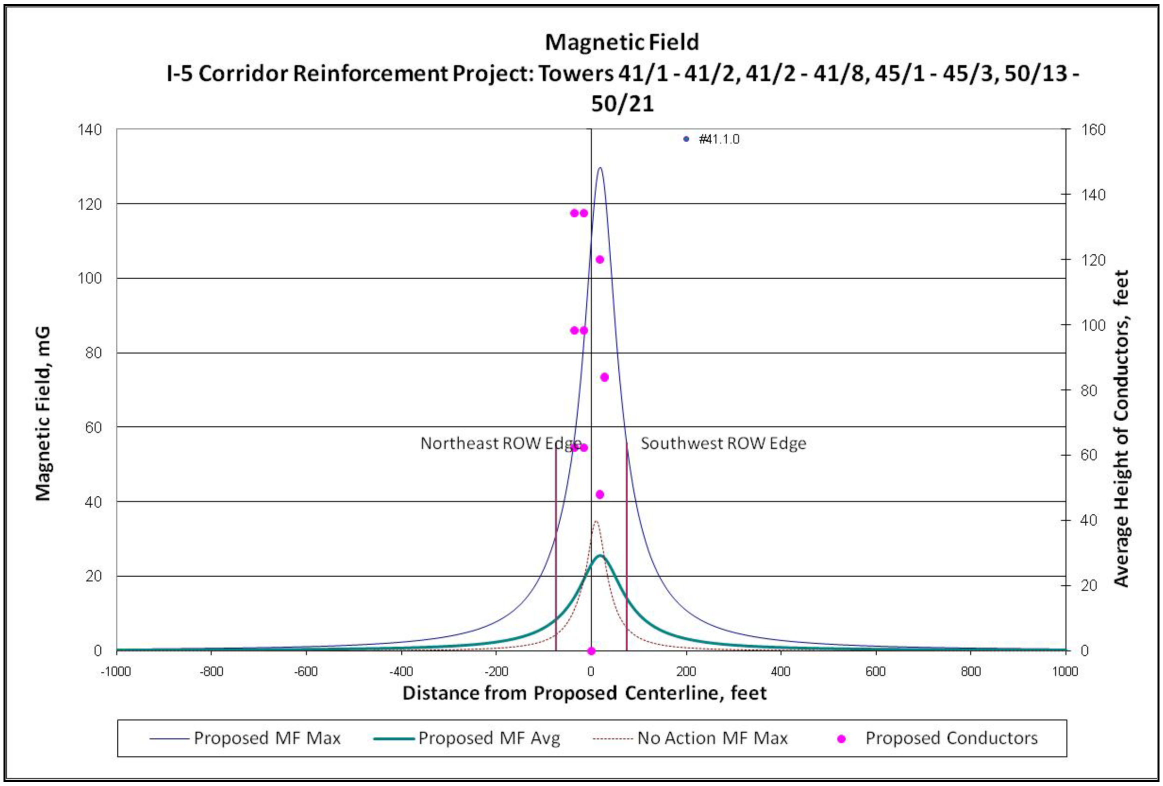

Figure 66: Calculation 41.1.0 – Audible Noise Levels

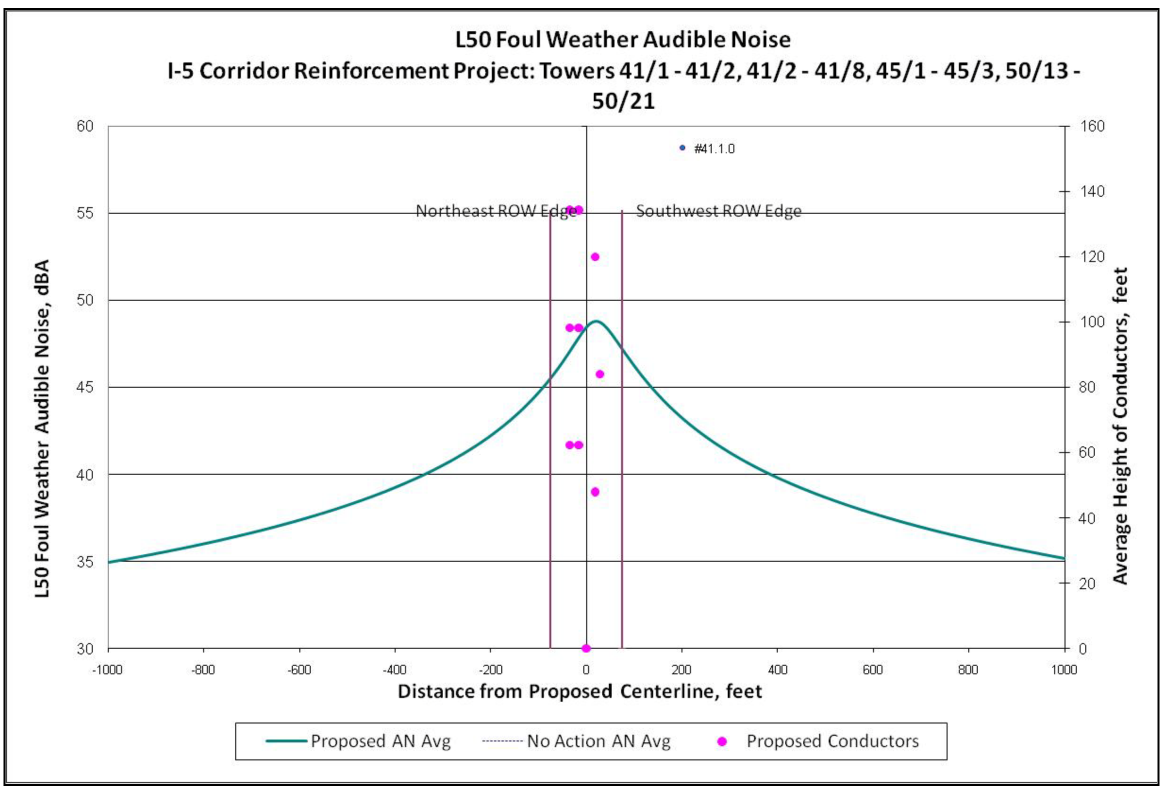

Table 29: Calculation 49.1.0

Calculation 49.1.0: Electrical Sections						
Segment	Towers	Length		Segment	Towers	Length
49	49/7 - 49/10	0.69				

Calculation 49.1.0: Summary of Fields and Corona Effects							
	ROW Status	Average			Maximum		
Location		South Edge	North Edge	Peak On ROW	South Edge	North Edge	Peak On ROW
Electric Field, kV/m	No Action	0.6	0.1	2.3	0.0	0.5	4.0
	Proposed	0.5	2.3	5.4	0.5	2.4	8.9
Magnetic Field, mG	No Action	7	1	33	21	3	141
	Proposed	6	13	33	18	50	178
Audible Noise, dBA Foul weather L50	No Action	39.8	36.6	Not Applicable			
	Proposed	43.4	47.6				
Fair Weather RI, dB(uV/m) @ 100 ft from conductors	No Action	26	26	Not Applicable			
	Proposed	26	36				
Foul Weather TVI, dB(uV/m) @ 100 ft from conductors	No Action	13	13	Not Applicable			
	Proposed	13	21				

Figure 67: Calculation 49.1.0 – Electric Fields

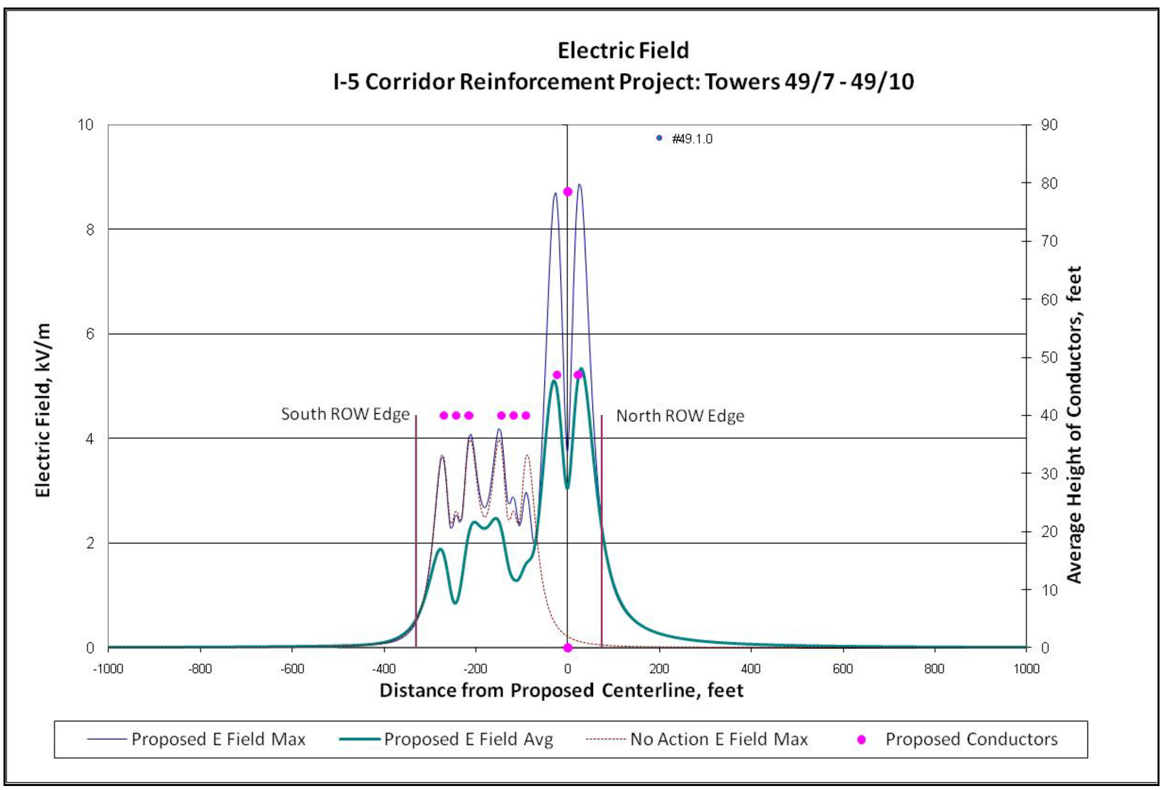

Figure 68: Calculation 49.1.0 – Magnetic Fields

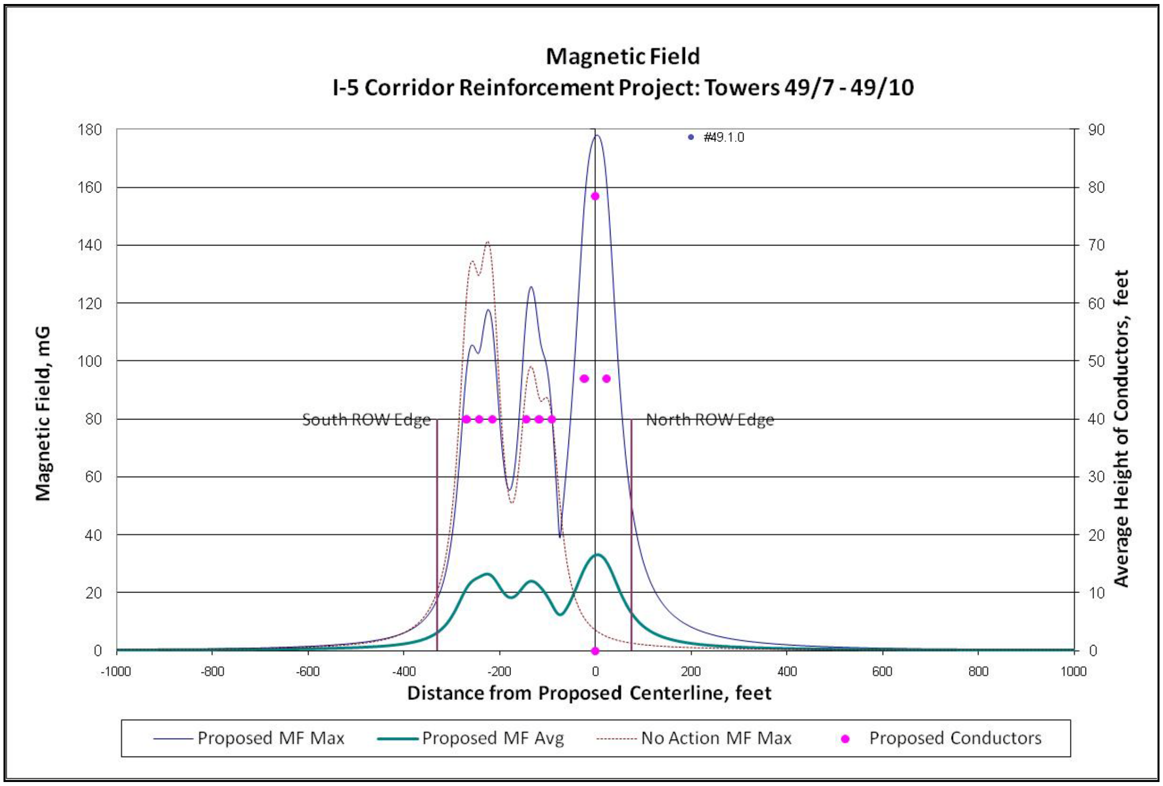

Figure 69: Calculation 49.1.0 – Audible Noise Levels

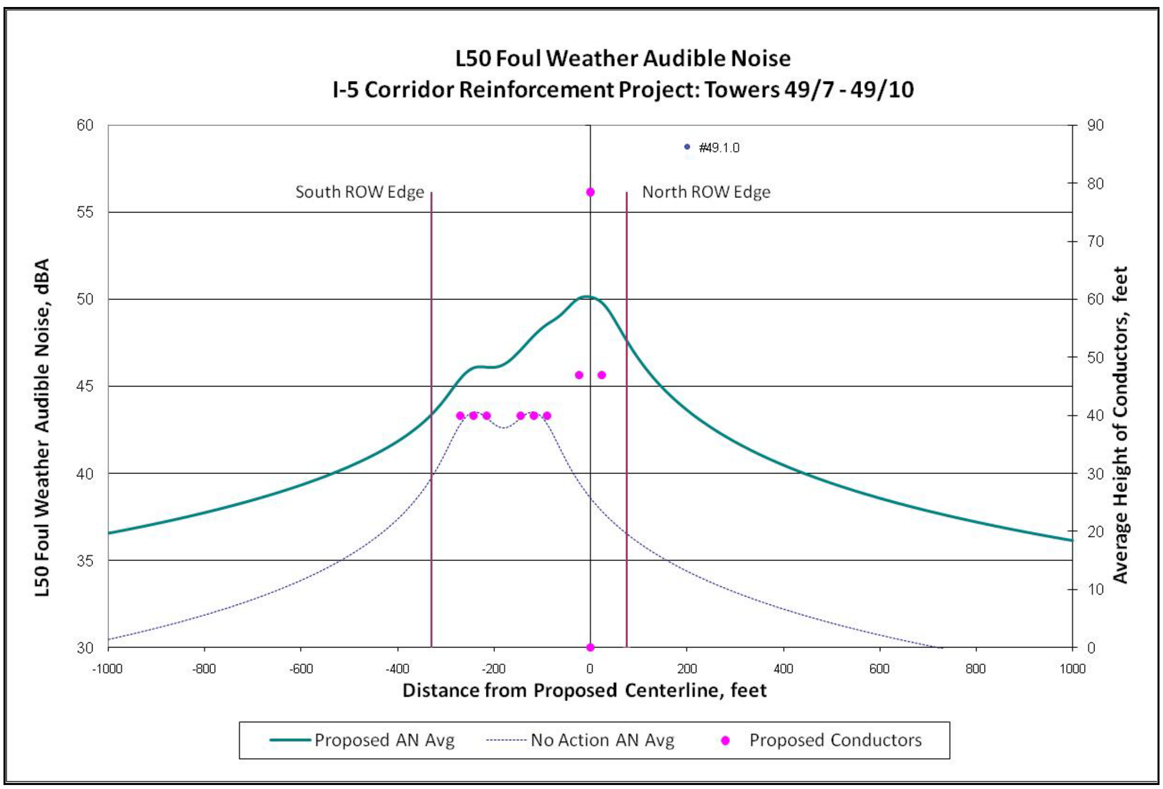

Table 30: Calculation 49.1.1

Calculation 49.1.1: Electrical Sections						
Segment	Towers	Length		Segment	Towers	Length
49	49/7 - 49/10	0.69				

Calculation 49.1.1: Summary of Fields and Corona Effects							
	ROW Status	Average			Maximum		
Location		South Edge	North Edge	Peak On ROW	South Edge	North Edge	Peak On ROW
Electric Field, kV/m	No Action	0.6	0.1	2.3	0.0	0.5	4.0
	Proposed	0.5	2.2	5.5	0.4	2.3	8.7
Magnetic Field, mG	No Action	7	1	33	21	3	141
	Proposed	5	11	35	15	45	183
Audible Noise, dBA Foul weather L50	No Action	39.8	36.6	Not Applicable			
	Proposed	43.1	47.3				
Fair Weather RI, dB(uV/m) @ 100 ft from conductors	No Action	26	26	Not Applicable			
	Proposed	26	36				
Foul Weather TVI, dB(uV/m) @ 100 ft from conductors	No Action	13	13	Not Applicable			
	Proposed	14	21				

Figure 70: Calculation 49.1.1 – Electric Fields

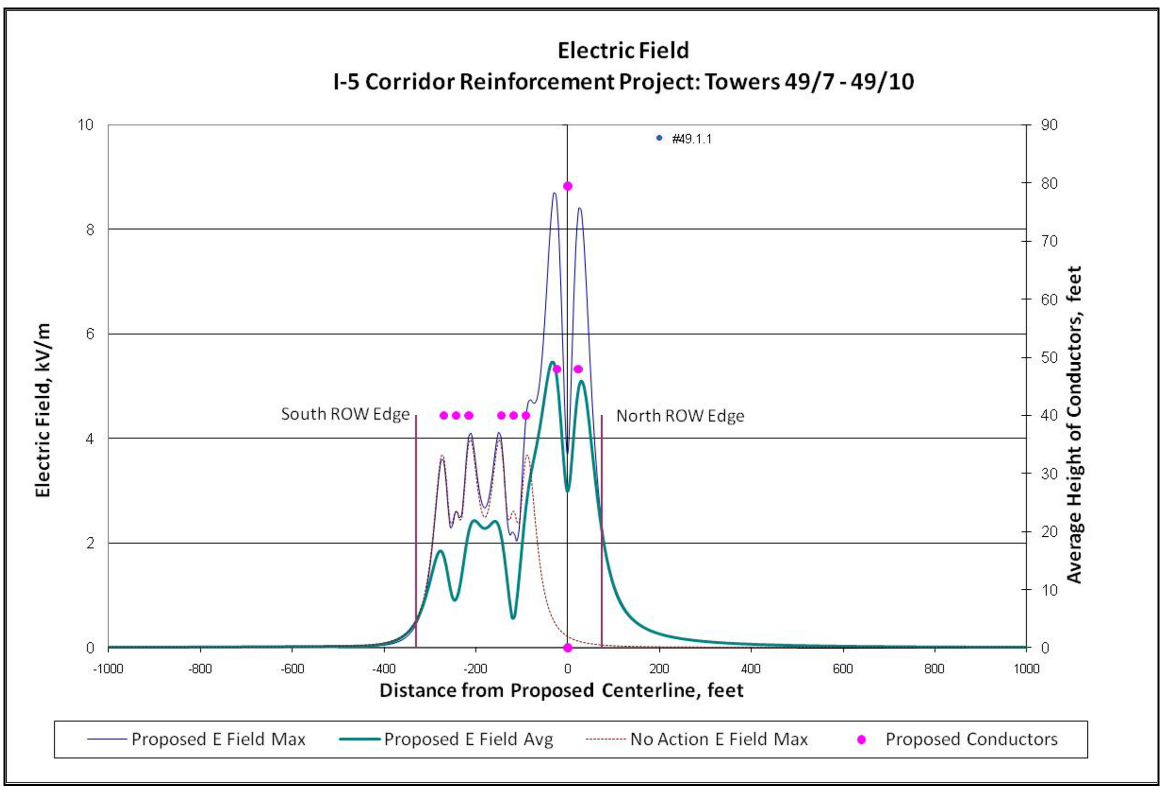

Figure 71: Calculation 49.1.1 – Magnetic Fields

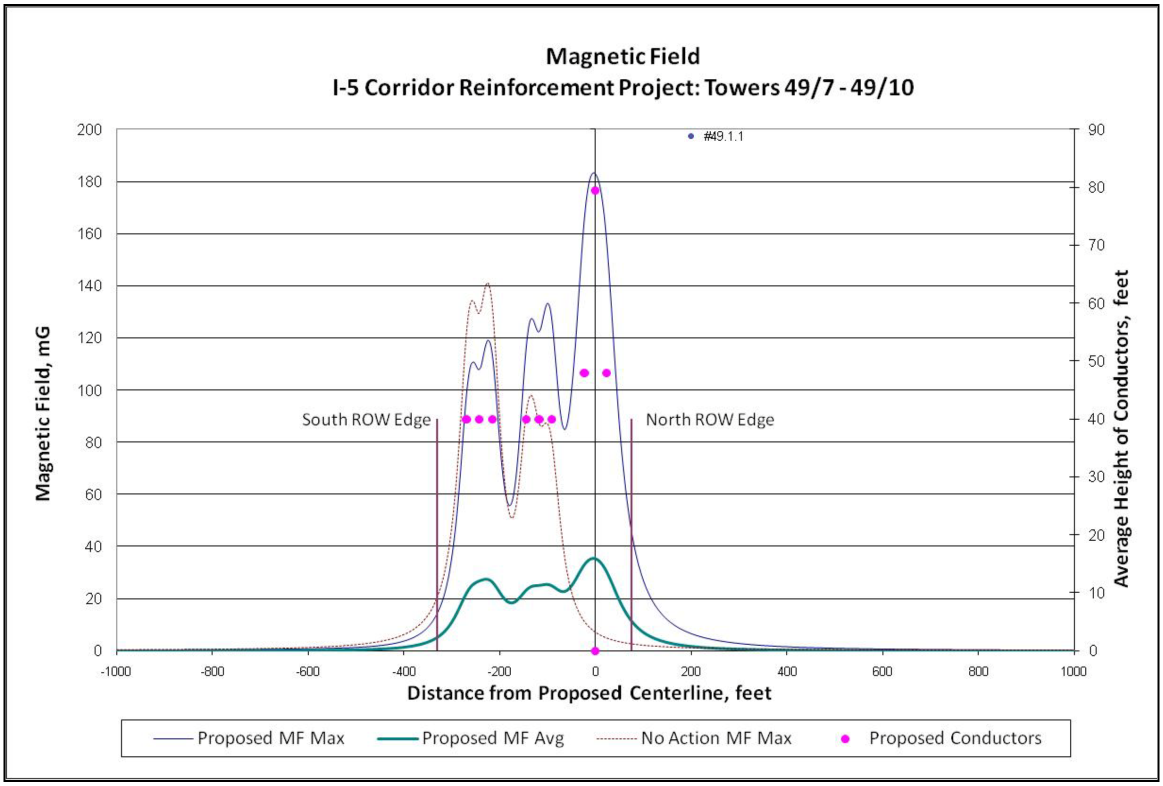

Figure 72: Calculation 49.1.1 – Audible Noise Levels

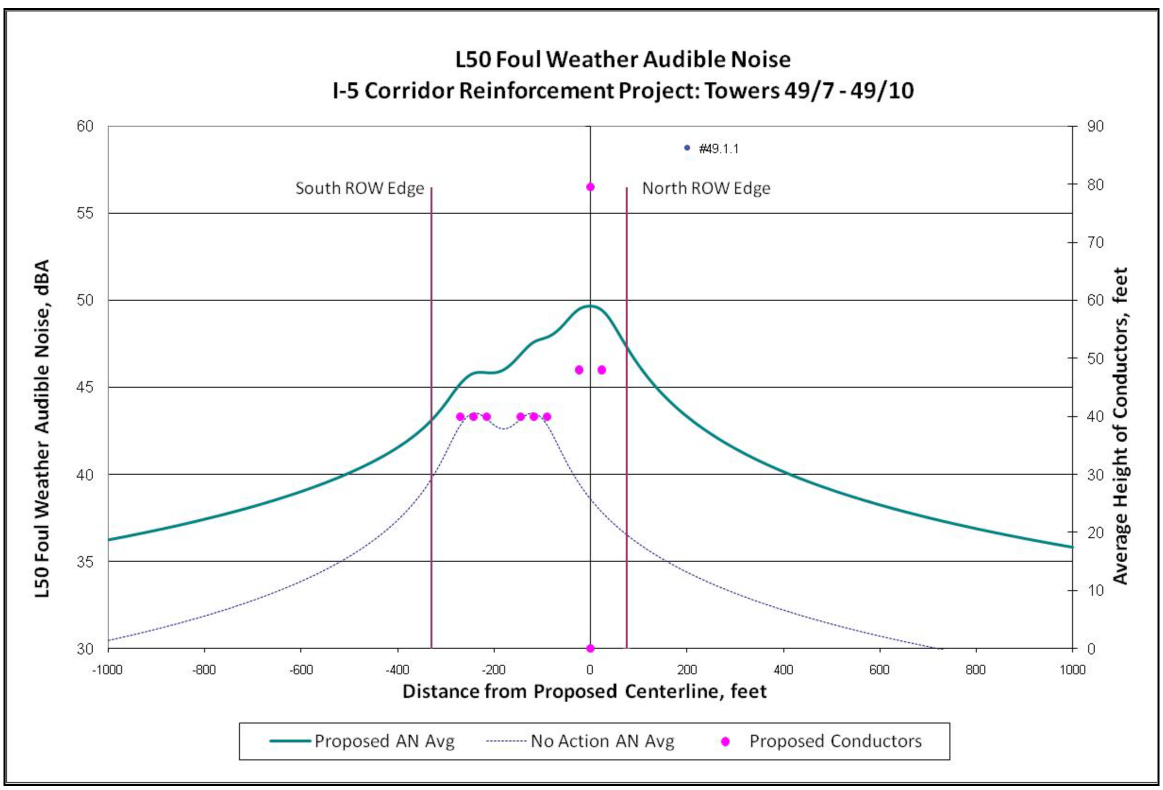

Table 31: Calculation 49.2.0

Calculation 49.2.0: Electrical Sections						
Segment	Towers	Length		Segment	Towers	Length
49	49/10 - 49/15	0.80				

Calculation 49.2.0: Summary of Fields and Corona Effects							
	ROW Status	Average			Maximum		
Location		South Edge	North Edge	Peak On ROW	South Edge	North Edge	Peak On ROW
Electric Field, kV/m	No Action	0.6	0.6	2.3	0.5	0.5	4.0
	Proposed	0.5	0.9	5.6	0.4	0.9	8.9
Magnetic Field, mG	No Action	7	3	33	21	13	141
	Proposed	7	13	26	20	51	133
Audible Noise, dBA Foul weather L50	No Action	39.8	39.8	Not Applicable			
	Proposed	43.7	47.2				
Fair Weather RI, dB(uV/m) @ 100 ft from conductors	No Action	26	26	Not Applicable			
	Proposed	30	40				
Foul Weather TVI, dB(uV/m) @ 100 ft from conductors	No Action	13	13	Not Applicable			
	Proposed	14	20				

Figure 73: Calculation 49.2.0 – Electric Fields

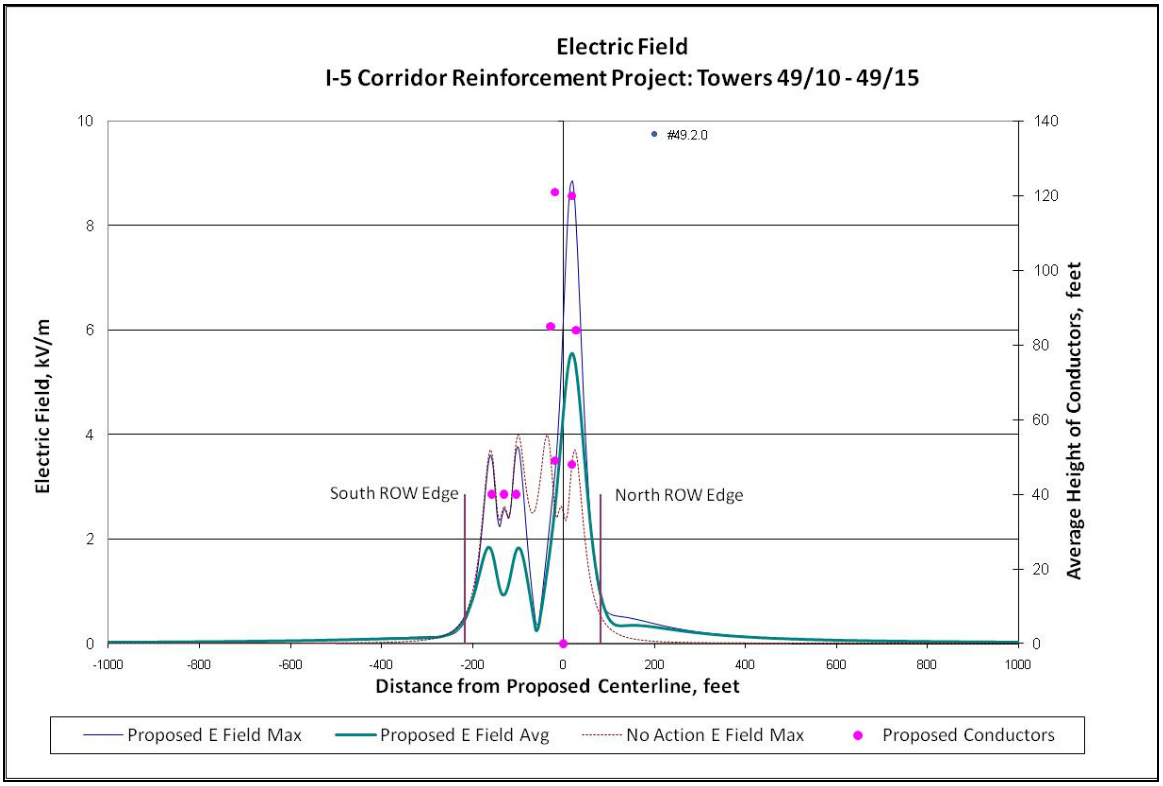

Figure 74: Calculation 49.2.0 – Magnetic Fields

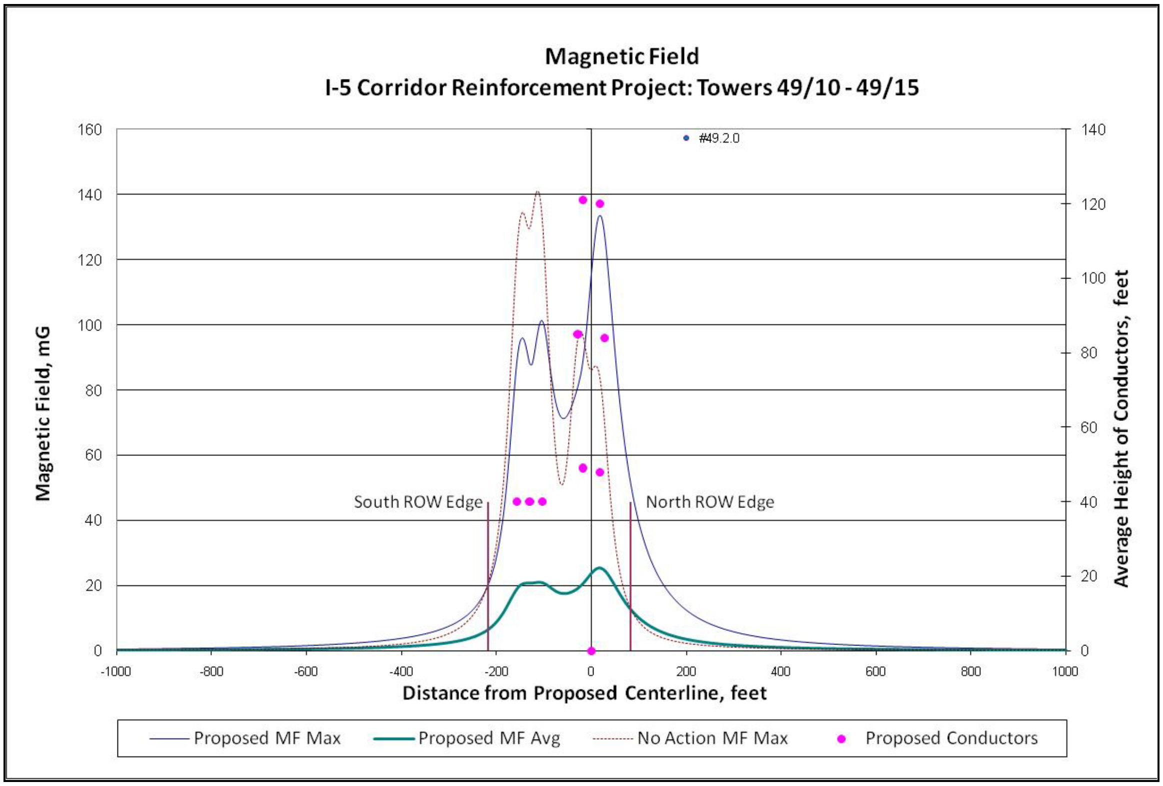

Figure 75: Calculation 49.2.0 – Audible Noise Levels

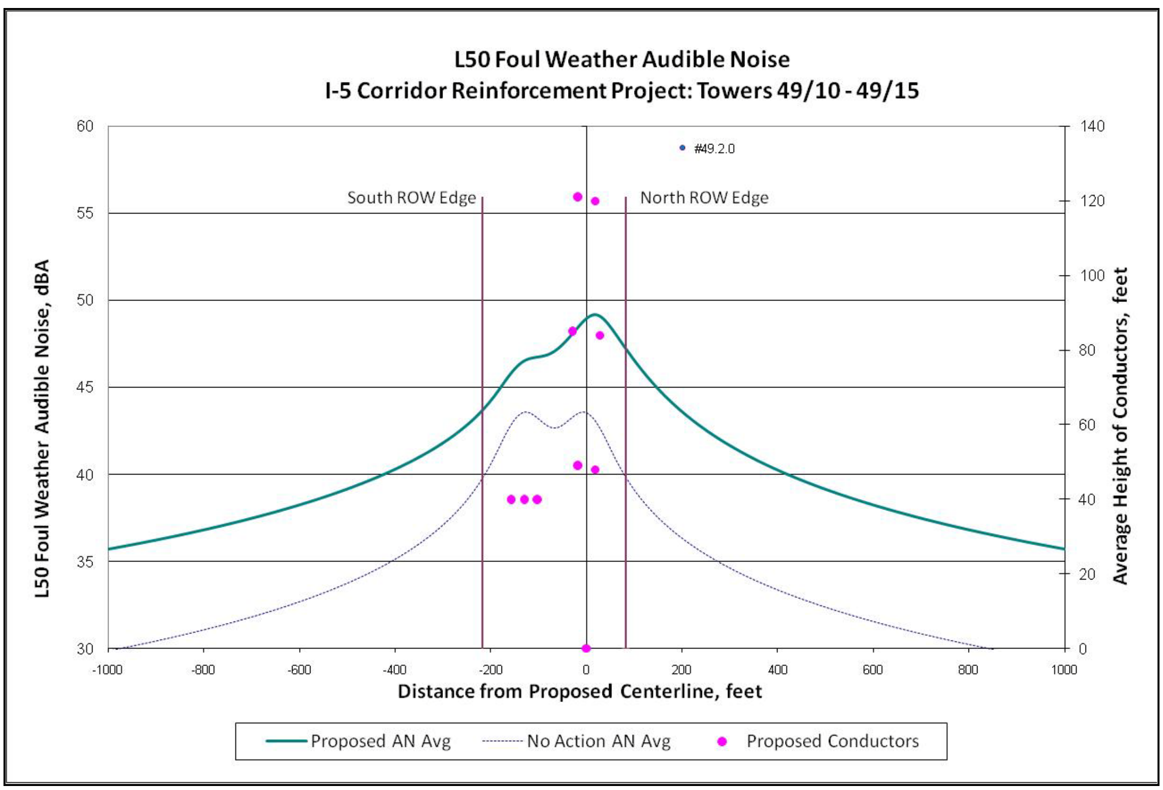

Table 32: Calculation 49.2.1

Calculation 49.2.1: Electrical Sections						
Segment	Towers	Length		Segment	Towers	Length
49	49/10 - 49/15	0.80				

Calculation 49.2.1: Summary of Fields and Corona Effects							
	ROW Status	Average			Maximum		
Location		South Edge	North Edge	Peak On ROW	South Edge	North Edge	Peak On ROW
Electric Field, kV/m	No Action	0.6	0.6	2.3	0.5	0.5	4.0
	Proposed	0.6	0.9	5.9	0.5	0.9	8.8
Magnetic Field, mG	No Action	7	3	33	21	13	141
	Proposed	6	15	28	19	59	136
Audible Noise, dBA Foul weather L50	No Action	39.8	39.8	Not Applicable			
	Proposed	43.0	46.1				
Fair Weather RI, dB(uV/m) @ 100 ft from conductors	No Action	26	26	Not Applicable			
	Proposed	30	40				
Foul Weather TVI, dB(uV/m) @ 100 ft from conductors	No Action	13	13	Not Applicable			
	Proposed	13	18				

Figure 76: Calculation 49.2.1 – Electric Fields

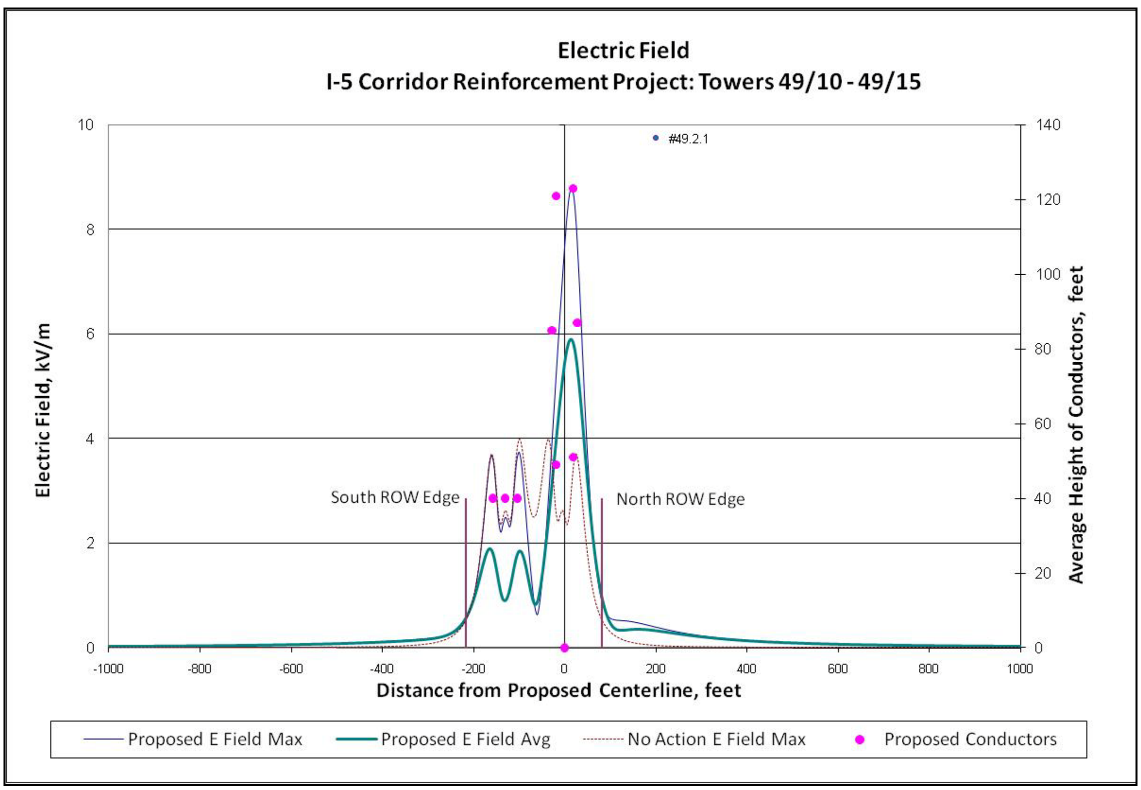

Figure 77: Calculation 49.2.1 – Magnetic Fields

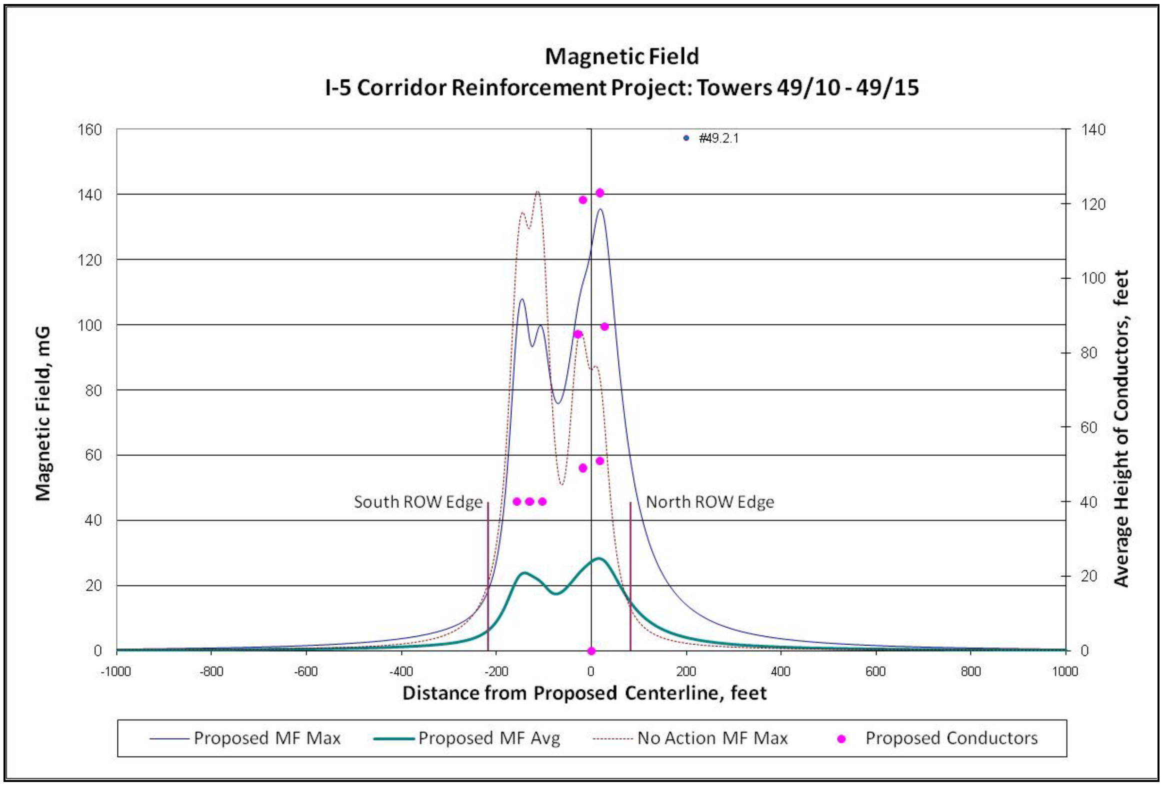

Figure 78: Calculation 49.2.1 – Audible Noise Levels

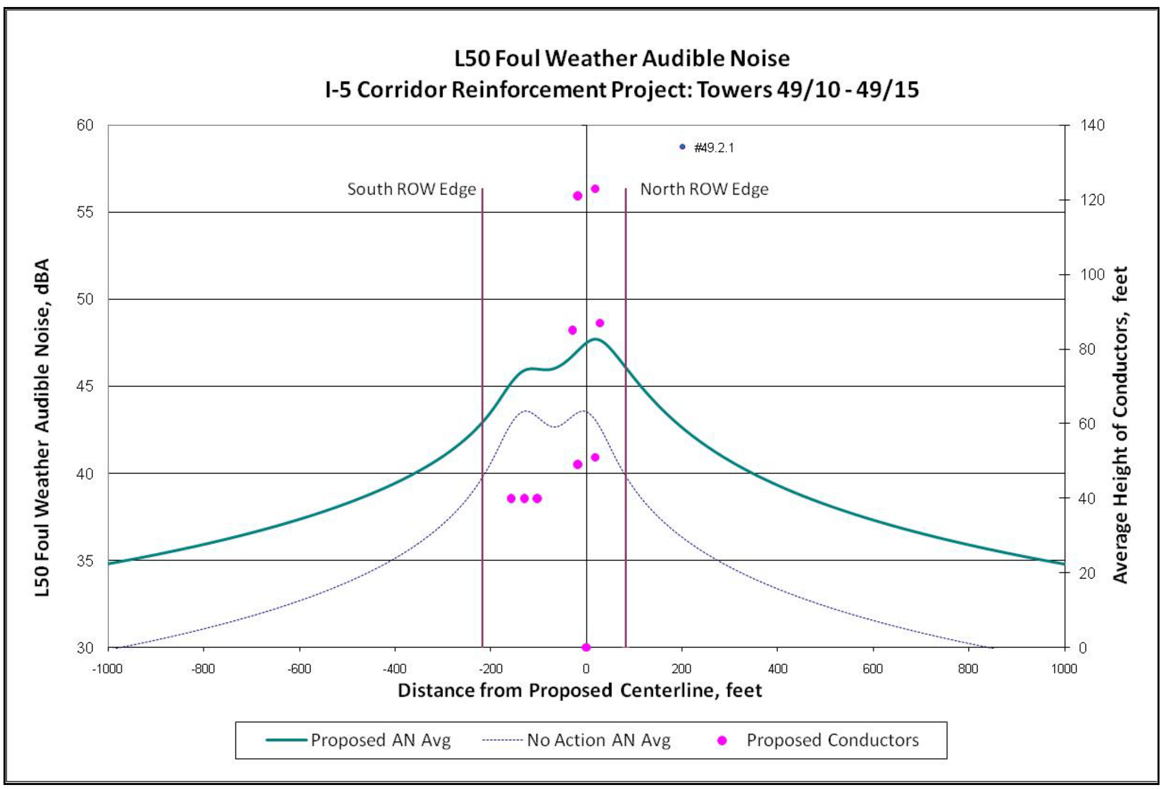

Table 33: Calculation 50.1.0

Calculation 50.1.0: Electrical Sections						
Segment	Towers	Length		Segment	Towers	Length
50	50/5 - 50/13	1.46				
50	50/21 - 50/26	0.80				

Calculation 50.1.0: Summary of Fields and Corona Effects							
	ROW Status	Average			Maximum		
Location		North Edge	South Edge	Peak On ROW	North Edge	South Edge	Peak On ROW
Electric Field, kV/m	No Action	0.1	0.0	0.8	0.1	0.1	1.6
	Proposed	0.3	2.3	5.3	0.2	2.4	8.9
Magnetic Field, mG	No Action	1	0	3	8	1	35
	Proposed	3	12	35	12	48	185
Audible Noise, dBA Foul weather L50	No Action	19.8	14.6	Not Applicable			
	Proposed	44.2	47.2				
Fair Weather RI, dB(uV/m) @ 100 ft from conductors	No Action	10	10	Not Applicable			
	Proposed	30	36				
Foul Weather TVI, dB(uV/m) @ 100 ft from conductors	No Action	-7	-7	Not Applicable			
	Proposed	12	21				

Figure 79: Calculation 50.1.0 – Electric Fields

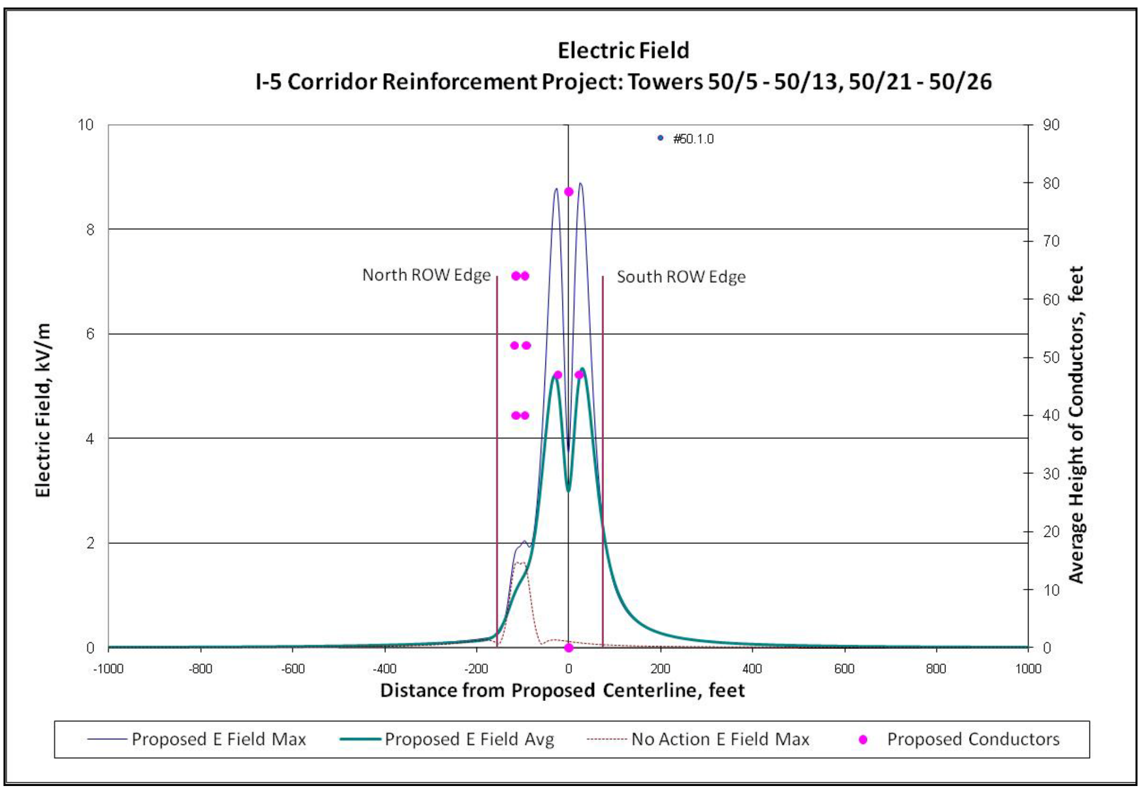

Figure 80: Calculation 50.1.0 – Magnetic Fields

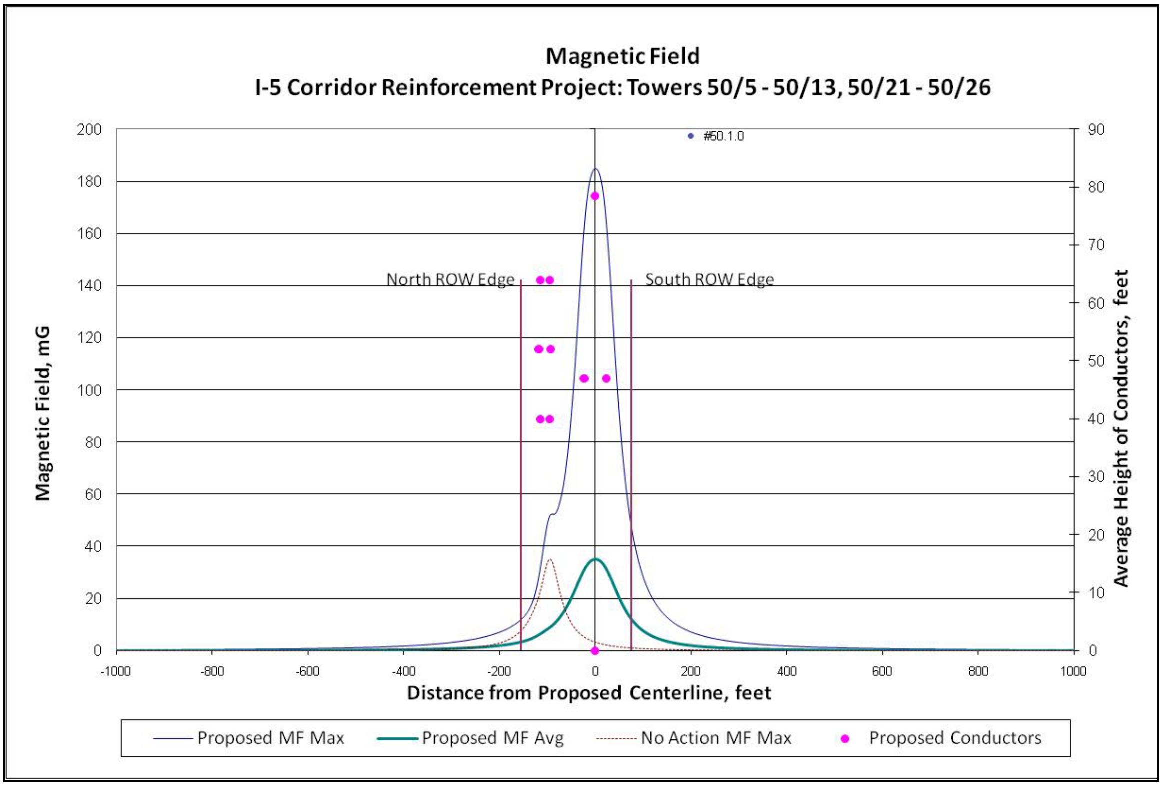

Figure 81: Calculation 50.1.0 – Audible Noise Levels

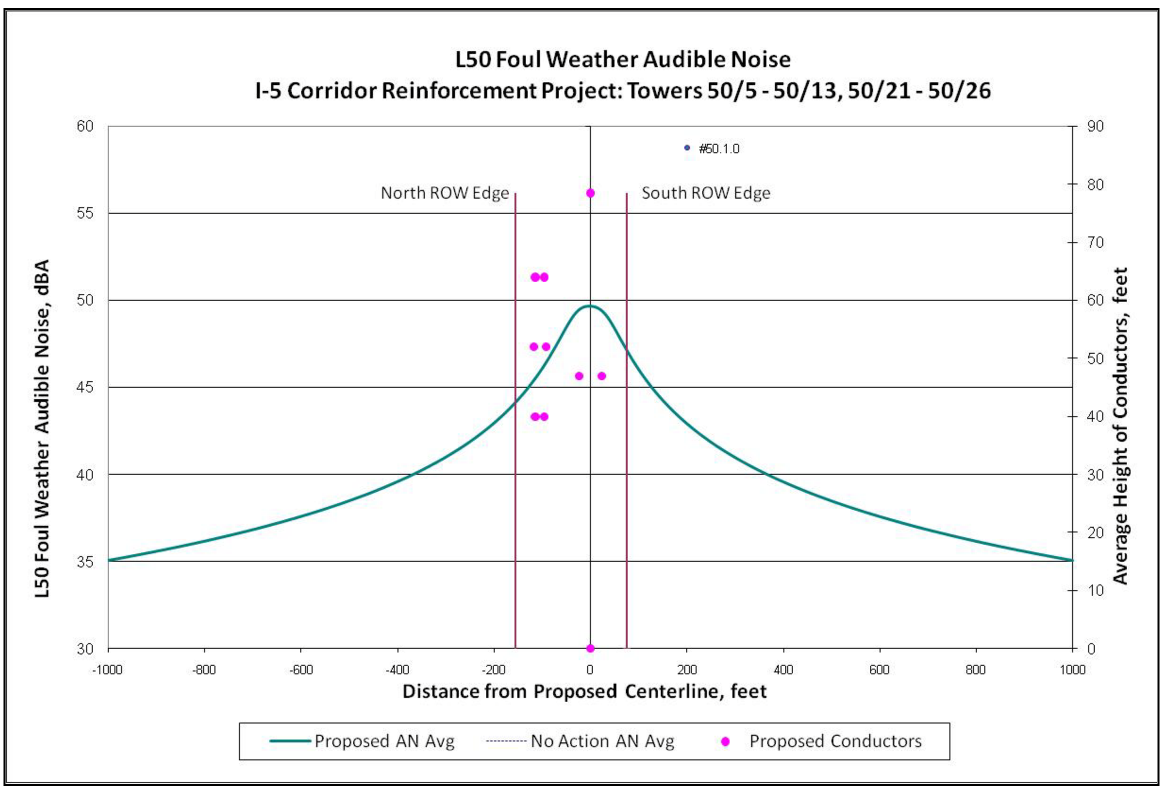

Table 34: Calculation 50.1.1

Calculation 50.1.1: Electrical Sections						
Segment	Towers	Length		Segment	Towers	Length
50	50/5 - 50/13	1.46				
50	50/21 - 50/26	0.80				

Calculation 50.1.1: Summary of Fields and Corona Effects							
	ROW Status	Average			Maximum		
Location		North Edge	South Edge	Peak On ROW	North Edge	South Edge	Peak On ROW
Electric Field, kV/m	No Action	0.1	0.0	0.8	0.1	0.1	1.6
	Proposed	0.2	2.3	5.3	0.3	2.3	8.8
Magnetic Field, mG	No Action	1	0	3	8	1	35
	Proposed	3	12	34	11	48	183
Audible Noise, dBA Foul weather L50	No Action	19.8	14.6	Not Applicable			
	Proposed	44.1	47.2				
Fair Weather RI, dB(uV/m) @ 100 ft from conductors	No Action	10	10	Not Applicable			
	Proposed	30	36				
Foul Weather TVI, dB(uV/m) @ 100 ft from conductors	No Action	-7	-7	Not Applicable			
	Proposed	12	21				

Figure 82: Calculation 50.1.1 – Electric Fields

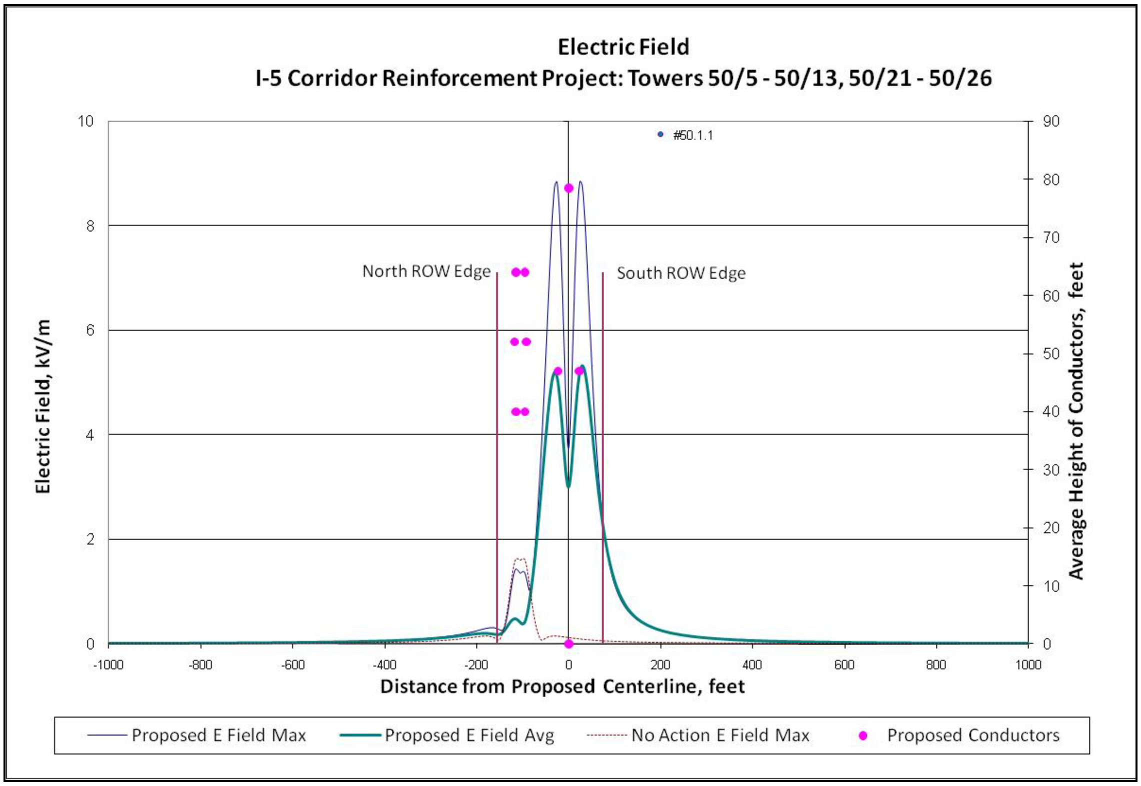

Figure 83: Calculation 50.1.1 – Magnetic Fields

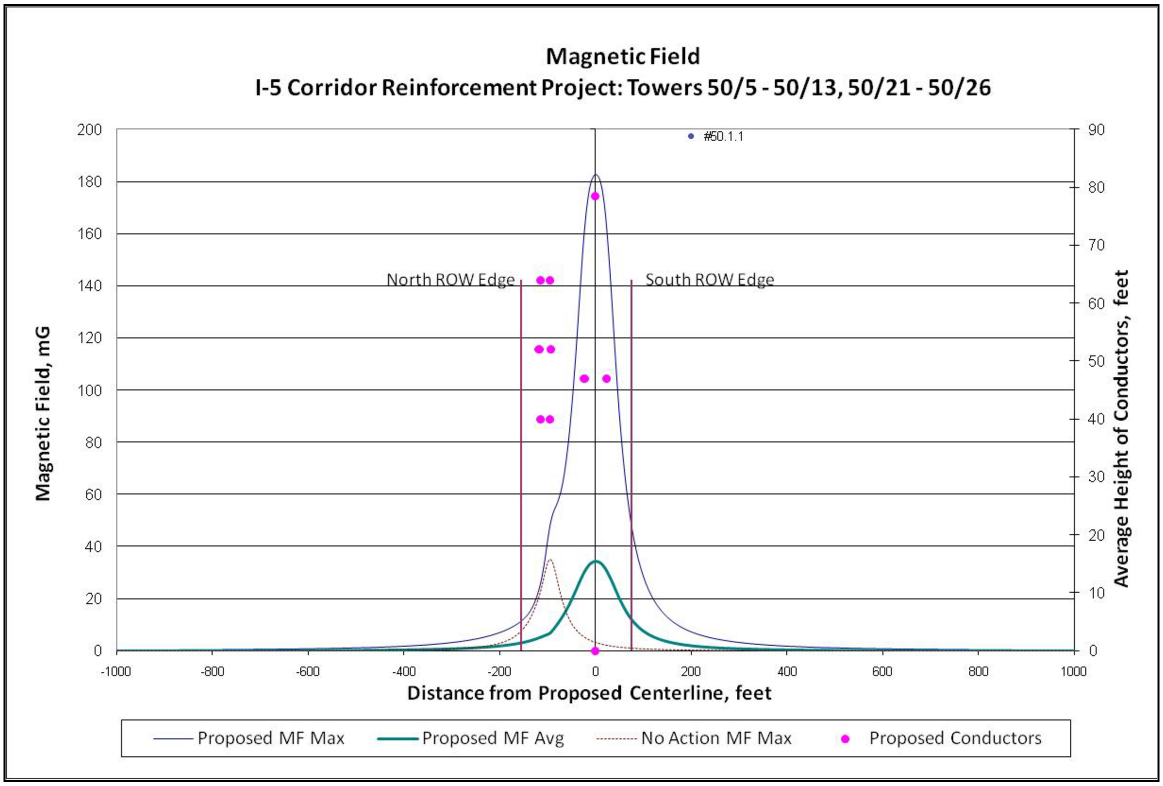

Figure 84: Calculation 50.1.1 – Audible Noise Levels

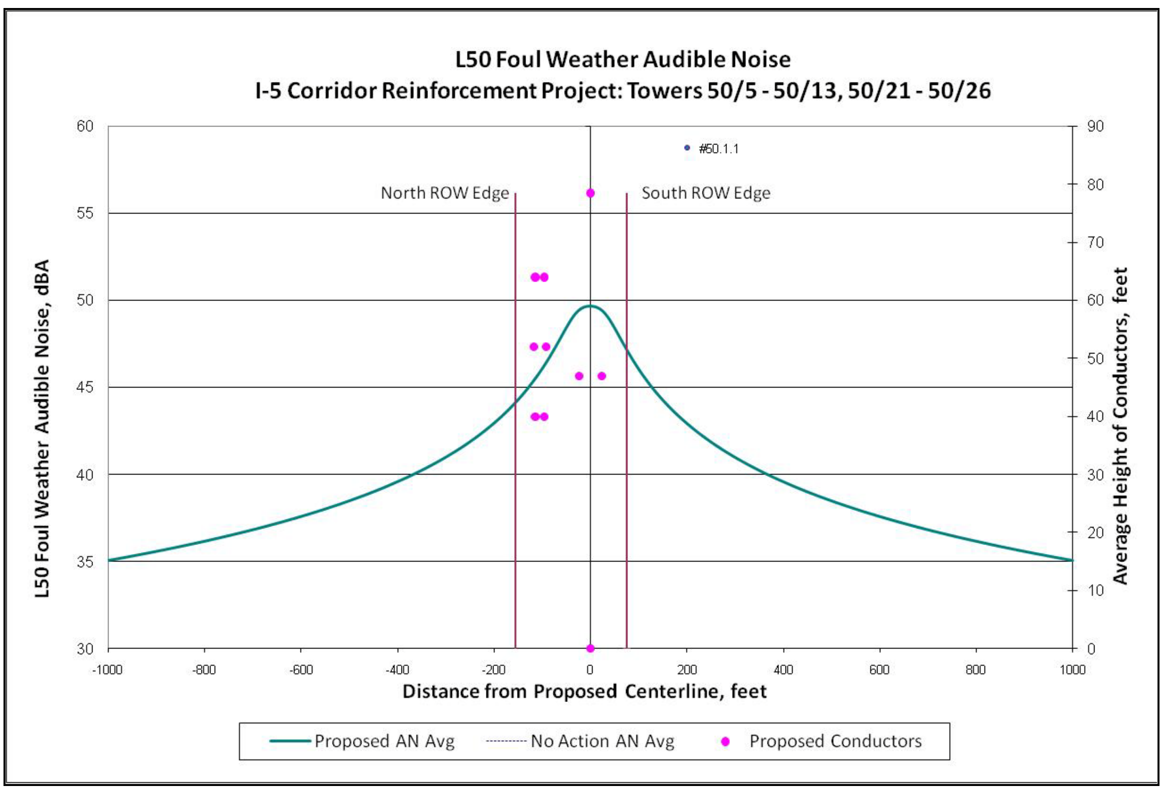

Table 35: Calculation 51.1.0

Calculation 51.1.0: Electrical Sections						
Segment	Towers	Length		Segment	Towers	Length
51	51/1 - 51/11	2.07		52	52/9 - 52/12	0.44
52	52/1 - 52/2	0.13				

Calculation 51.1.0: Summary of Fields and Corona Effects							
	ROW Status	Average			Maximum		
Location		East Edge	West Edge	Peak On ROW	East Edge	West Edge	Peak On ROW
Electric Field, kV/m	No Action	1.2	1.2	2.0	1.4	1.4	3.8
	Proposed	0.2	2.0	5.3	0.2	2.0	8.9
Magnetic Field, mG	No Action	15	15	29	48	48	129
	Proposed	8	11	33	24	43	179
Audible Noise, dBA Foul weather L50	No Action	42.1	42.1	Not Applicable			
	Proposed	46.2	47.5				
Fair Weather RI, dB(uV/m) @ 100 ft from conductors	No Action	27	27	Not Applicable			
	Proposed	31	36				
Foul Weather TVI, dB(uV/m) @ 100 ft from conductors	No Action	14	14	Not Applicable			
	Proposed	13	21				

Figure 85: Calculation 51.1.0 – Electric Fields

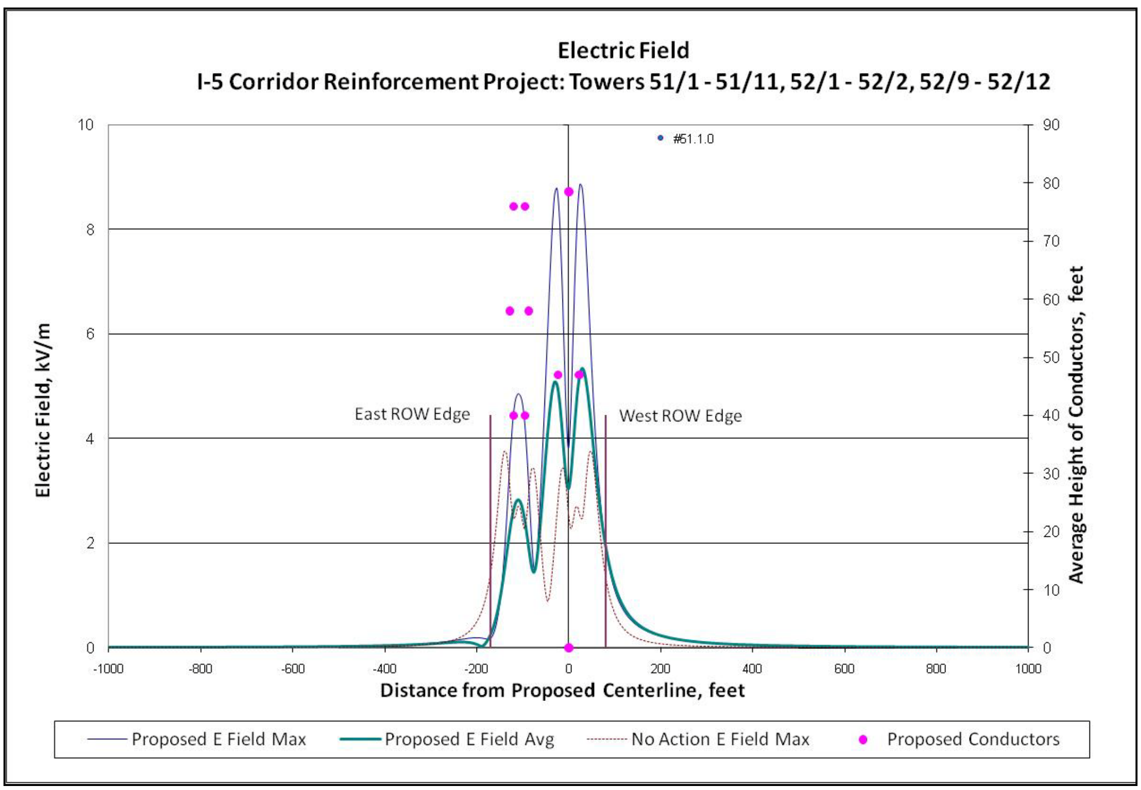

Figure 86: Calculation 51.1.0 – Magnetic Fields

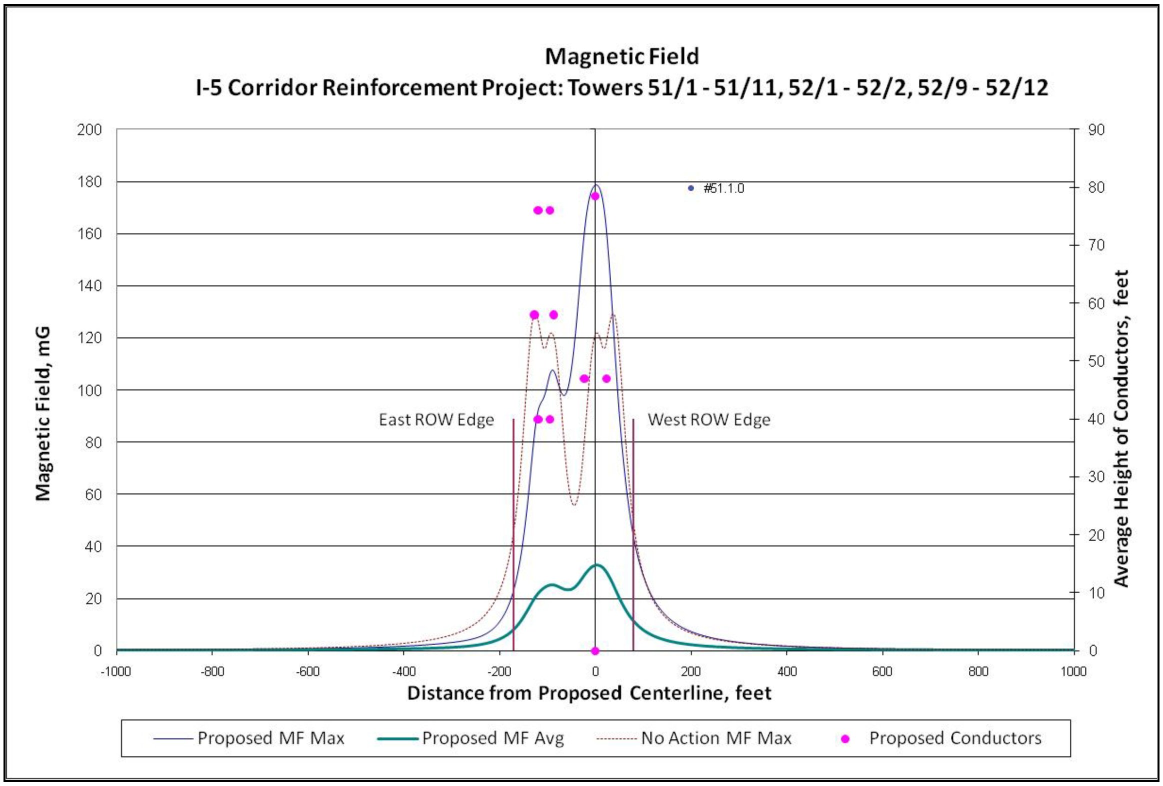

Figure 87: Calculation 51.1.0 – Audible Noise Levels

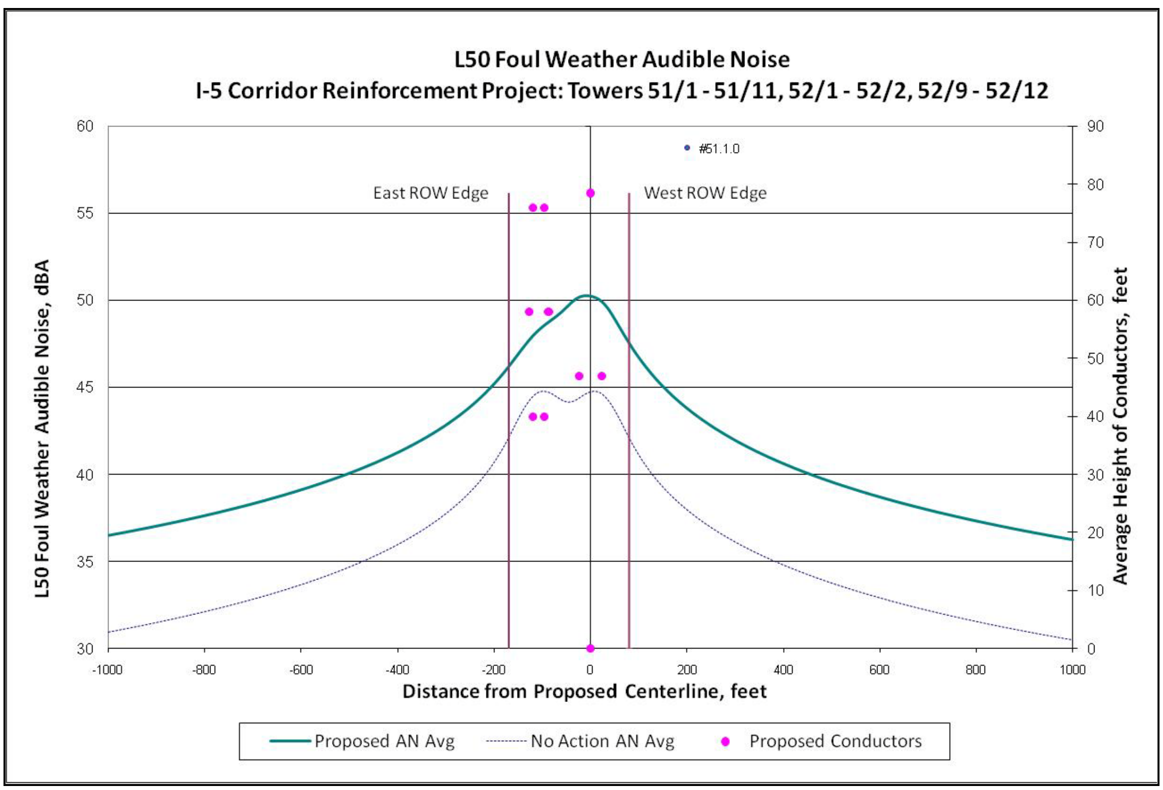

Table 36: Calculation 51.1.1

Calculation 51.1.1: Electrical Sections						
Segment	Towers	Length		Segment	Towers	Length
52	52/12 - 52/17	1.23				

Calculation 51.1.1: Summary of Fields and Corona Effects							
	ROW Status	Average			Maximum		
Location		East Edge	West Edge	Peak On ROW	East Edge	West Edge	Peak On ROW
Electric Field, kV/m	No Action	1.2	1.2	2.3	1.3	1.3	4.0
	Proposed	0.5	2.0	5.4	0.5	2.0	8.9
Magnetic Field, mG	No Action	13	13	35	42	42	147
	Proposed	8	12	35	26	44	183
Audible Noise, dBA Foul weather L50	No Action	41.9	41.9	Not Applicable			
	Proposed	46.7	47.7				
Fair Weather RI, dB(uV/m) @ 100 ft from conductors	No Action	27	27	Not Applicable			
	Proposed	30	36				
Foul Weather TVI, dB(uV/m) @ 100 ft from conductors	No Action	15	15	Not Applicable			
	Proposed	14	21				

Figure 88: Calculation 51.1.1 – Electric Fields

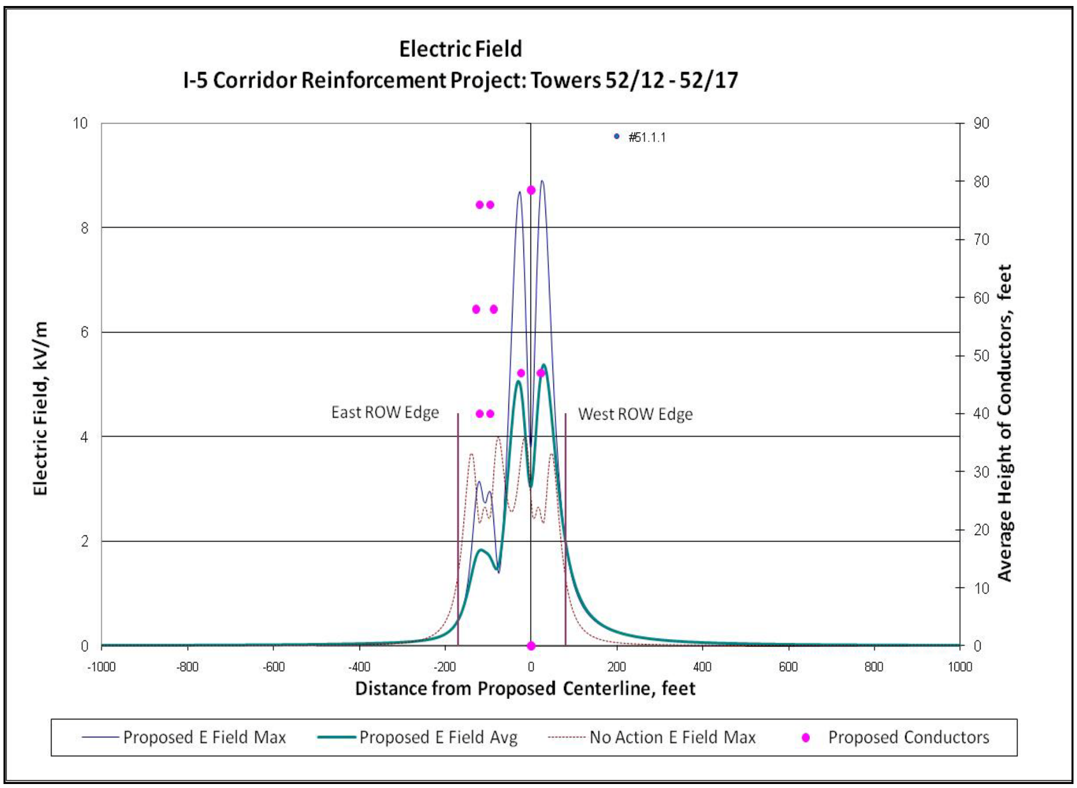

Figure 89: Calculation 51.1.1 – Magnetic Fields

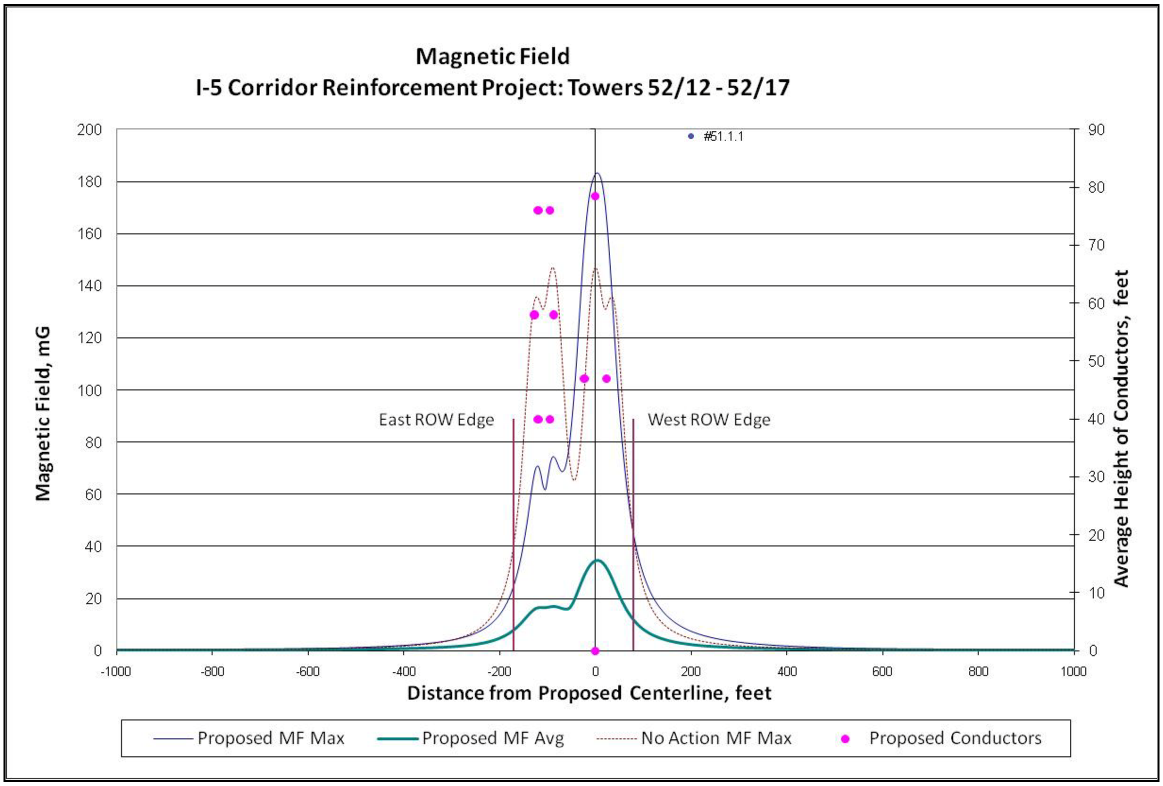

Figure 90: Calculation 51.1.1 – Audible Noise Levels

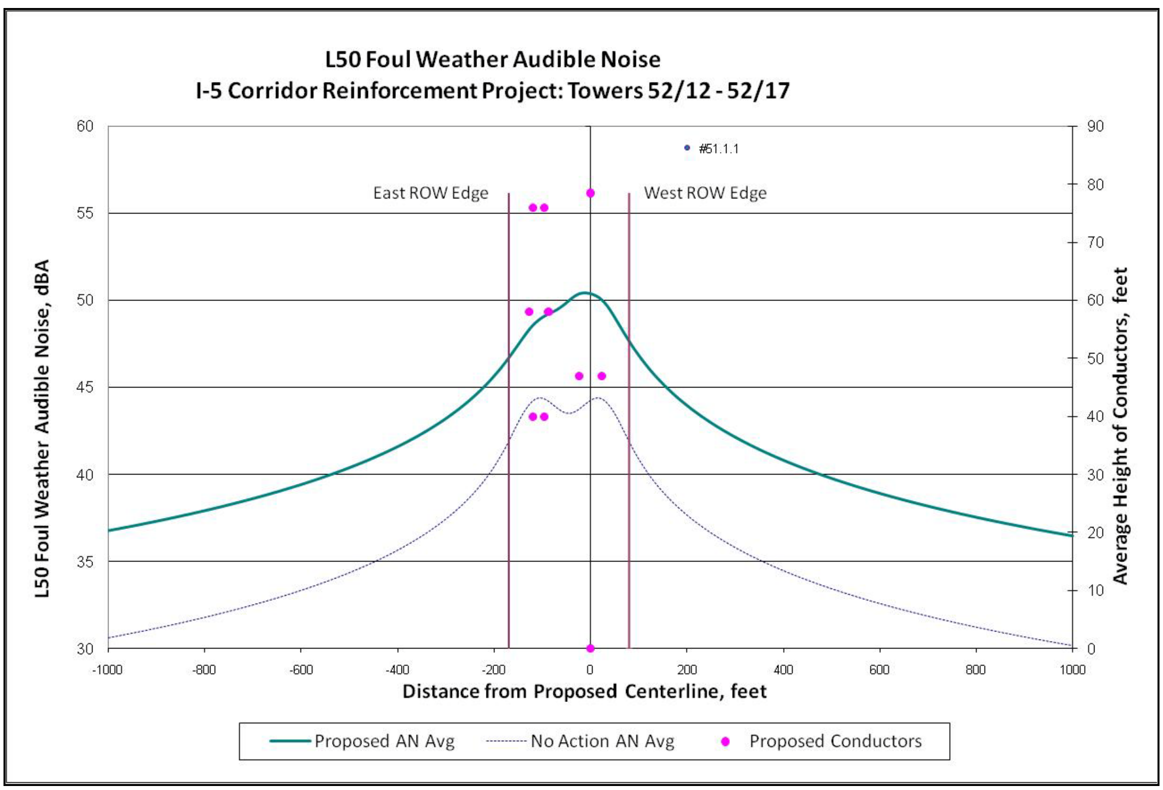

Table 37: Calculation 52.2.0

Calculation 52.2.0: Electrical Sections						
Segment	Towers	Length		Segment	Towers	Length
52	52/2 - 52/9	1.48				

Calculation 52.2.0: Summary of Fields and Corona Effects							
	ROW Status	Average			Maximum		
Location		East Edge	West Edge	Peak On ROW	East Edge	West Edge	Peak On ROW
Electric Field, kV/m	No Action	0.2	1.2	2.0	1.4	0.2	3.8
	Proposed	0.1	2.0	5.3	0.1	2.0	8.9
Magnetic Field, mG	No Action	4	15	29	11	48	129
	Proposed	2	11	33	5	43	179
Audible Noise, dBA Foul weather L50	No Action	39.2	42.1	Not Applicable			
	Proposed	44.0	47.5				
Fair Weather RI, dB(uV/m) @ 100 ft from conductors	No Action	27	27	Not Applicable			
	Proposed	31	36				
Foul Weather TVI, dB(uV/m) @ 100 ft from conductors	No Action	14	14	Not Applicable			
	Proposed	13	21				

Figure 91: Calculation 52.2.0 – Electric Fields

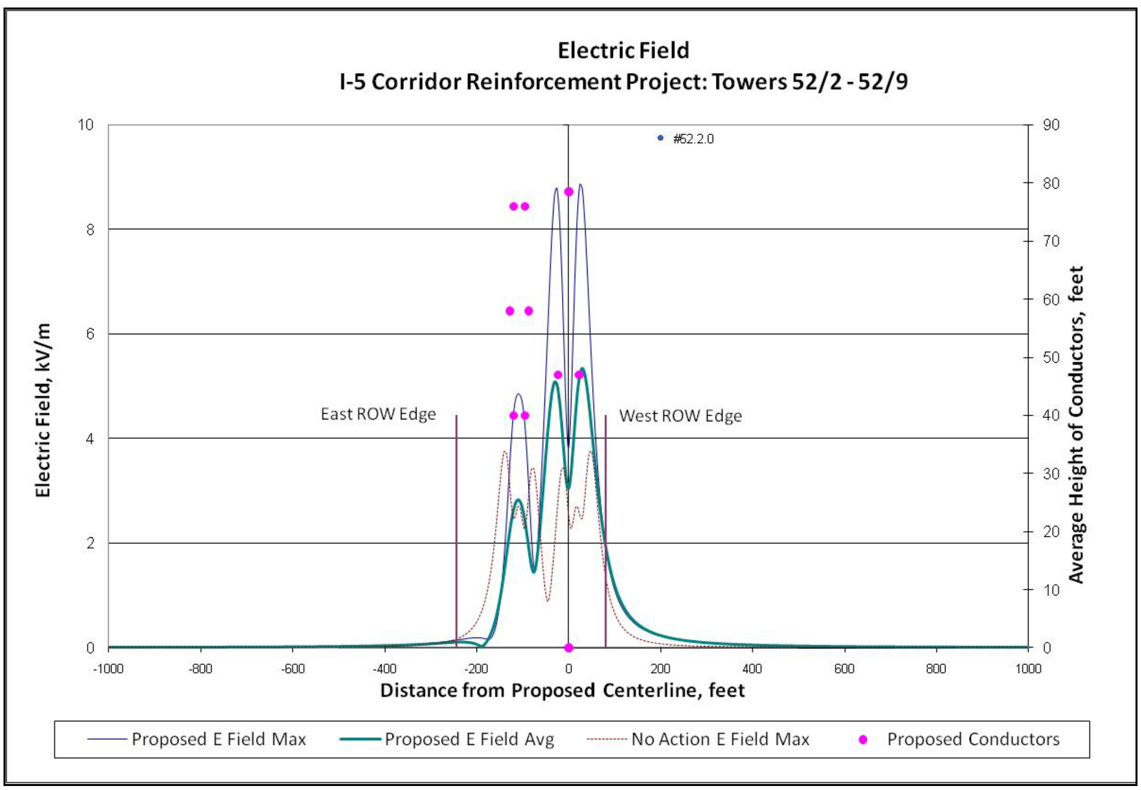

Figure 92: Calculation 52.2.0 – Magnetic Fields

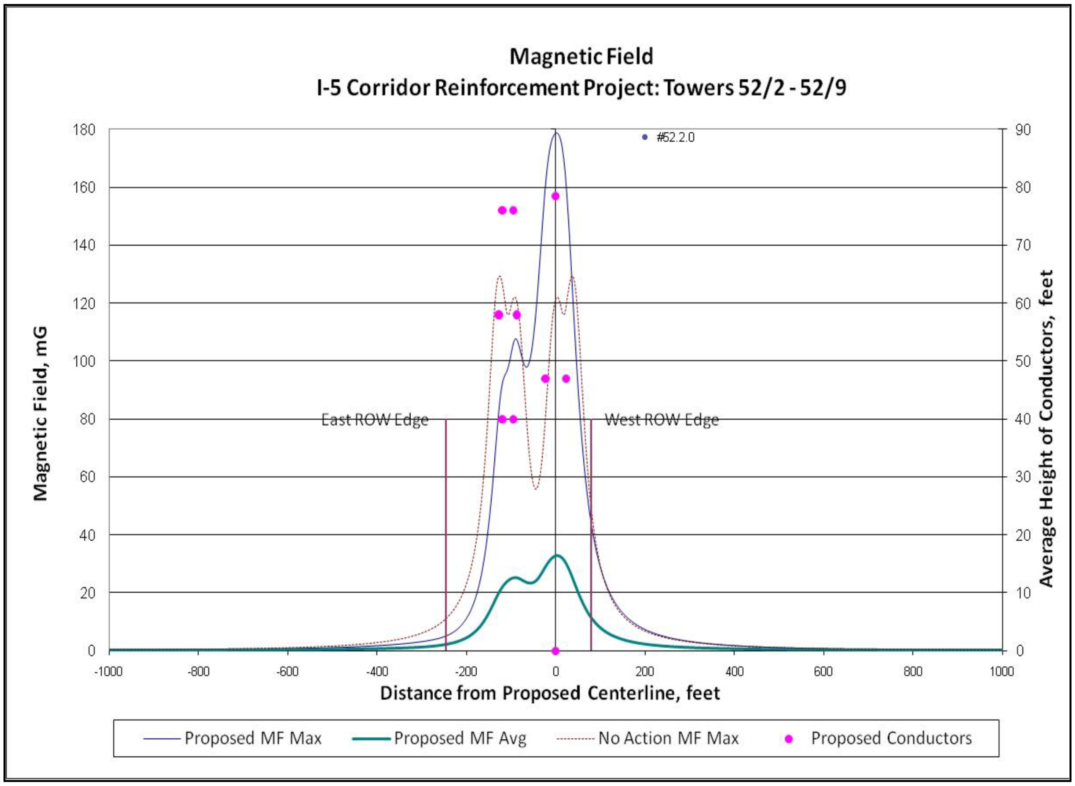

Figure 93: Calculation 52.2.0 – Audible Noise Levels

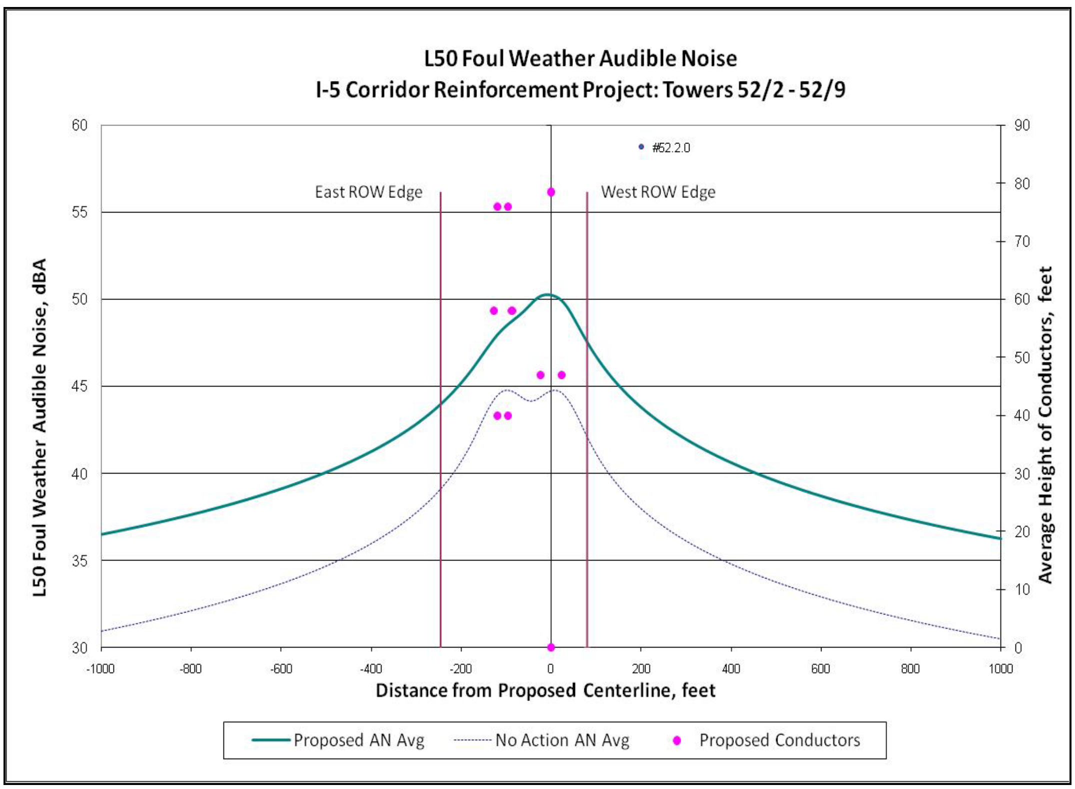

Table 38: Calculation A.1.0

Calculation A.1.0: Electrical Sections						
Segment	Towers	Length		Segment	Towers	Length
A	A/1 - A/9	1.81				
A	A/9 - A/12	0.71				

Calculation A.1.0: Summary of Fields and Corona Effects							
	ROW Status	Average			Maximum		
Location		East Edge	West Edge	Peak On ROW	East Edge	West Edge	Peak On ROW
Electric Field, kV/m	No Action	0.1	2.6	5.5	0.1	2.9	9.0
	Proposed	1.9	2.6	5.5	1.9	2.9	9.0
Magnetic Field, mG	No Action	2	18	49	6	73	235
	Proposed	12	19	62	44	75	257
Audible Noise, dBA Foul weather L50	No Action	50.7	52.4	Not Applicable			
	Proposed	52.2	52.6				
Fair Weather RI, dB(uV/m) @ 100 ft from conductors	No Action	36	36	Not Applicable			
	Proposed	36	36				
Foul Weather TVI, dB(uV/m) @ 100 ft from conductors	No Action	18	21	Not Applicable			
	Proposed	21	21				

Figure 94: Calculation A.1.0. – Electric Fields

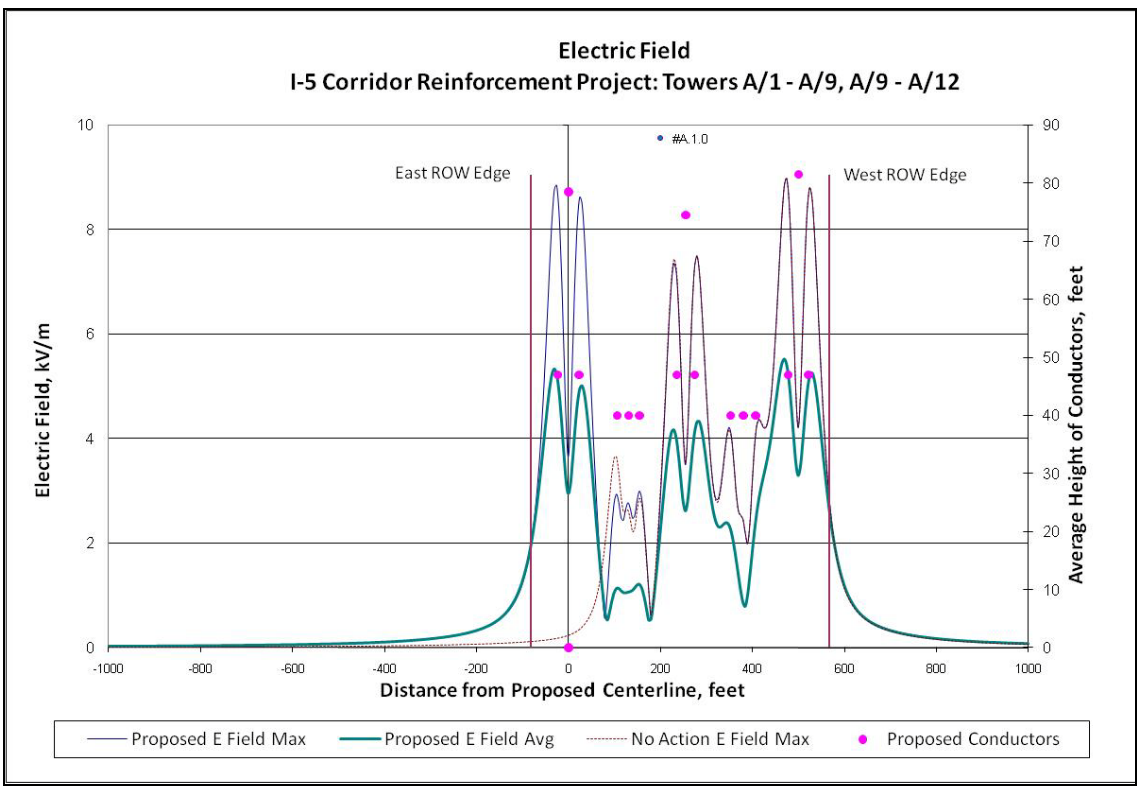

Figure 95: Calculation A.1.0. – Magnetic Fields

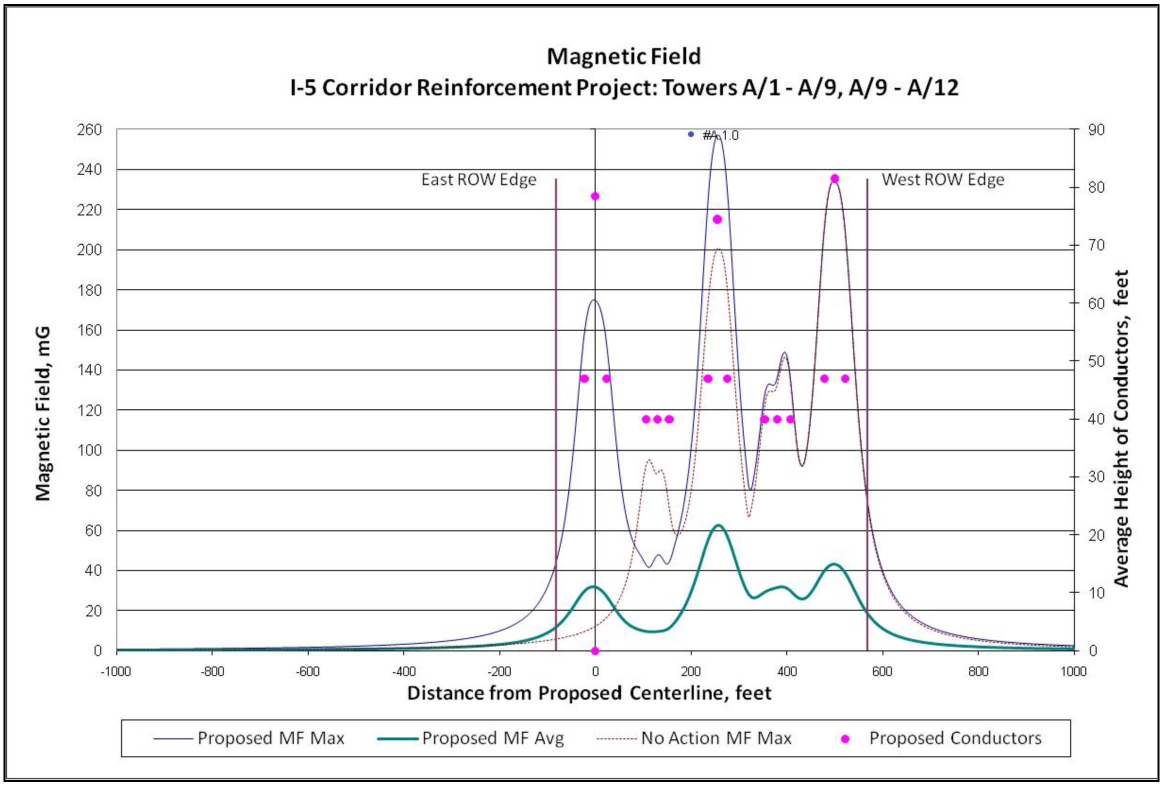

Figure 96: Calculation A.1.0. – Audible Noise Levels

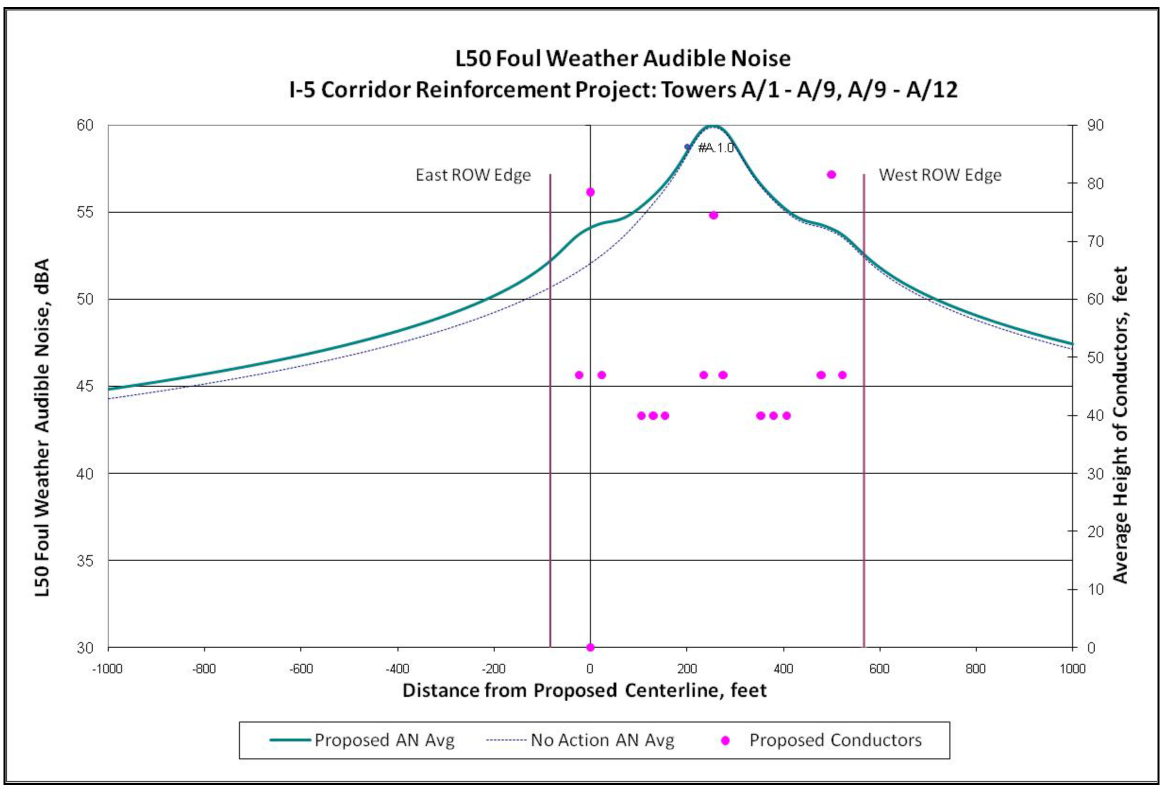

Table 39: Calculation C.1.0

Calculation C.1.0: Electrical Sections						
Segment	Towers	Length		Segment	Towers	Length
C	C/1 - C/17	3.00				
E	E/1 - E/6	1.07				

Calculation C.1.0: Summary of Fields and Corona Effects							
	ROW Status	Average			Maximum		
Location		East Edge	West Edge	Peak On ROW	East Edge	West Edge	Peak On ROW
Electric Field, kV/m	No Action	1.3	2.6	5.5	1.3	2.9	9.0
	Proposed	1.2	2.6	5.8	1.3	2.9	8.8
Magnetic Field, mG	No Action	14	18	49	41	73	235
	Proposed	8	19	68	28	74	270
Audible Noise, dBA Foul weather L50	No Action	56.5	51.4	Not Applicable			
	Proposed	56.4	51.6				
Fair Weather RI, dB(uV/m) @ 100 ft from conductors	No Action	44	36	Not Applicable			
	Proposed	45	36				
Foul Weather TVI, dB(uV/m) @ 100 ft from conductors	No Action	29	21	Not Applicable			
	Proposed	30	21				

Figure 97: Calculation C.1.0. – Electric Fields

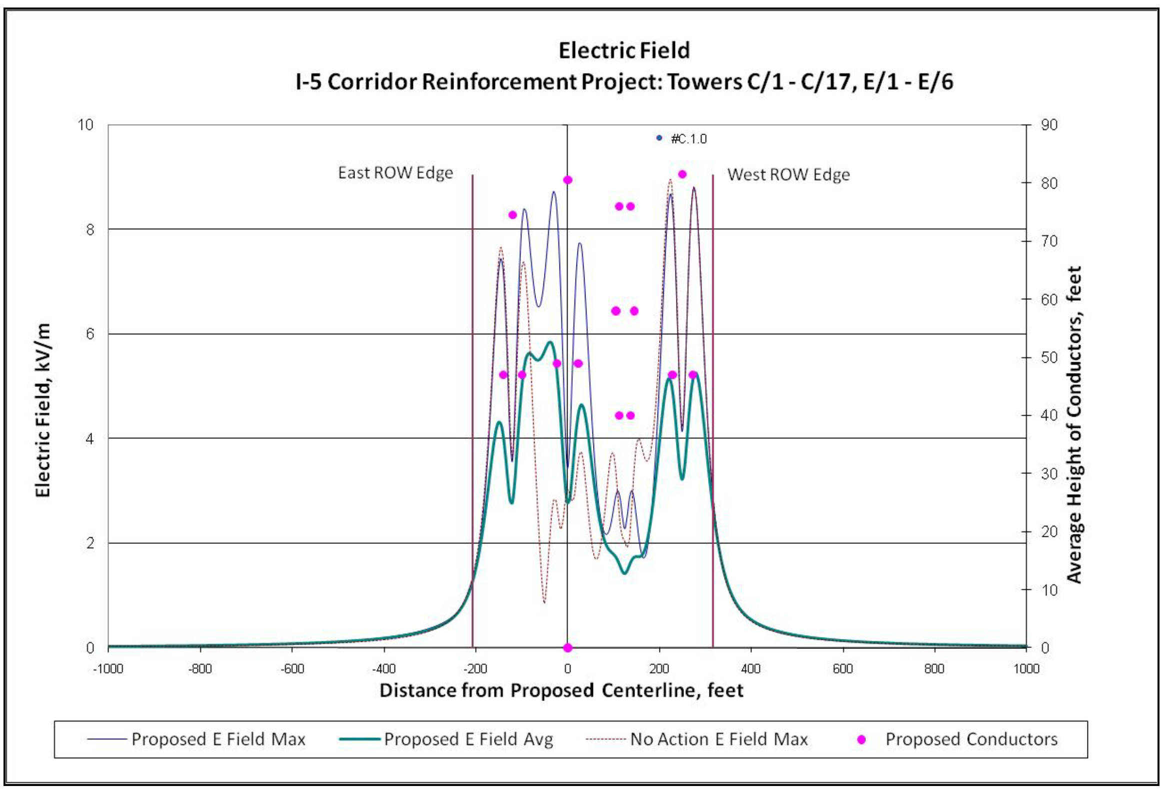

Figure 98: Calculation C.1.0. – Magnetic Fields

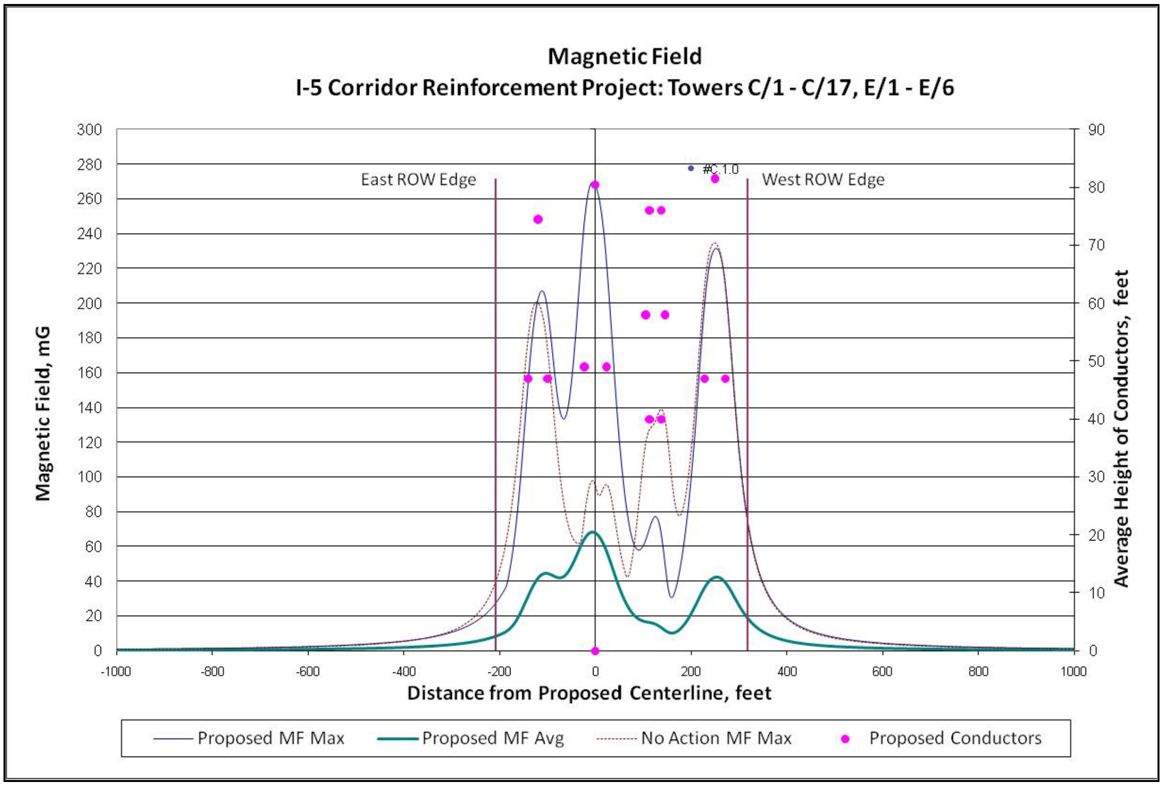

Figure 99: Calculation C.1.0. – Audible Noise Levels

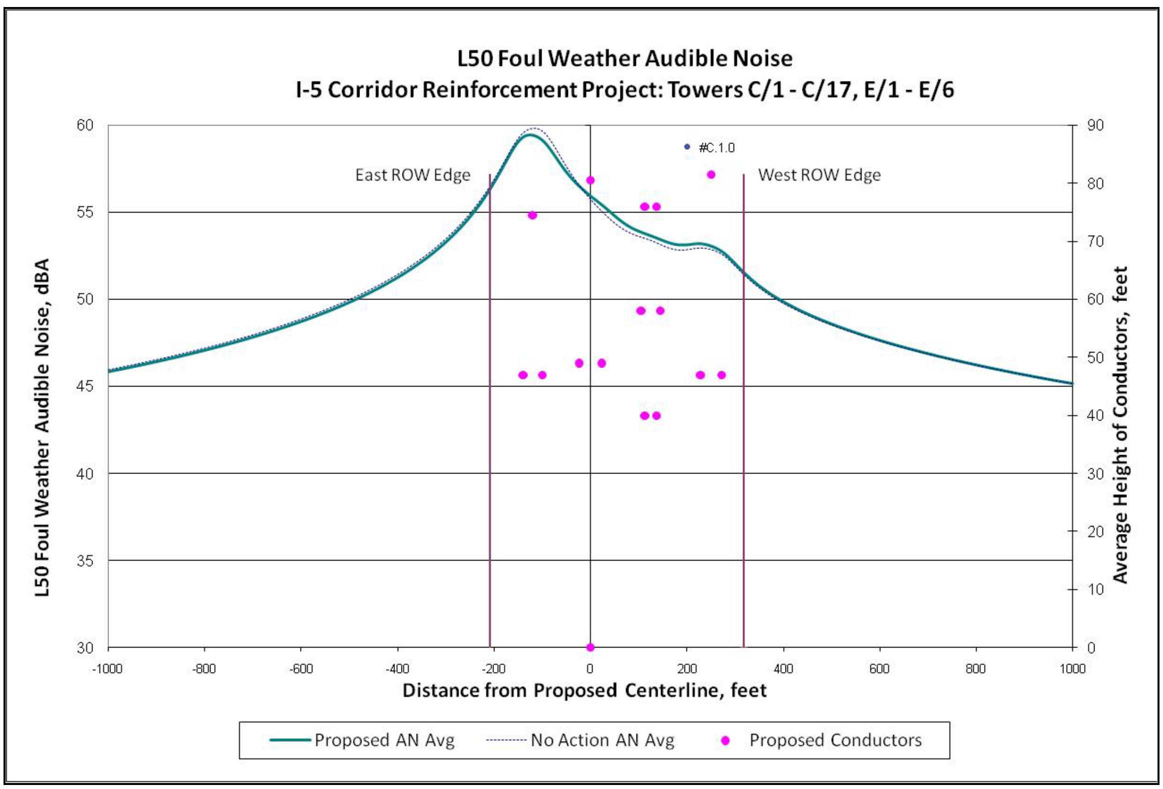

Table 40: Calculation D.1.0

Calculation D.1.0: Electrical Sections						
Segment	Towers	Length		Segment	Towers	Length
D	D/1 - D/17	2.86				

Calculation D.1.0: Summary of Fields and Corona Effects							
	ROW Status	Average			Maximum		
Location		East Edge	West Edge	Peak On ROW	East Edge	West Edge	Peak On ROW
Electric Field, kV/m	No Action	0.2	2.6	5.5	0.2	2.9	9.0
	Proposed	1.8	2.6	5.8	1.8	2.9	9.0
Magnetic Field, mG	No Action	3	18	49	8	73	235
	Proposed	8	18	68	31	72	278
Audible Noise, dBA Foul weather L50	No Action	52.7	51.4	Not Applicable			
	Proposed	53.4	51.5				
Fair Weather RI, dB(uV/m) @ 100 ft from conductors	No Action	44	36	Not Applicable			
	Proposed	37	36				
Foul Weather TVI, dB(uV/m) @ 100 ft from conductors	No Action	29	21	Not Applicable			
	Proposed	21	21				

Figure 100: Calculation D.1.0. – Electric Fields

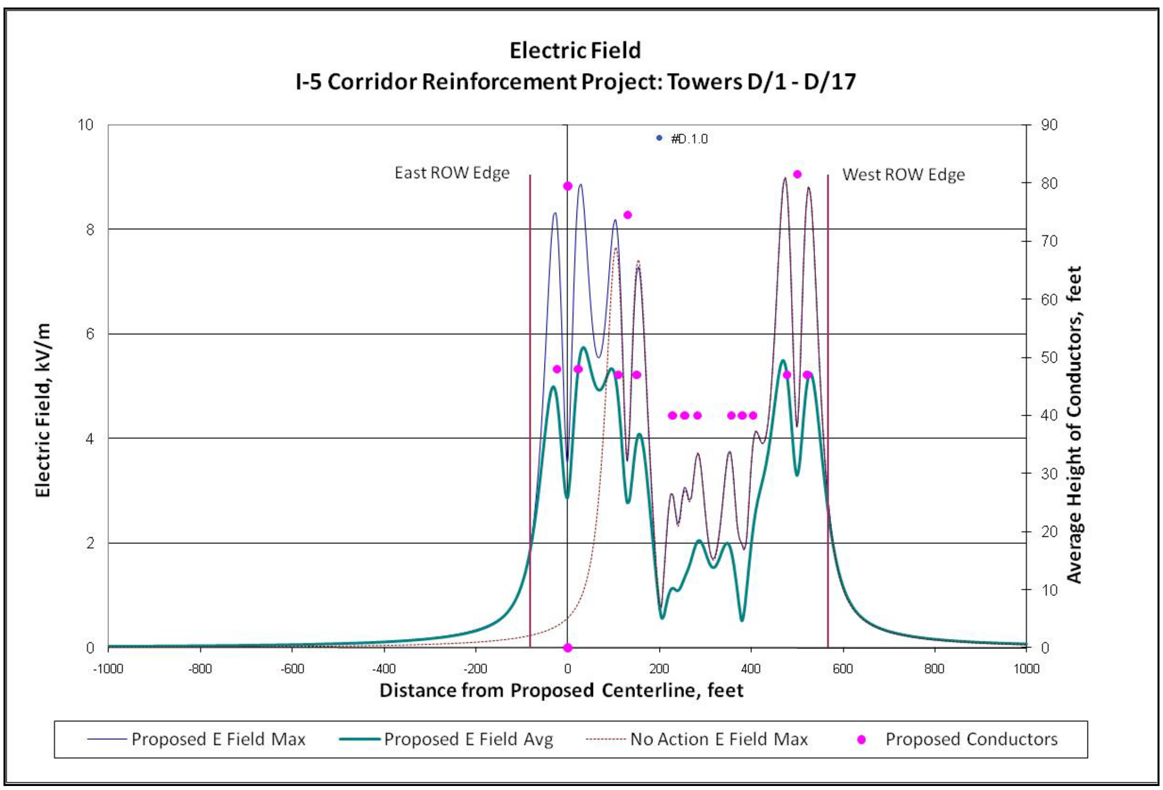

Figure 101: Calculation D.1.0. – Magnetic Fields

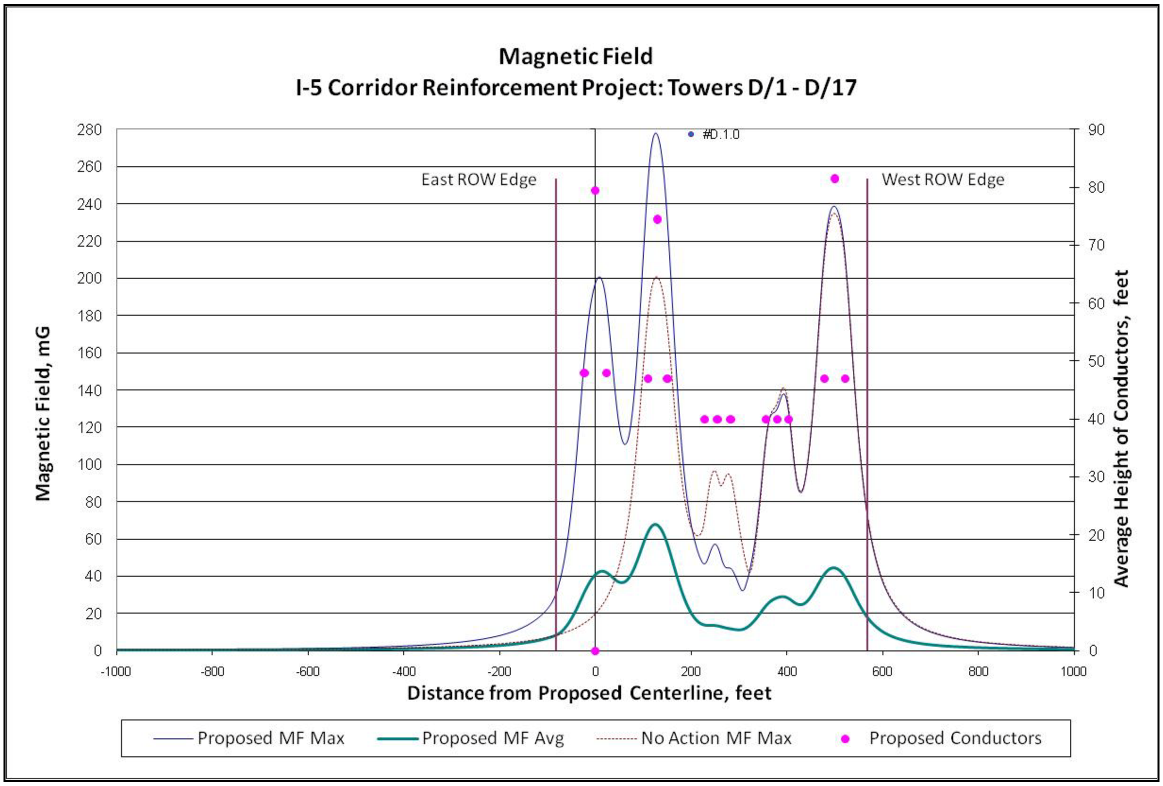

Figure 102: Calculation D.1.0. – Audible Noise Levels

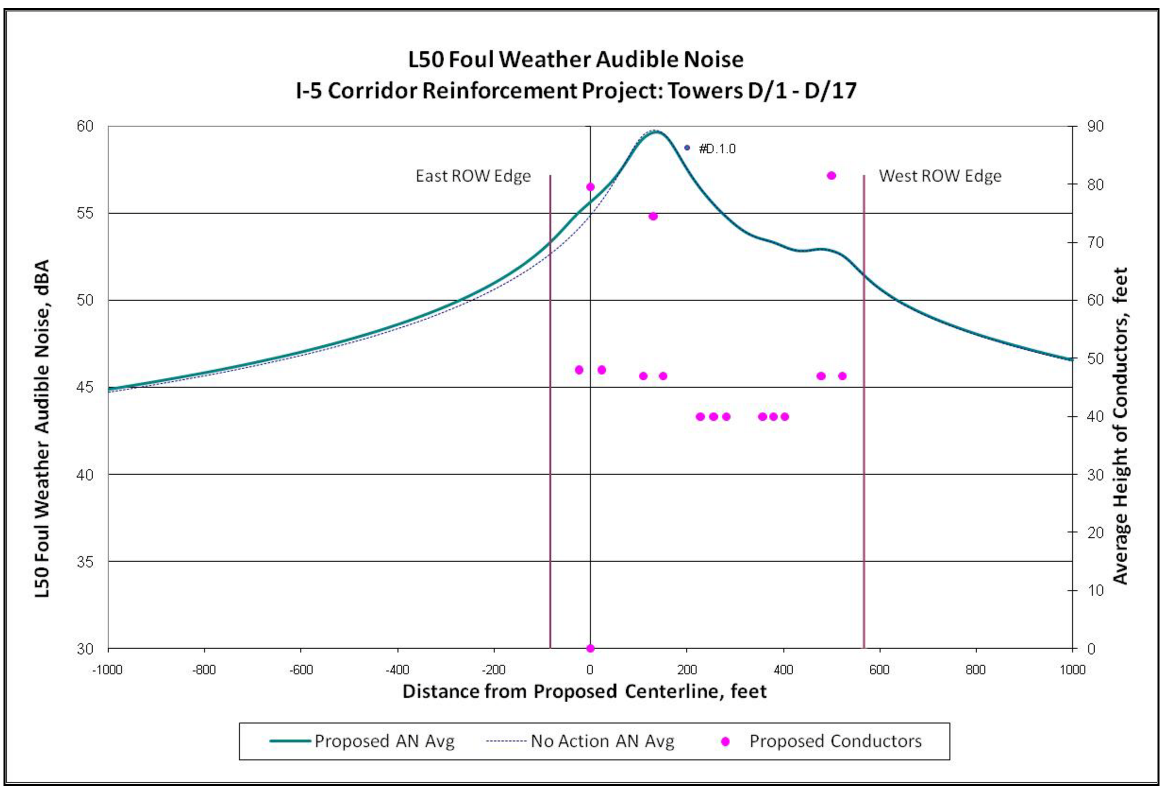

Table 41: Calculation R.1.0

Calculation R.1.0: Electrical Sections						
Segment	Towers	Length		Segment	Towers	Length
R	R/10 - R/19	1.75				

Calculation R.1.0: Summary of Fields and Corona Effects							
	ROW Status	Average			Maximum		
Location		South Edge	North Edge	Peak On ROW	South Edge	North Edge	Peak On ROW
Electric Field, kV/m	No Action	0.3	0.1	2.9	0.1	0.4	5.3
	Proposed	0.3	2.2	5.7	0.4	2.3	8.8
Magnetic Field, mG	No Action	3	4	48	10	6	133
	Proposed	3	9	53	13	42	186
Audible Noise, dBA Foul weather L50	No Action	48.0	47.9	Not Applicable			
	Proposed	48.3	50.0				
Fair Weather RI, dB(uV/m) @ 100 ft from conductors	No Action	29	37	Not Applicable			
	Proposed	29	36				
Foul Weather TVI, dB(uV/m) @ 100 ft from conductors	No Action	12	23	Not Applicable			
	Proposed	13	21				

Figure 103: Calculation R.1.0. – Electric Fields

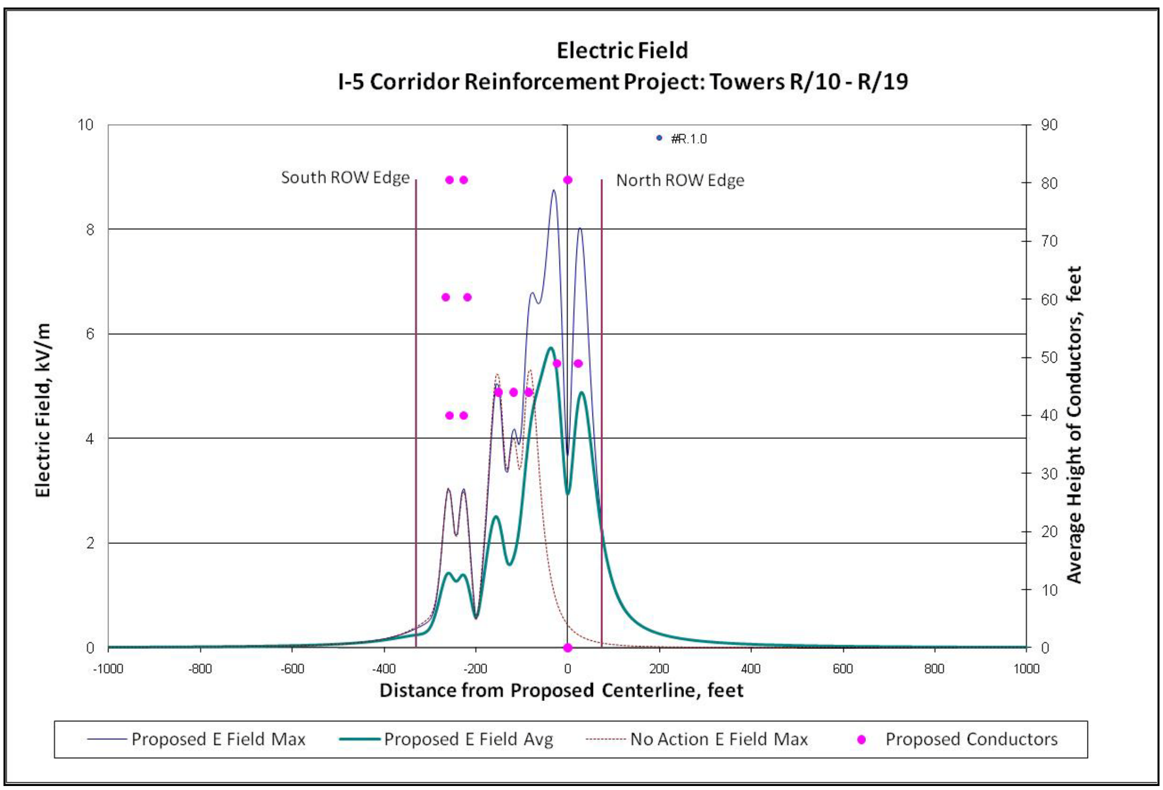

Figure 104: Calculation R.1.0. – Magnetic Fields

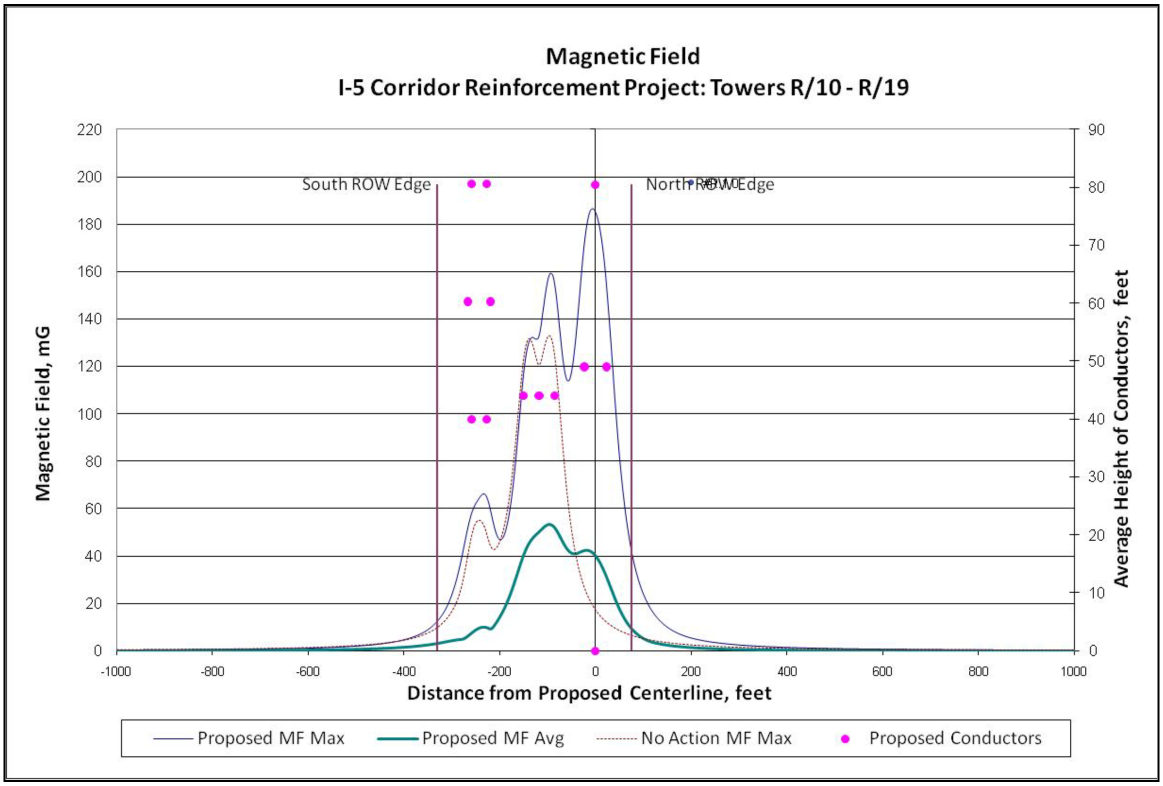

Figure 105: Calculation R.1.0. – Audible Noise Levels