Appendix E

Electric Fields, Magnetic Fields, Noise, and Radio Interference

BIG EDDY – KNIGHT
500-kV TRANSMISSION PROJECT

APPENDIX E

ELECTRICAL EFFECTS

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for

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ELECTRICAL EFFECTS FROM THE PROPOSED BIG EDDY – KNIGHT 500-kV TRANSMISSION LINE PROJECT

1.0 Introduction

The Bonneville Power Administration (BPA) is proposing to build an approximately 28-mile 500-kilovolt (kV) transmission line from the existing BPA Big Eddy Substation in Wasco County, Oregon to the proposed BPA Knight Substation near Goldendale in Klickitat, County, Washington. The proposed line is designated the Big Eddy – Knight transmission line. The proposed transmission line will traverse mostly arid pasture and agricultural land that is sparsely populated. However, there are scattered structures throughout the project area. Three alternative routes – West, Middle and East - are under consideration for the proposed transmission line as shown in Figure 1.

The purpose of this report is to describe and quantify the electrical effects of the proposed Big Eddy – Knight 500-kV transmission line along the alternative routes. 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 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 Big Eddy – Knight line. 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 lower voltage lines along portions of the route. The length of the sections with parallel line depends on the alternative route. Electrical effects were analyzed for all segments with or without parallel lines that had constant physical and electrical characteristics for over more than one mile. Shorter segments (< 1 mile) could occur where the line changes direction, crosses a roadway or enters a substation. The electrical effects associated with these short line segments would be very similar to those for the analyzed segments. The proposed project has 13 different line configurations (physical and electrical changes that could affect the field levels) with line segments greater than one mile in length. The 13 line configurations are described in Table 1.

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 approach was used to estimate fields for the proposed Big Eddy -Knight line, where minimum clearances were assumed to provide worst-case (highest) estimates for the 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 current and power flow direction for the proposed line were provided by BPA and are based on the projected system normal annual peak power loads in 2013.

Electric and magnetic fields for the proposed line were calculated at the standard height (3.28 ft. or 1 m) above the ground (IEEE, 1987). Calculations were performed out to 300 ft. (91 m) from the centerline of the existing corridor. 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 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 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 (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 an estimated average operating voltage (536 kV for the proposed line) and with the average line height over a span of 47 ft. (14.3 m).

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 Big Eddy -Knight transmission line, such conditions are expected to occur about 1 percent of the time during a year, based on hourly precipitation records during years with complete records for Moro, Oregon (2000-2003) and Kennewick, WA (2006-2008).(NOAA, 2010) Corona activity also increases with altitude. For purposes of evaluating corona effects from the proposed line, an altitude that corresponded to the average where each line configuration would be constructed was assumed for that configuration. Assumed altitudes ranged from 350 to 1650 ft. (100 to 500 m).

2.0 Physical Description

2.1 Proposed Line

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). For the 500-kV line, each phase actually is carried on a bundle of three conductors (wires) and there are three bundles per circuit as shown in Figure 2.

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. The proposed line would be placed either on single-circuit towers with the phases arranged in a delta (triangular) configuration (Figure 2) or on double-circuit towers with three of six phase conductors or bundles arranged vertically on either side of the tower (Figure 8). The double-circuit towers would support both the proposed line and an existing parallel lower voltage line or just the proposed line with the proposed line located on the west side of the double-circuit tower. For some configurations, the proposed line would be operated as a split-phase line. In this case, each phase is split between two bundles, one on either side of the double-circuit tower. A total of 13 configurations were identified for the project based on parallel lines, tower type and conductors.

BPA provided the physical and operating characteristics of the proposed and existing lines. The electrical characteristics and physical dimensions for the configurations of the proposed line are shown in Table 2 and the configurations are shown in Figures 2 to 12.

The maximum phase-to-phase voltage for the proposed line would be 550 kV and the average voltage would be 536 kV. The maximum electrical current on the line would be 970 amperes (A) per phase, based on the BPA projected system annual peak load in 2013 as the base year. The load factor for this line will be about 0.50 (average load = peak load x load factor), resulting in an average current of 485 A.

For most of the configurations 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. Some portions of the line could have slightly larger conductors to meet a BPA design criterion for audible noise performance. In this case, the conductor bundles would be comprised of three 1.600-inch diameter conductors arranged in an inverted triangle with approximately 19-in. (48.9 cm) spacing.

For the double-circuit tower configurations the east circuit on the tower would be strung with a 1x1.300-in conductor for configurations with an existing 115-kV circuit on that side. For the two configurations where an existing 230- or 345-kV line would be placed on the double-circuit tower, then a 3x1.300-in bundle would be used. The three-conductor bundle would also be used if the proposed 500-kV line was split between the two sides of the tower.

For the single-circuit tower with the phases arranged in a triangle or delta 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).

For the double-circuit tower the horizontal spacing between the top and bottom pairs of conductor bundles would be 36.5 ft. (11.1 m) and the spacing between the middle pair of conductor bundles would be 56.5 ft. (17.2 m). The vertical spacing between the bundles would be 36 ft. (11.0 m).

Minimum conductor-to-ground clearance would be 35 or 36 ft. (10.7 or 11.0 m) at a conductor temperature of 122°F (50°C). This temperature represents heavy operating conditions and high ambient air temperatures; clearances above ground would be greater under normal operating temperatures. The larger 36-foot clearance would be employed to ensure that the BPA criterion for maximum electric field at ground level (9 kV/m) is met along the entire route. The 35-foot clearance would be used for the single circuit towers except for Configuration 3 where it could be raised to 36 feet, depending on the relative phases of the proposed and adjacent 345-kV line. The 36-foot clearance would also be used for the double-circuit tower configurations (Configurations 7-12). The average clearance above ground along a span will be approximately 47 ft. (14.3 m); this value was used for corona calculations and to estimate average electric and magnetic fields along the line.

The minimum clearance of 35 ft (10.7-m) or greater provided by BPA exceeds the minimum distance of the conductors above ground required to meet the National Electric Safety Code (NESC) (IEEE, 2002). At road crossings, the ground clearance would be at least 50 ft. (15.2 m).

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.

2.2 Existing Lines

The proposed Big Eddy – Knight 500-kV line would parallel existing transmission lines along parts of all three alternative routes. In all, there are five existing lines that could be paralleled: the Harvalum - Big Eddy 230-kV line, the McNary – Ross 345-kV line, the Chenowick – Goldendale 115-kV line, the Spearfish Tap 115-kV line and the Big Eddy – Spring Creek 230-kV line. The lines to be paralleled and lengths of their parallel segments are dependent on the route. Descriptions of the three routes and five existing lines and their associated routes are given in Tables 1 and 2.

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 2013, 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 at midspan, 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

Table 3 shows the calculated values of electric field at 3.28 ft. (1 m) above ground for the proposed Big Eddy - Knight 500-kV transmission-line configurations. The maximum value on the right-of-way and the value at the edge of the right-of-way are given for the proposed configurations at minimum conductor clearance and at the estimated average clearance along a span. Both the maximum and average fields were computed with the line operating at the maximum voltage of 550 kV. Lateral profiles of the electric fields for the 13 configurations are shown in Figures 13 – 24.

The calculated maximum electric fields expected on the right-of-way of the proposed line range from 7.4 to 8.8 kV/m, depending on the configuration. For average clearance, the peak field ranges from 4.2 to 5.8 kV/m. As shown in Figures 13 to 24, the peak values would be present only at locations directly under the line, near mid-span, where the conductors are at the minimum clearance. The conditions of minimum conductor clearance at maximum current and maximum voltage occur very infrequently. The calculated peak 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.

The average values expected at the edge of the right-of-way of the proposed line range from 2.4 to less than 0.1 kV/m. The largest field values at the edge of the right-of-way occur for configurations where the centerline of the proposed single-circuit delta tower is located 75 ft from the edge.

For comparison the electric fields along the existing corridors for the No-action alternative are also shown in Table 3. For the existing lines the maximum fields range from 0 to 4.5 kV/m and the average peak field ranges from 0 to 2.6 kV/m. Average fields at the edge of the right-of-way vary from 0 to 1.3 kV/m for the No-action alternative. The principal reason for the lower fields in the No-action alternative is the absence of a 500-kV line among the existing lines.

3.4 Environmental Electric Fields

The electric fields associated with the proposed Big Eddy - Knight transmission line 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 in order 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. Although there have been no large studies of residential electric fields, sufficient data are available to indicate field levels and characteristics. 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. Sheppard and Eisenbud (1977) reported fields of 250 V/m at a distance of approximately 1 ft. (0.3 m). 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 Big Eddy – Knight 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 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, the maximum or peak magnetic fields occur in areas near the centerline and at midspan where the 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

Table 4 gives the calculated values of the magnetic field at 3.28 ft. (1 m) height for the proposed 500-kV transmission-line configurations. 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 during system annual peak load in 2013. Field levels at the same locations for average current and average conductor clearance are also given. The projected maximum currents are 970 A on each of the three phases of the proposed line. For double-circuit configurations where the phases are split between two sets of conductors, the maximum current on each set of conductors would be 485 A. Average currents over the year would be about 50 percent of the maximum values.

Figures 25 to 38 show lateral profiles of magnetic fields under these same current and clearance conditions for the proposed 500-kV transmission line and the existing adjacent lines. The levels for maximum current and minimum clearance shown in the figures represent the highest magnetic fields under the proposed Big Eddy – Knight 500-kV line except under extreme temperature conditions. 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 the 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 maximum calculated 60-Hz magnetic fields expected at 3.28 ft. (1 m) above ground for the proposed line range from 219mG to 60 mG for the 13 configurations of the proposed line. The highest fields would occur for single and double circuit towers that are adjacent to the existing Harvalum - Big Eddy 230-kV line (Configurations 2, 3 and 9). The lowest maximum fields would occur for the double-circuit tower configurations with split-phasing (Configurations 7 and 12). Maximum fields on the existing rights-of-way would range from 176 to 0 mG should the proposed line not be built – the No-action alternative. The maximum fields in this case would occur under the existing Big Eddy – Spring Creek and Harvalum - Big Eddy 230-kV lines.

The estimated average peak fields on the right-of-way for the proposed line would range from 65 to 17 mG. The average peak field on the existing rights-of-way would range from 48 to 0 mG for the No-action alternative.

At the edge of the right-of-way of the proposed line (on new right-of-way with no adjacent lines), estimated maximum fields would be 42 mG for the single-circuit tower (Configuration 1), 14 mG for the double-circuit tower with split phasing (Configurations 7) and 52 mG for the double-circuit tower with a single circuit on one side (Configurations 7A and 10). The peak average fields at the edge of the right-of-way for these configurations would be 18, 6, and 21 mG, respectively.

On existing rights-of-way with parallel adjacent lines, the calculated levels at the edge of the right-of-way obviously depend on the width of the right-of-way and the current on the existing line. Consequently, on existing rights-of-way, the maximum magnetic field at the edge of the right-of-way for maximum current conditions would range from 67 to less than 1 mG, while the average field at the edge would range from 23 to less than 1 mG. The maximum edge of right-of-way values for the No-action alternative would range from 67 to 0 mG, while the average values range from 23 to 0 mG. The highest edge of right-of-way levels for the No-action alternative occur adjacent to the Harvalum - Big Eddy and Big Eddy - Spring Creek 230-kV lines.

The magnetic field falls off rapidly as distance from the line increases. At a distance of 200 ft. (61 m) from the centerline of the proposed single-circuit tower line with maximum current, the field would be 6.4 mG and the average field would be about 3 mG. At the same current and distance from the double-circuit tower with the split phase configuration, the maximum and average fields would be less than 2 mG. For the double-circuit tower with only a single-circuit on one side, the maximum and average fields at 200 feet would be about 10 and 3 mG, respectively. The largest maximum and average fields at 200 feet from the existing lines for the No-action alternative would be 6-7 mG and 2-4 mG, respectively. These largest values for existing lines would occur adjacent to the Harvalum - Big Eddy 230-kV line, the Big Eddy – Spring Creek 230-kV line, and the McNary – Ross 345-kV line.

There would 2 to 5 houses within 300 feet of the proposed centerline and 10 to 12 houses within 500 ft, depending on which route and line designs are selected (Table 5). The average magnetic fields at these houses would range from 0.5 to 22.3 mG for the single-circuit configuration routes and from 0.1 to 3.5 mG for the double circuit routes. The range of maximum fields would be from 1.1 to 45 mG for the single-circuit routes and from 0.2 to 7 mG for the double circuit routes. (Note: A single house at 71 ft from the centerline of the proposed single-circuit configuration contributes the high upper ranges of average and maximum fields for the East and Middle alternatives shown in Table 5.)

In general, magnetic fields at houses would be higher for the East and Middle alternatives than for the West alternative when single circuit configurations are used. The opposite would be true if double-circuit configurations were used: in this case, magnetic fields would be higher at houses along the West alternative than along the other two routes.

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 Big Eddy - Knight 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.

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. The issue of 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 for the environmental assessment for the proposed Big Eddy – Knight 500-kV transmission line (Exponent, 2009).

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 Big Eddy - Knight 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. For example, in order for Configuration 3 to meet the 5.0 kV/m criterion at a clearance of 50 feet, adjacent phases of the proposed Big Eddy – Knight 500-kV line and the existing McNary – Ross 345-kV line could not be the same; for Configurations 7A and 10 clearance would have to be increased to 54 feet to meet the 5.0 kV/m criterion. In any case, 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 sailboating.

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 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 midspan.

(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).

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 midspan, 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 eliminated 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 those from existing 500-kV lines in the area of the proposed line.

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 5.

The American Conference of Governmental Industrial Hygienists (ACGIH) sets guidelines (Threshold Limit Values or TLVs) for occupational exposures to environmental agents (ACGIH, 2008). 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 5-7 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, 2008).

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, 1998). 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 0.83 G (830 mG) for magnetic fields (ICNIRP, 1998).

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, field limits for pacemaker wearers have been established by the ACGIH. They recommend that, lacking additional information about 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, 2008). Additional discussion of interference with implanted devices is given in the accompanying technical report on health effects (Exponent, 2009).

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. However, several states have been active in establishing 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 6.

Government agencies and utilities operating transmission systems have established design criteria that include EMF levels. BPA has maximum allowable electric fields of 9 and 5 kV/m on and at the edge of the right-of-way, respectively (USDOE, 1996). 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 6). 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).

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 dB(A) or 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 7 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. This criterion has been interpreted by the state and BPA to meet Oregon Noise Control Regulations (Perry, 1982).

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 (10:00 pm to 7:00 am), 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, 2006). 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 allows 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 meteorologic records over several years from Kennewick, WA and Moro, OR , such conditions are expected to occur about 1 percent of the time during the year in the vicinity of the proposed line.

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.

All except Configuration 7 would use three 1.30-inch diameter conductors per phase to yield acceptable corona levels. However, Configuration 7 with split-phase 500-kV circuits on either side of the double circuit tower would employ three 1.60-inch diameter conductors per phase to achieve the required 50 dBA or less at the edge of the right-of-way.

7.3 Predicted Audible Noise Levels

Audible noise levels are calculated for average voltage of 536 kV and average conductor heights for fair- and foul-weather conditions. The predicted levels of corona-generated audible noise at the edge of the right-of-way for the proposed line configurations are given in Table 8. The L_{50} foul-weather levels for the proposed configurations range from 40 to 49 dBA. The highest levels would generally occur when the new 500-kV circuit is at the minimum distance of 75 feet from the edge of the right-of-way. This occurs for Configurations 1, 4, 6, 7, and 10. Predicted profiles of the L_{50} foul-weather levels for Configurations 1 and 7 are shown in Figure 37.

The audible noise levels for the No-action alternative are generally lower than the levels at the same locations with the proposed configurations. For the No-action alternative, the levels at the edges of existing rights-of-way range from ambient to 48 dBA. In this case, the existing McNary – Ross 345-kV and parallel Harvalum - Big Eddy 230-kV lines produce the highest noise levels.

During fair-weather conditions, which occur about 99 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 ambient levels during foul weather at the edges of the right-of-way. This would be especially true in areas where the centerline of the proposed 500-kV line is at 75 feet from the edge of the right-of-way. 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 where the proposed 500-kV line would be placed well away from the edge of the right-of-way.

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 49-dBA for the configurations 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 1 to 2 percent foul weather is about $L_{dn} = L_{50} - 6$ dB (Bracken, 1987). Therefore, assuming such conditions in the Big Eddy Transmission Line Project area, the estimated worst case L_{dn} at the edge of the right-of-way would be approximately 43 dBA, which is below the EPA L_{dn} guideline of 55 dBA.

No transformers will be installed at the new Knight Substation so that the audible noise at the edge of the substation will be due to the transmission lines entering the substation. Since the proposed transmission line will meet the 50 dBA criterion at the edge of the right-of-way, this criterion as it applies to substations will also be met (USDOE, 2006).

At the existing Big Eddy substation audible noise levels will also be predominantly due to foul weather corona noise from incoming and outgoing transmission lines. Noise levels produced from the new transformers will be lower than that from the existing equipment and unnoticeable when added to the existing noise levels at the edge of the substation property.

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

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 cause radio and television interference (RI and TVI). 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. This is especially true of interference with television signals. The bundle of three 1.3-inch (or 1.6-inch) diameter conductors used in the design of the proposed 500-kV line will mitigate corona generation and thus keep radio and television interference levels at acceptable levels.

Spark gaps on distribution lines and on low-voltage wood-pole transmission lines are 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.

8.3 Predicted RI Levels

The L_{50} fair-weather RI levels were predicted for all configurations at the furthest of 100 ft. (30 m) from the outside conductor or the edge of the right-of-way. The results are shown in Table 9. The L_{50} 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.

8.4 Television Interference (TVI)

Corona-caused TVI occurs during foul weather and is generally 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 is the case for RI, gap sources on distribution and low-voltage transmission lines are the principal observed sources of TVI. The use of modern hardware and construction practices for the proposed line would minimize such sources.

8.5 Predicted TVI Levels

The predicted foul-weather TVI levels at 75MHz from the proposed configurations operating at 536 kV are shown in Table 9. These levels are given for the further of 100 ft. (30 m) from the outside conductor or the edge of the right-of-way. The levels at these points range from 2 to 24 dBμV/m depending primarily on the distance from of the proposed 500-kV line. These levels are comparable to or lower than 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.

At the highest predicted levels, there is a potential for interference with television signals at locations very near the proposed line in fringe reception areas. However, several factors reduce the likelihood of occurrence. Corona-generated TVI 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 TVI. Cable television systems are also not affected.

Interference with television reception 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.

8.6 Interference with Other Devices

Corona-generated interference can conceivably cause disruption on other communications bands such as the citizen’s (CB) and mobile bands. However, mobile-radio communications are not susceptible to transmission-line interference because they are generally frequency modulated (FM). Similarly, cellular telephones operate at a frequency of about 900 MHz or higher, which is above the frequency where corona-generated interference is prevalent. In the unlikely event that interference occurs with these or other communications, mitigation can be achieved with the same techniques used for television and AM radio interference.

8.7 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 approximately 10 to 12 houses could be within 500 feet of the proposed line (Table 5) and possibly affected by interference. Whether interference occurs will depend on which 28-mile route alternative and line designs are selected as well as the type of television or radio receiver. 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 photochemical oxidants, of which ozone is the principal component, is 235 micrograms/cubic meter) or 120 parts per billion. 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

The number of nearby houses/businesses that could be impacted by field or corona effects is small and fairly consistent among the three line route alternatives: ranging from 2 to 5 within 300 feet of centerline and from 10 to 12 within 500 feet.

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 electric-field levels from the proposed line at minimum design clearance would be comparable to those from existing 500-kV lines in Washington and elsewhere. The expected magnetic-field levels from the proposed line would be comparable to, or less than, those from other 500-kV lines in Washington, Oregon and elsewhere.

The peak electric field expected under the proposed line would be 8.8 kV/m; the maximum value at the edge of the right-of-way would be about 2.4 kV/m. Clearances at road crossings would be increased to reduce the peak electric-field value to 5 kV/m or less.

Under maximum current conditions, the maximum magnetic fields on and at the edge of the right-of-way vary considerably among configurations: ranging from 219 to 60 mG on the right-of-way and from 82 to less than 1 mG at the edge of the right-of-way. Average values of the fields are much reduced and also vary widely between configurations. The average field value at the edge of the right-of way adjacent to the proposed line ranges from 21 to less than 1 mG depending on right-of-way width and the presence of other lines.

For the No-action alternative, maximum magnetic fields would range from 163 to 0 mG on the right-of-way and from 67 to 0 mG at the edge. For this alternative average fields would be reduced to a maximum of 48 on the right-of-way and 23 at the edge.

The electric fields from the proposed line would meet regulatory limits for public exposure in some states and guidelines set established by IEEE. However, the electric fields from the line could exceed the regulatory limits or guidelines for peak fields established in some states 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 those near existing 500-kV transmission lines in Oregon and Washington, 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. 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. The presence of only 10 to 12 residences/businesses closer than 500 feet (183 m) to the line and the rarity of precipitation conditions when TVI occurs (about 1% of time) make it unlikely that television reception will be affected. However, if legitimate complaints arise, BPA has a mitigation program.

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Table 1: Description of line configurations and associated segments along the proposed Big-Eddy– Knight 500-kV transmission line alternative routes.

Configuration		Line segments[2]	Segment length, miles	Total configuration length by alternative, miles		
No.	**Description[1]**			**West**	**Middle**	**East**
1	BE-KN SglCkt	W-1 thru W-3 W-5 W-8 M-3 M-5 M-7 E-4	3.9 0.8 4.9 1.9 7.6 4.9 14.0	9.6	14.0	14.4
2	BE-KN SglCkt & || HARV-BE	M-1 and M-2 E-1 and E-2	9.2 9.2	-	9.2	9.2
3	BE-KN SglCkt & || McN-RO & || HARV-BE	E-3	4.8	-	-	4.8
4	BE-KN SglCkt & || CHE-GOL	W-6 and W-7 M-6	16.4 2.1	16.4	2.1	-
5	BE-KN SglCkt & || Spearfish Tap	W-4	1.1	1.1	-	-
6	BE-KN SglCkt & ||BE-SPR	M-4	1.3	-	1.3	-
7	BE-KN DblCkt split-phase w/ 3x1.6” bundles	W-1 thru W-3	3.9	3.9	-	-
7A	BE-KN DblCkt tower with SglCkt w/ 3x1.3” bundles on one side	W-1 thru W-3	3.9	3.9	-	-
8	BE-KN DblCkt w/ HARV-BE	M-1 and M-2 E-1 and E-2	9.2 9.2	-	9.2	9.2
9	BE-KN DblCkt w/ McN-RO & ||HARV-BE	E-3	4.8	-	-	4.8
10	BE-KN DblCkt w/ CHE-GOL	W-6 and W-7 M-6	16.4 2.1	16.4	2.1	-
11	BE-KN DblCkt w/ Spearfish Tap	W-4	1.1	1.1	-	-
12	BE-KN DblCkt split phase & || Spearfish Tap	W-4	1.1	1.1	-	-

Notes for Table 1:

1 BE-KN = Big Eddy-Knight; HARV-BE = Harvalum-Big Eddy; McN-RO = McNary-Ross; CHE-GOL = Chenoweth-Goldendale; BE-SPR = Big Eddy Spring Creek; SglCkt = Single circuit; DblCkt = Double circuit; || = parallel to.

2 Physical locations of alternative routes and segments are shown in Figure 1. Segments are numbered from Big Eddy to Knight by route: W = West alternative, M = Middle alternative; E = East alternative

Table 2: Physical and electrical characteristics of transmission lines in the Big Eddy – Knight 500-kV Transmission Line Project corridor.

Line Characteristics	Proposed Line		Existing Lines				
	Big Eddy – Knight 500-kV[2]		Harvalum-Big Eddy 230-kV	McNary-Ross 345-kV	Chenoweth-Goldendale 115-kV[5]	Spearfish Tap 115-kV	Big Eddy-Spring Creek 230 kV
Voltage, kV Maximum/Average[1]	550/536		241.5/232	362/350	0/0	121/118	241.5/237
Circuit Configuration[2]	Single	Double	Single	Single	Single	Single	Single
Proposed Current, A Peak/Average	970/485	485/243	1075/505	630/380	0/0	35/9	872/244
No-action Current, A Peak/Average	-	-	820/410	520/244	0/0	35/9	950/266
Electric Phasing (looking towards Knight)	B A C	A C B B C A	C B A	C A B	B C A	C B A	B A C
Clearance, ft. Minimum/Average[1, 3]	35/47	36/47	32.5/45.4	33.8/47.6	25.9/34.4	25.9/29.5	33.8/46.7
Tower configuration	Delta	DC-Vert	Flat	Flat	Flat	Flat	Flat
Phase spacing, ft.	46H, 31.5V	36.5, 56.5H 36V	27	32	12	12	27
Conductor: #/Diameter, in.	3/1.3	3/1.3 or 3x1.6[2]	1/1.382	1/1.602	1/0.563	1/0.642	1/1.382
Centerline distance to edge of ROW, ft.[4]	75	75	187.5/62.5	312.5/187.5	50	425/50	62.5
Centerline distance to proposed line, ft.	-	-	125	125	125	125	125
Average altitude, ft.	1500	1500	600	600	1600	350	1650

Notes for Table 2:

1 Average voltage and average clearance used for corona calculations.
2 When the proposed Big Eddy – Knight 500-kV line is energized on all six 3x1.6” phase bundles on a double circuit tower (Configuration 7), the three phases of the line will be split between six conductor bundles with each carrying one half of the single-circuit current. When the proposed Big Eddy – Knight 500-kV line is energized with only three 3x1.3” phase bundles on the double circuit tower (Configuration 7A), the non-energized phases will be left ungrounded. In Configuration 7A the energized circuit of the proposed line could be on either the west or east side of the tower. When the proposed Big-Eddy – Knight 500-kV line is on a double circuit tower with one of the existing parallel lines, the respective circuits will have the same voltages and currents as the individual single-circuit lines. When the existing Harvalum - Big Eddy or McNary – Ross line is the parallel line, they will have a 3x1.3” bundle (Configurations 8 and 9). The Chenoweth – Goldendale and Spearfish Tap lines would have a single 1.3” conductor when placed on the double circuit tower (Configurations 10 and 11).
3 To meet the BPA 9 kV/m limit for peak electric field and use consistent design clearances, the minimum clearance for all proposed double-circuit tower configurations was increased to 36 feet.
4 The distance to the west and east) edges of the right-of-way depends on the configuration as shown in Figures 2 – 10.
5 The Chenoweth – Goldendale 115-kV line is normally open at both ends with no current.

Table 3: Calculated maximum and average electric fields for the proposed Big Eddy – Knight 500-kV line operated at maximum voltage by configuration. Configurations are described in Tables 1 and 2. [Note: all 1.3" bundles except Config. 7]

Configuration		**Electric Field, kV/m Proposed Alternative**				**Electric Field, kV/m No-action Alternative**			
No.	**Location**	**Peak on ROW**		**At Edge of ROW[2]**		**Peak on ROW**		**At Edge of ROW[2]**	
	Field Description	**Maximum**	**Average**	**Maximum**	**Average**	**Maximum**	**Average**	**Maximum**	**Average**
1	BE-KN SglCkt	8.6	5.4	2.4, 2.4	2.3, 2.3	-	-	-	-
2	BE-KN SglCkt & HARV-BE	8.6	5.4	2.4, 1.5	2.4, 1.2	2.9	1.7	0.1, 1.3	0.1, 1.1
3	BE-KN SglCkt & McN-RO & HARV-BE[3] Use CAB phasing	8.8	5.8	0.2, 1.3	0.2, 1.1	4.5	2.6	<0.1, 1.3	<0.1, 1.1
4	BE-KN SglCkt & CHE-GOL	8.6	5.4	2.4, 0.3	2.3, 0.3	0.0	0.0	0.0	0.0
5	BE-KN SglCkt & Spearfish Tap	8.6	5.4	0.1, 0.2	0.1, 0.2	1.2	1.0	0.1, 0.4	0.2, 0.4
6	BE-KN SglCkt & BE-SPR	8.6	5.4	2.4, 1.4	2.3, 1.2	2.7	1.6	1.3, 1.3	1.1, 1.1
7	BE-KN DblCkt w/ 3x1.6" bundles[3]	7.3	4.3	1.3, 1.3	1.3, 1.3	-	-	-	-
7A	BE-KN DblCkt w/ only 1 circuit[3]	8.8	5.8	1.3, 0.1	1.4, 0.3	-	-	-	-
8	BE-KN DblCkt w/ HARV-BE[3]	7.9	4.9	0.3, 0.5	0.2, 0.4	2.9	1.7	1.3, 0.1	1.1, 0.1
9	BE-KN DblCkt w/ McN-RO & HARV-BE[3]	7.6	4.6	0.1, 1.3	0.1, 1.1	4.5	2.6	<0.1, 1.3	<0.1, 1.1
10	BE-KN DblCkt w/ CHE-GOL[3]	8.7	5.7	1.3, 0.1	1.4, 0.2	0.0	0.0	0.0	0.0
11	BE-KN DblCkt w/ Spearfish Tap[3]	8.5	5.6	0.1, 0.2	0.1, <0.1	1.2	1.0	0.0, 0.4	0.2, 0.4
12	BE-KN DblCkt & Spearfish Tap[3]	7.0	4.2	0.1, 0.3	0.1, 0.3	1.2	1.0	0.0, 0.4	0.2, 0.4

Notes for Table 3:

1 BE-KN = Big Eddy-Knight; HARV-BE = Harvalum- Big Eddy; McN-RO = McNary-Ross; CHE-GOL = Chenoweth-Goldendale; BE-SPR = Big Eddy Spring Creek; SngCkt = Single circuit; DblCkt = Double circuit

2 Field at west (north) edge of ROW shown first.

3 To meet the BPA 9 kV/m limit for peak electric field and use consistent design clearances, the minimum clearance for all proposed double-circuit tower configurations was increased to 36 feet.

Table 4: Calculated maximum and average magnetic fields for the proposed Big Eddy – Knight 500-kV line operated at maximum current/minimum clearance and average current/average clearance. Configurations are described in Tables 1 and 2.

Configuration[1]		**Magnetic Field, mG Proposed Alternative**				**Magnetic Field, mG No-action Alternative**			
No.	**Location** **Field Description**	**Peak on ROW**		**At Edge of ROW[2]**		**Peak on ROW**		**At Edge of ROW[2]**	
		Maximum	**Average**	**Maximum**	**Average**	**Maximum**	**Average**	**Maximum**	**Average**
1	BE-KN SglCkt	159	50	42, 42	18, 18	-	-	-	-
2	BE-KN SglCkt & HARV-BE	219	65	49, 82	21, 31	163	48	7, 60	3, 22
3	BE-KN SglCkt & McN-RO & HARV-BE	214	62	7, 78	3, 29	161	46	3, 61	2, 23
4	BE-KN SglCkt & CHE-GOL	159	50	42, 8	18, 4	0	0	0	0
5	BE-KN SglCkt & Spearfish Tap	160	50	3, 8	1, 4	7	2	0, 2	0, <1
6	BE-KN SglCkt & BE-SPR	155	49	43, 64	18, 14	176	31	67, 67	15, 15
7	BE-KN DblCkt w/ 3x1.6" bundles	60	17	14, 14	6, 6	-	-	-	-
7A	BE-KN DblCkt w/ only 3 bundles	118	38	52, 29	21, 13	-	-	-	-
8	BE-KN DblCkt w/ HARV-BE	128	35	3, 33	2, 12	163	48	7, 60	3, 22
9	BE-KN DblCkt w/ McN-RO & HARV-BE	212	61	3, 79	1, 29	161	46	3, 61	2, 23
10	BE-KN DblCkt w/ CHE-GOL 36'	117	38	52, 29	21, 13	0	0	0	0
11	BE-KN DblCkt w/ Spearfish Tap 36'	116	38	3, 27	1, 13	7	2	0, 2	0, <1
12	BE-KN DblCkt & Spearfish Tap	60	17	<1, 3	<1, 1	7	2	0, 2	0, <1

Notes for Table 4:

1 BE-KN = Big Eddy-Knight; HARV-BE = Harvalum- Big Eddy; McN-RO = McNary-Ross; CHE-GOL = Chenoweth-Goldendale; BE-SPR = Big Eddy Spring Creek; SngCkt = Single circuit; DblCkt = Double circuit

2 Field at west (north) edge of ROW shown first.

3 To meet the BPA 9 kV/m limit for peak electric field and use consistent design clearances, the minimum clearance for all proposed double-circuit tower configurations was increased to 36 feet.

Table 5: **Locations and ranges of average and maximum magnetic fields at residences and businesses near proposed line by primary circuit configuration and line route.**

Primary Configuration	**Single Circuit**			**Double Circuit+**		
Route Alternative	**East***	**Middle***	**West**	**East**	**Middle**	**West**
Houses < 300 ft	3	2	4	5	4	4
Houses < 500 ft	12	11	10	10	10	10
Range of Distances from Centerline, ft	71 - 484	71 - 425	203 - 486	191 - 484	191 - 495	203 - 486
Range of Average Magnetic Field, mG	0.5 - 22.3	0.7 - 22.3	0.5 - 3.1	0.3 - 1.8	0.1 - 1.8	0.1 - 3.5
Range of Maximum Magnetic Field, mG	1.1 - 45	1.4 - 45	1.1 - 6.2	0.7 - 4.6	0.2 - 4.5	0.2 - 7

* A single house at 71 feet from the proposed centerline contributes the high field levels along the East and Middle alternatives.

+ Double circuit configuration counts include houses from single circuit sections E-4 and M-5, where no double circuit is planned.

Table 6: 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	833
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, 2008; ICNIRP, 1998; ICES, 2002

Table 7: 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 Environmental 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.

Notes for Table 6:
1 At road crossings
2 Landowner may waive limit
3 At highway and private road crossings, respectively

Source: USDOE, 1996

Table 8: 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, 1985; USDOE, 1996.

Table 9: Calculated median (L_{50}) foul-weather audible noise levels at the edge of the right-of-way for the proposed Big Eddy – Knight 500-kV line operated at average voltage. Configurations are described in Table 1.

Configuration		**Foul weather L50 Audible Noise, dBA**	
No.	**Description[1]**	**Proposed Alternative[2]**	**No-action Alternative[2]**
1	BE-KN SglCkt	49, 49	-
2	BE-KN SglCkt & HARV-BE	48, 45	30, 35
3	BE-KN SglCkt & McN-RO & HARV-BE	48, 49	45, 48
4	BE-KN SglCkt & CHE-GOL	49, 46	-
5	BE-KN SglCkt & Spearfish Tap	42, 45	13, 23
6	BE-KN SglCkt & BE-SPR	49, 46	37, 37
7	BE-KN DblCkt w/ 3x1.6” bundles	49, 49	-
7A	BE-KN DblCkt w/ only SglCkt on west side	48, 46	-
8	BE-KN DblCkt w/ HARV-BE	45, 47	30, 35
9	BE-KN DblCkt w/ McN-RO & HARV-BE	43, 44	45, 48
10	BE-KN DblCkt w/ CHE-GOL	49, 47	-
11	BE-KN DblCkt w/ Spearfish Tap	40, 46	13, 23
12	BE-KN DblCkt & Spearfish Tap	46, 48	13, 23

Notes for Table 8:

1 BE-KN = Big Eddy-Knight; HARV-BE = Harvalum-Big Eddy; McN-RO = McNary-Ross; CHE-GOL = Chenoweth-Goldendale; BE-SPR = Big Eddy Spring Creek; SglCkt = Single circuit; DblCkt = Double circuit

2 Field at west (north) edge of ROW shown first.

Table 10 Calculated median (L_{50}) fair-weather radio interference level and foul weather television level for the proposed Big Eddy – Knight 500-kV line operated at average voltage. Configurations are described in Table 1.

Configuration		L50 Fair-Weather RI Level at 1 MHz, dB(μV/m)[2]	Foul-Weather TVI at 75 MHz, dB(μV/m) [2]
No.	**Description[1]**		
1	BE-KN SglCkt	39, 39	24, 24
2	BE-KN SglCkt & HARV-BE	39, 31	23, 10
3	BE-KN SglCkt & McN-RO & HARV-BE	34, 31	16, 13
4	BE-KN SglCkt & CHE-GOL	39, 36	24, 17
5	BE-KN SglCkt & Spearfish Tap	29, 35	6, 16
6	BE-KN SglCkt & BE-SPR	39, 32	24, 11
7	BE-KN DblCkt w/ 3x1.6” bundles	38, 38	21, 21
7A	BE-KN DblCkt w/ only 3 bundles	41, 37	23, 18
8	BE-KN DblCkt w/ HARV-BE	37, 38	17, 18
9	BE-KN DblCkt w/ McN-RO & HARV-BE	33, 33	7, 8
10	BE-KN DblCkt w/ CHE-GOL	41, 37	23, 18
11	BE-KN DblCkt w/ Spearfish Tap	25, 36	2, 17
12	BE-KN DblCkt & Spearfish Tap	34, 36	8, 13

Notes for Table 9:

1 BE-KN = Big Eddy-Knight; HARV-BE = Harvalum- Big Eddy; McN-RO = McNary-Ross; CHE-GOL = Chenoweth-Goldendale; BE-SPR = Big Eddy Spring Creek; SglCkt = Single circuit; DblCkt = Double circuit

2 Field at west (north) side of ROW shown first. Calculated levels shown at 100 feet (30 m) from the outside conductor or at the edge of the right-of-way, whichever is further from the conductor.

Figure 1: Alternative Routes and Segments for the Proposed Big Eddy – Knight 500-kV Transmission Line.

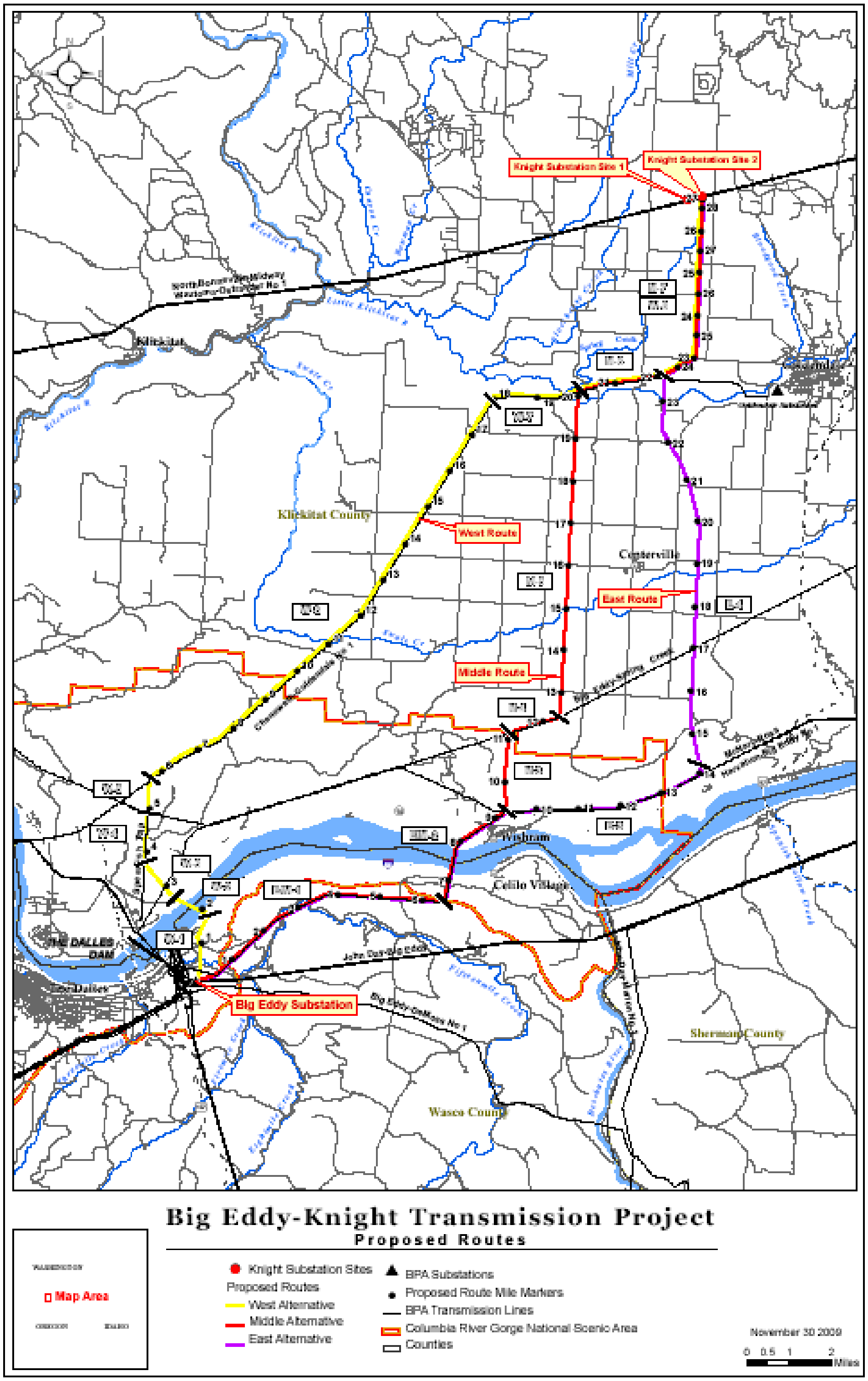
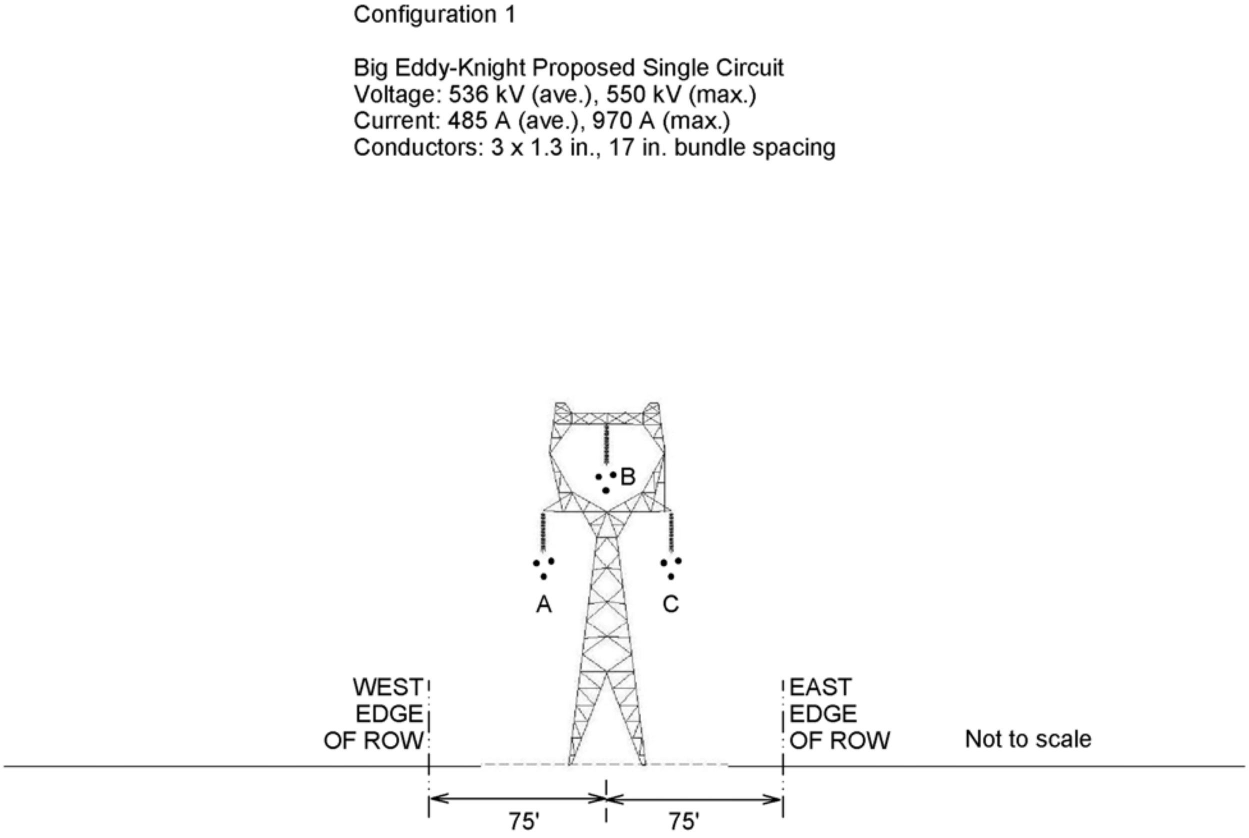


Figure 2: Single-circuit Configuration 1 for the proposed Big Eddy – Knight 500-kV line. Configurations are described in Tables 1 and 2.


Configuration 1

Big Eddy-Knight Proposed Single Circuit
Voltage: 536 kV (ave.), 550 kV (max.)
Current: 485 A (ave.), 970 A (max.)
Conductors: 3 x 1.3 in., 17 in. bundle spacing

Figure 3: Single-circuit Configuration 2 for the proposed Big Eddy – Knight 500-kV line. Configurations are described in Tables 1 and 2.

Configuration 2

Big Eddy-Knight Proposed Single Circuit
Voltage: 536 kV (ave.), 550 kV (max.)
Current: 485 A (ave.), 970 A (max.)
Conductors: 3 x 1.3 in., 17 in. bundle spacing

Harvalum-Big Eddy Single Circuit
Voltage: 232 kV (ave.), 241.5 kV (max.)
Current: 505 A (ave.), 1075 A (max.)
Conductors: 1 x 1.382 in.

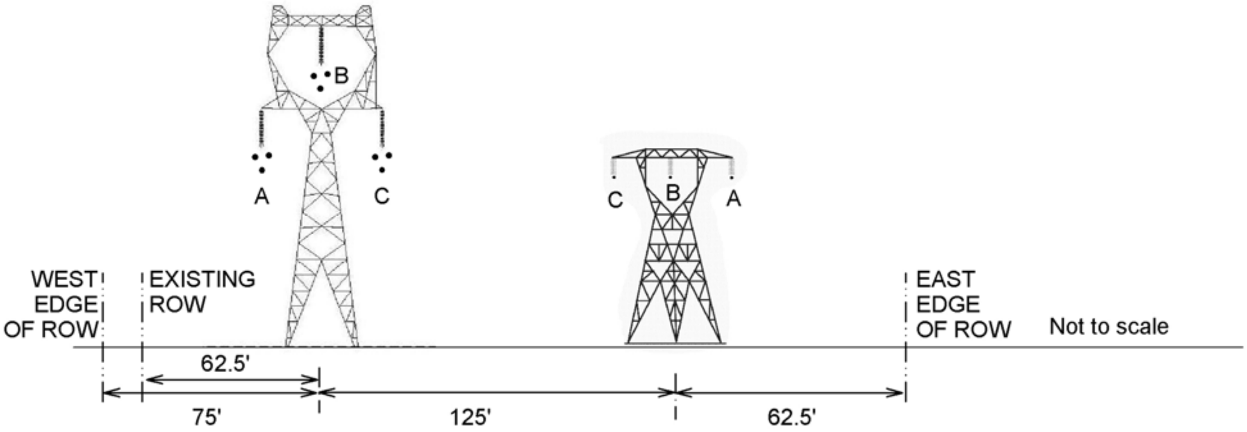


Figure 4: Single-circuit Configuration 3 for the proposed Big Eddy – Knight 500-kV line. Configurations are described in Tables 1 and 2.

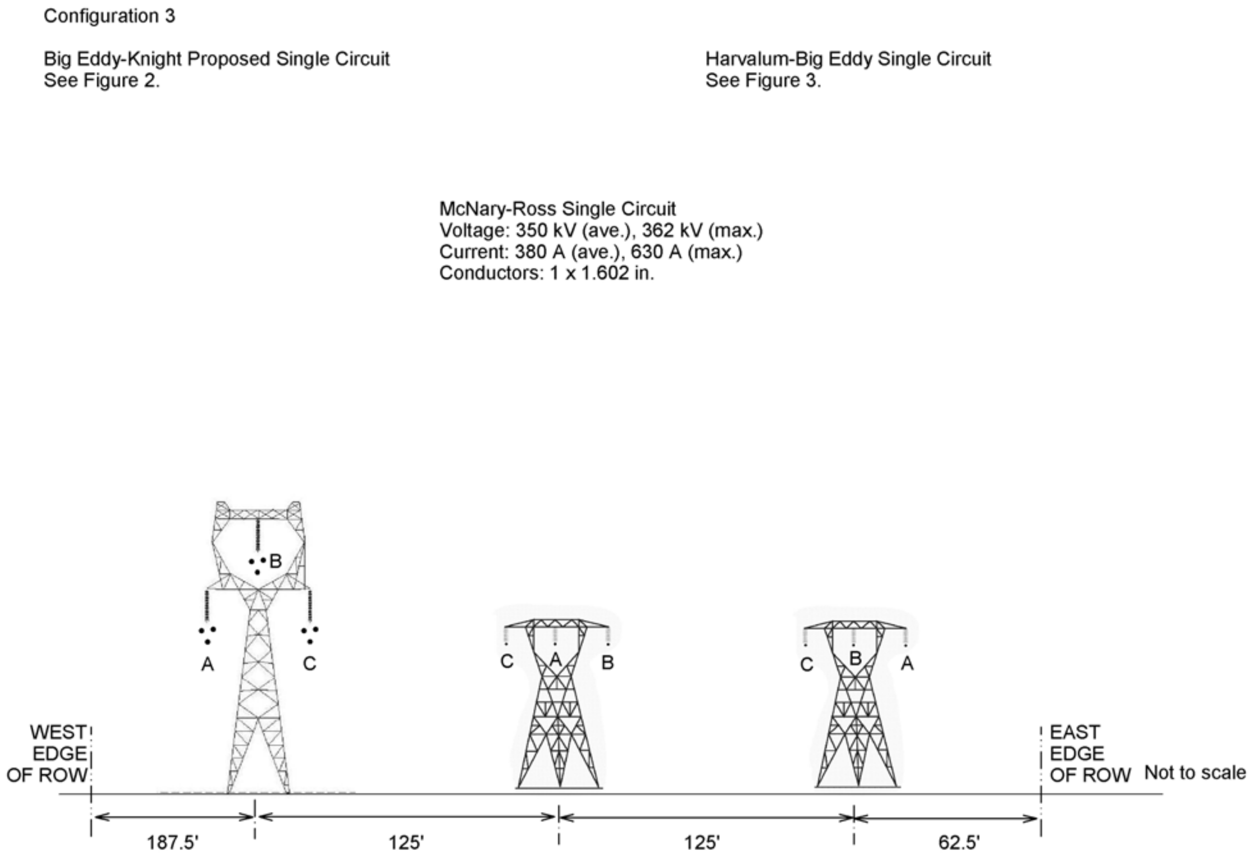
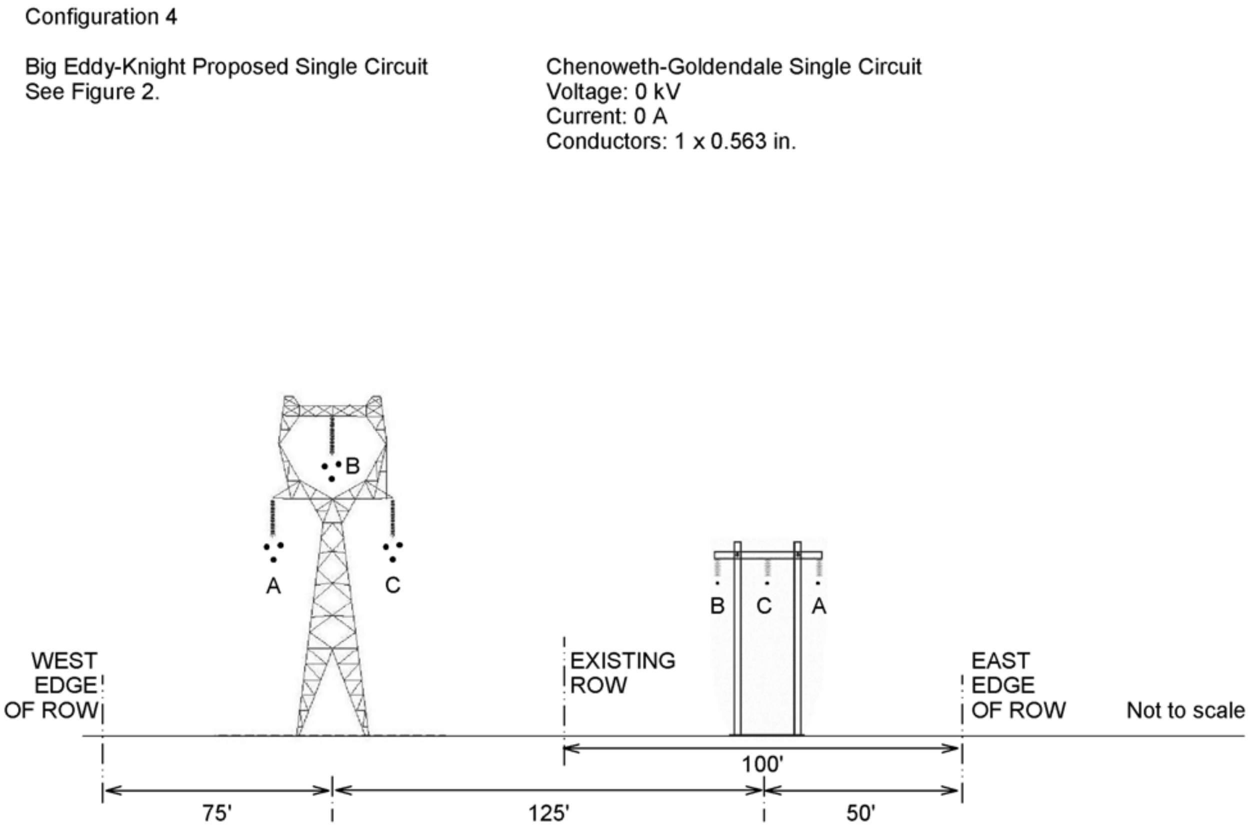


Figure 5: Single-circuit Configuration 4 for the proposed Big Eddy – Knight 500-kV line. Configurations are described in Tables 1 and 2.



Configuration 4

Big Eddy-Knight Proposed Single Circuit
See Figure 2.

Chenoweth-Goldendale Single Circuit
Voltage: 0 kV
Current: 0 A
Conductors: 1 x 0.563 in.

Figure 6: Single-circuit Configuration 5 for the proposed Big Eddy – Knight 500-kV line. Configurations are described in Tables 1 and 2.

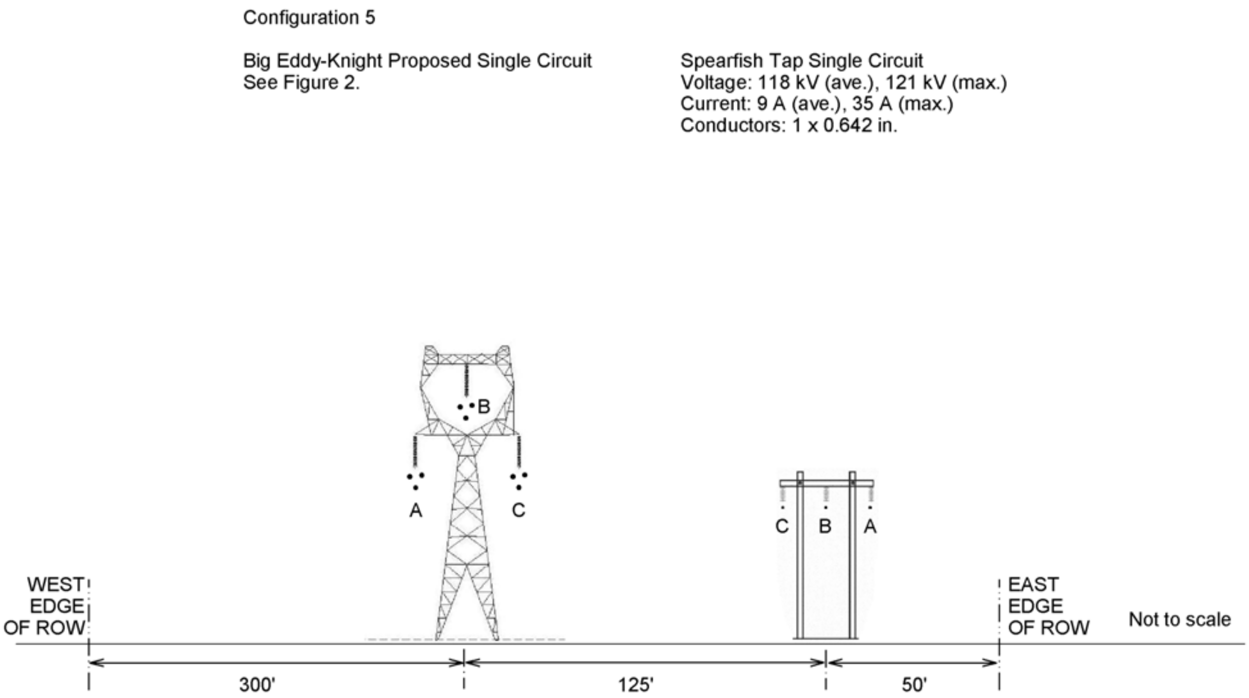
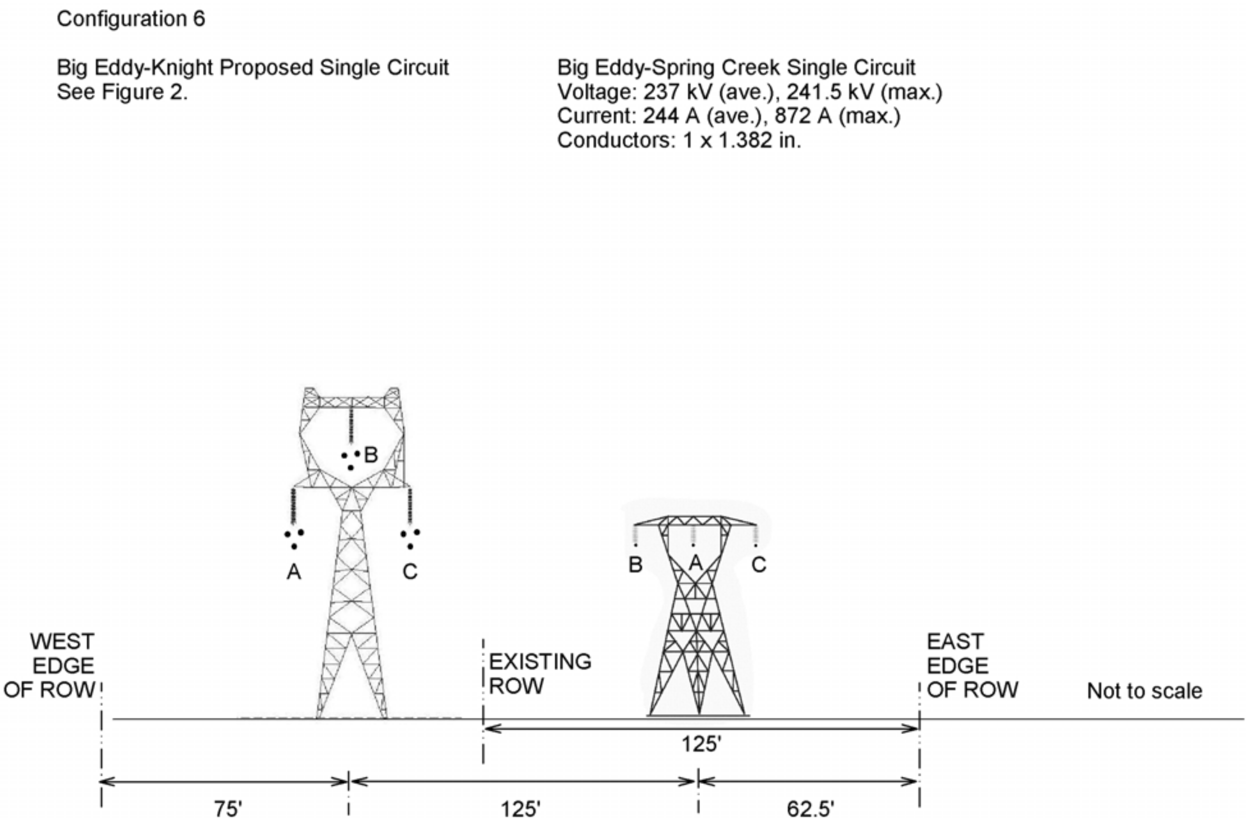


Figure 7: Single-circuit Configuration 6 for the proposed Big Eddy – Knight 500-kV line. Configurations are described in Tables 1 and 2.



Configuration 6

Big Eddy-Knight Proposed Single Circuit
See Figure 2.

Big Eddy-Spring Creek Single Circuit
Voltage: 237 kV (ave.), 241.5 kV (max.)
Current: 244 A (ave.), 872 A (max.)
Conductors: 1 x 1.382 in.

Figure 8: Double-circuit Configurations 7 and 7A for the proposed Big Eddy – Knight 500-kV line. The current is split between the two circuits in Configuration 7. The current is only on the west circuit in Configuration 7A and the east circuit conductors carry zero current and are not grounded. Configurations are described in Tables 1 and 2.

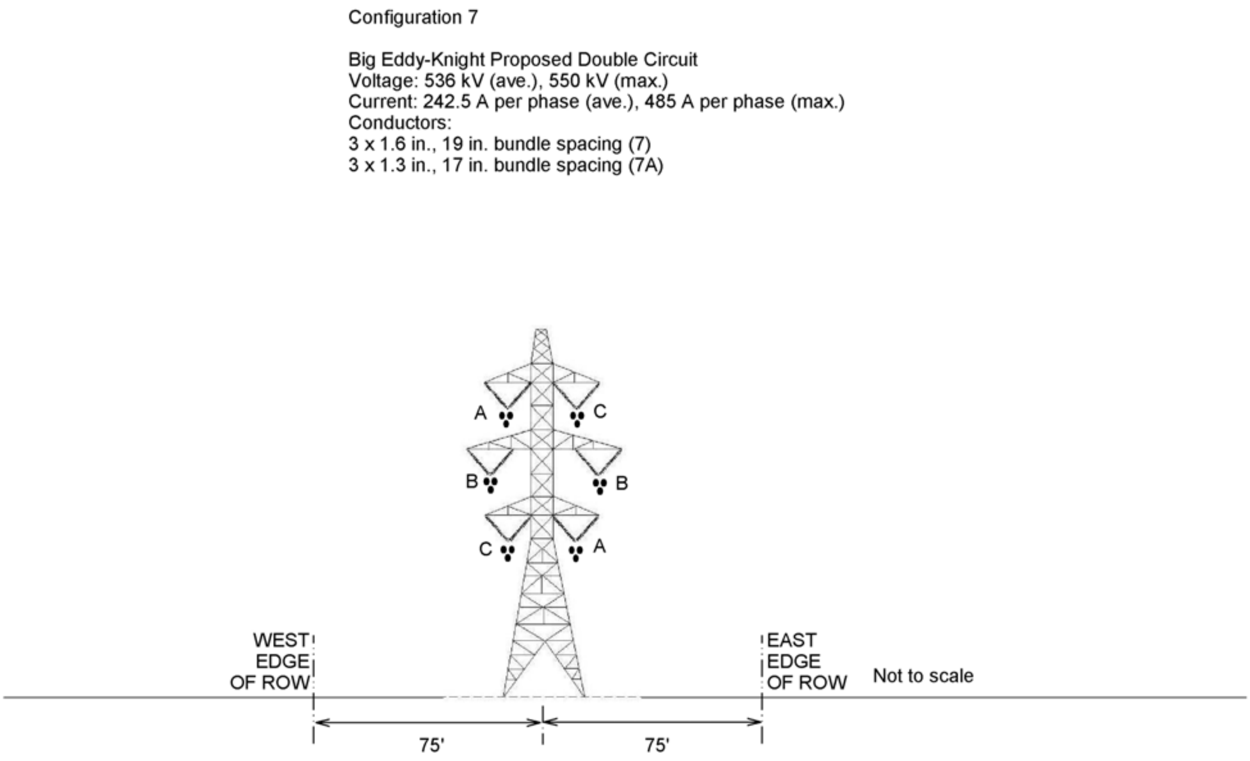


Figure 9: Double-circuit Configuration 8 for the proposed Big Eddy – Knight 500-kV line. Configurations are described in Tables 1 and 2.

Configurations 8

Big Eddy-Knight Proposed Double Circuit	Harvalum-Big Eddy 230 kV
Voltage: 536 kV (ave.), 550 kV (max.)	Voltage: 232 kV (ave.), 241.5 kV (max.)
Current: 485 A (ave.), 970 A (max.)	Current: 505 A (ave.), 1075 A (max.)
Conductors: 3 x 1.3 in., 17 in. bundle spacing	Conductors: 3 x 1.3 in., 17 in. bundle spacing

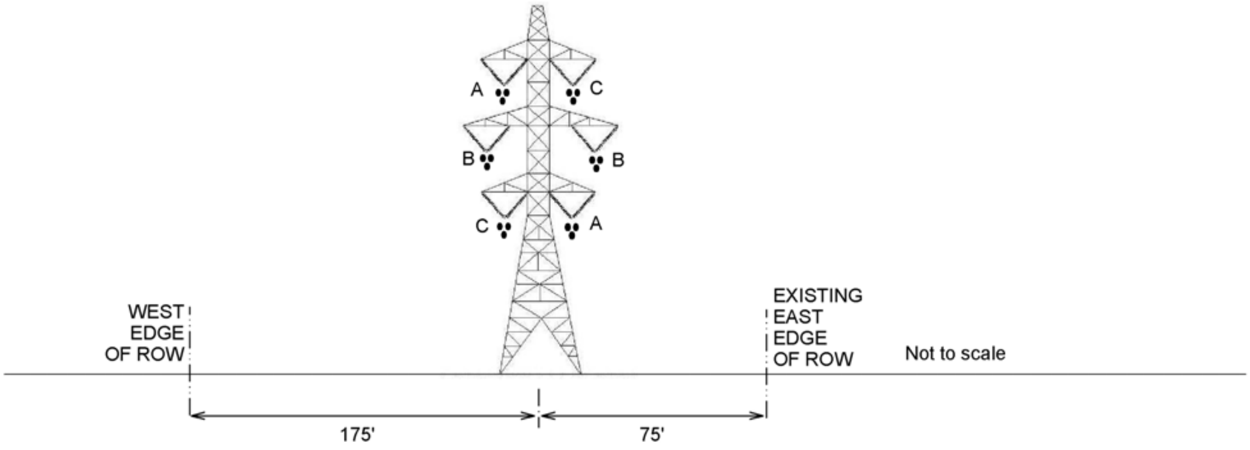


Figure 10: Double-circuit Configuration 9 for the proposed Big Eddy – Knight 500-kV line. Configurations are described in Tables 1 and 2.

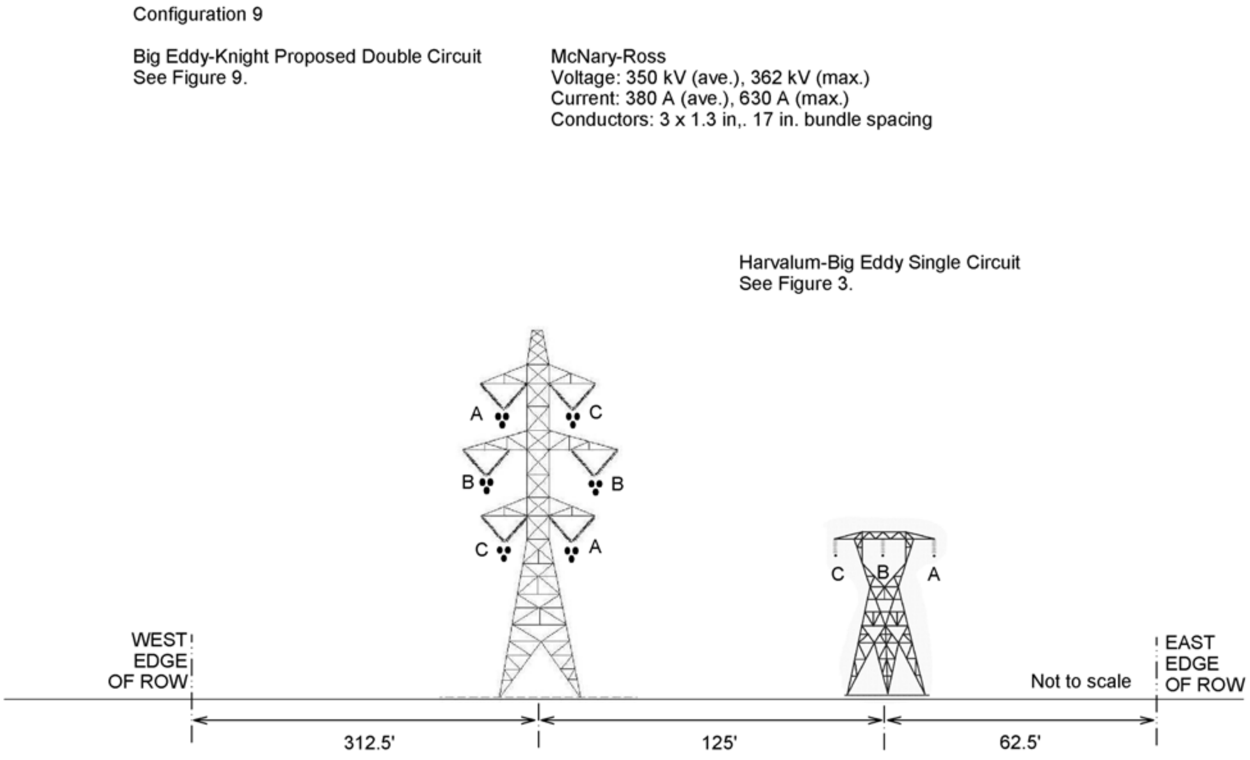


Figure 11: Double-circuit Configurations 10 and 11 for the proposed Big Eddy – Knight 500-kV line. The west circuit will be the proposed Big Eddy – Knight line and the east circuit will be the existing Chenoweth – Goldendale line (Configuration 10) or the existing Spearfish Tap line (Configuration 11). Configurations are described in Tables 1 and 2.

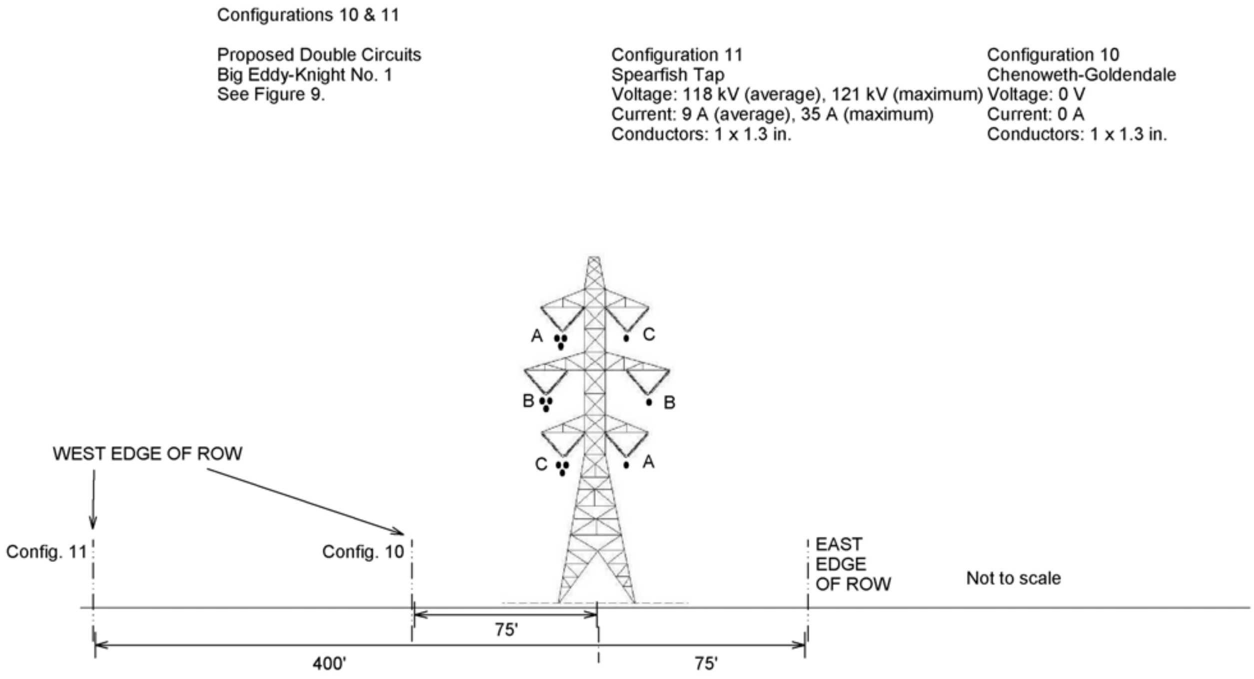


Figure 12: Double-circuit Configuration 12 for the proposed Big Eddy – Knight 500-kV line. Configurations are described in Tables 1 and 2.

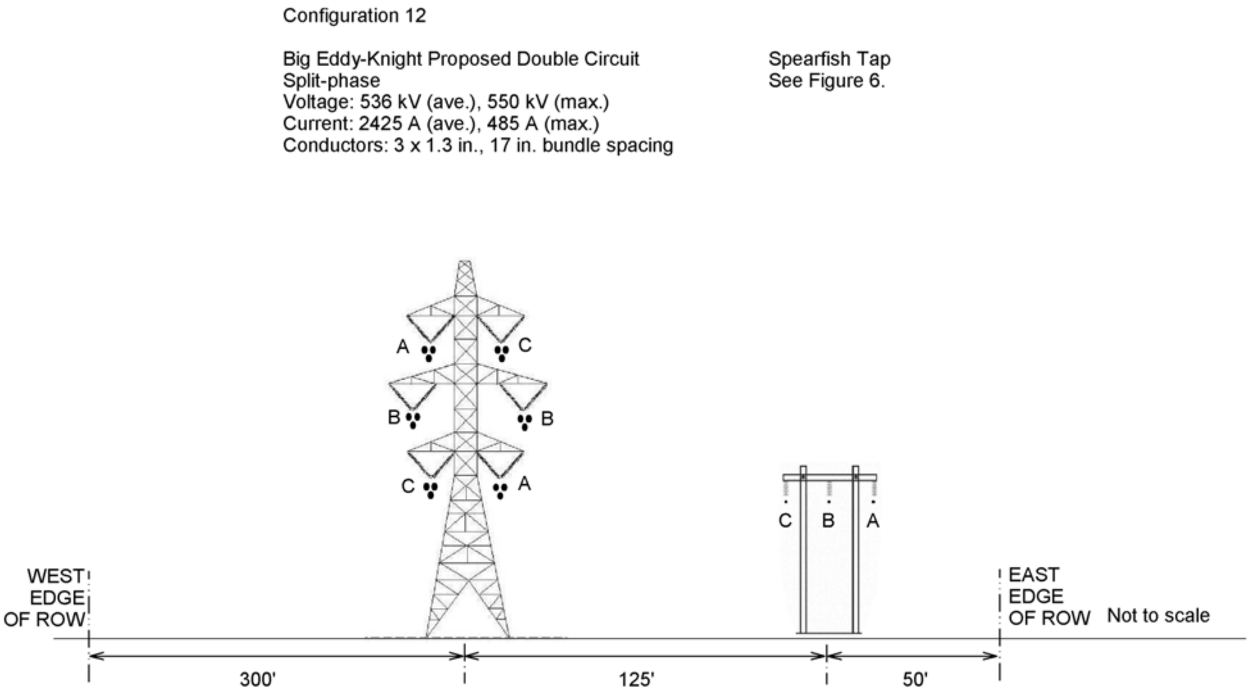


Figure 13: Electric-field profiles for single-circuit Configuration 1 of the proposed Big Eddy – Knight 500-kV line. Fields for maximum voltage with minimum and average clearances are shown. Configurations are described in Tables 1 and 2.

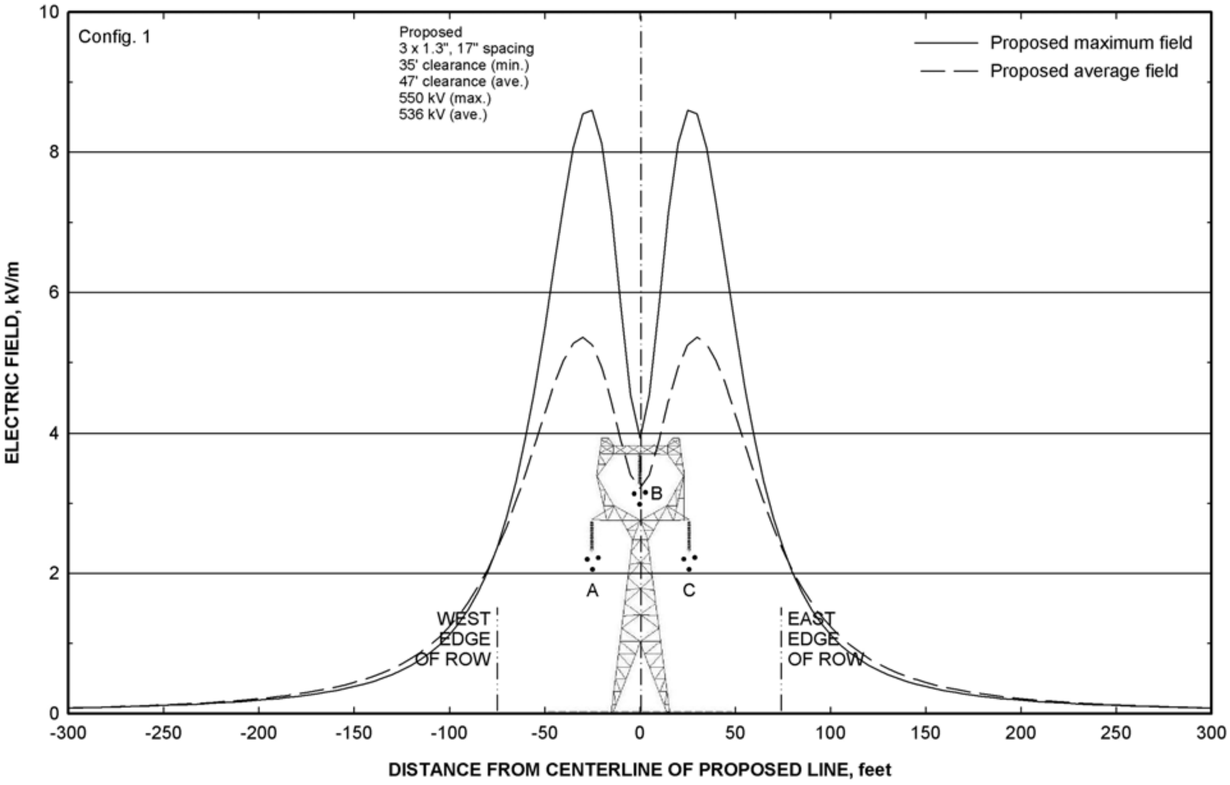


Figure 14: Electric-field profiles for single-circuit Configuration 2 of the proposed Big Eddy – Knight 500-kV line. Fields for maximum voltage with minimum and average clearances are shown. Configurations are described in Tables 1 and 2.

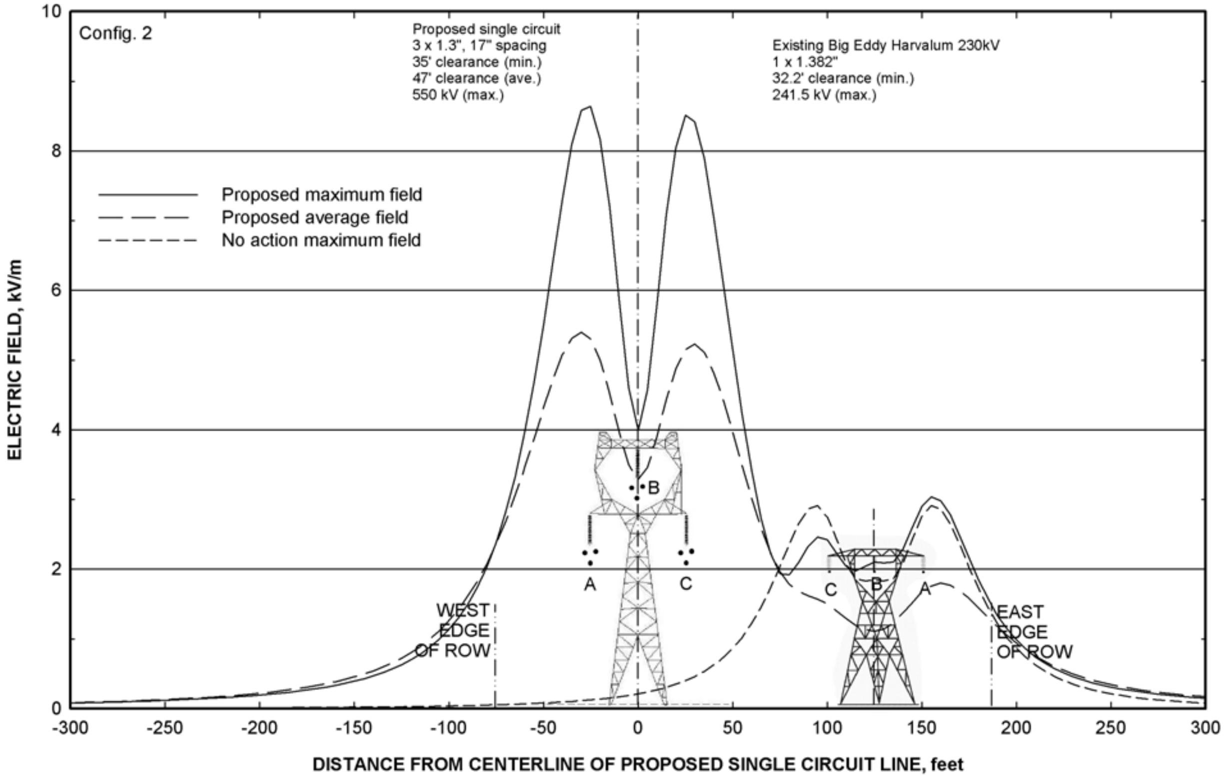


Figure 15: Electric-field profiles for single-circuit Configuration 3 of the proposed Big Eddy – Knight 500-kV line. Fields for maximum voltage with minimum and average clearances are shown. Configurations are described in Tables 1 and 2.

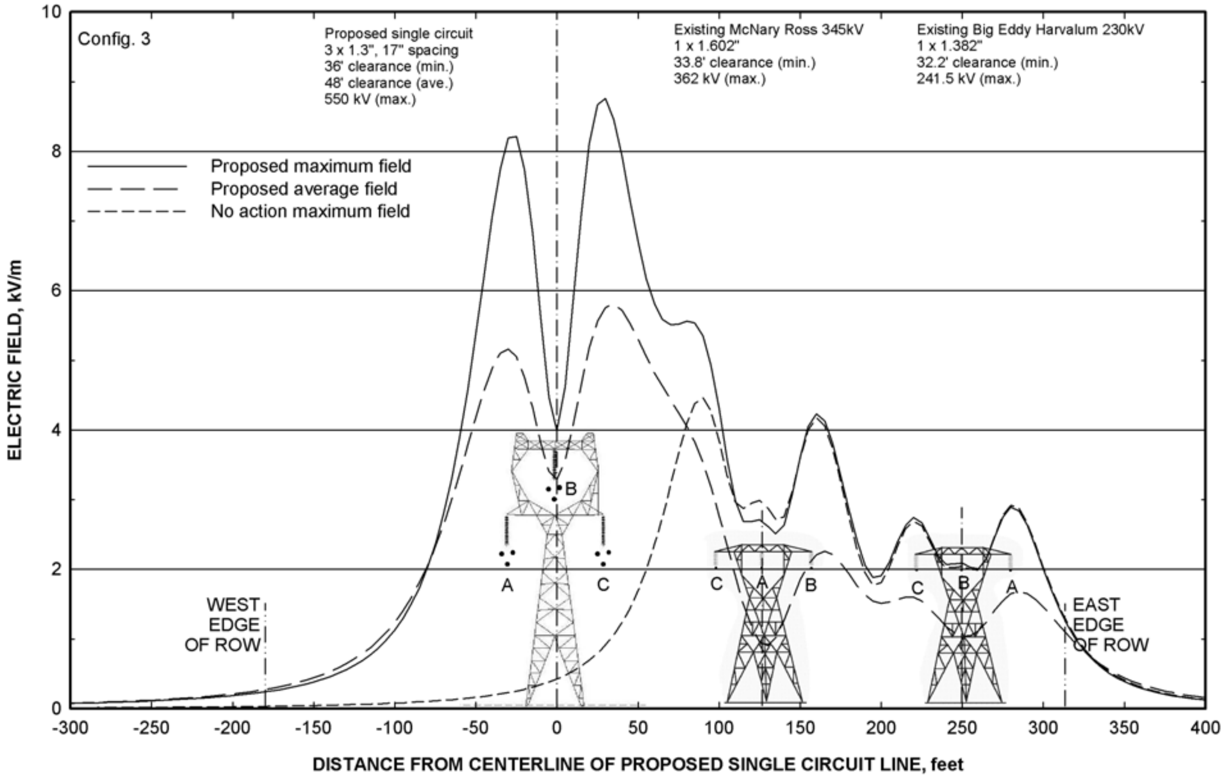


Figure 16: Electric-field profiles for single-circuit Configuration 4 of the proposed Big Eddy – Knight 500-kV line: Fields for maximum voltage with minimum and average clearances are shown. Configurations are described in Tables 1 and 2.

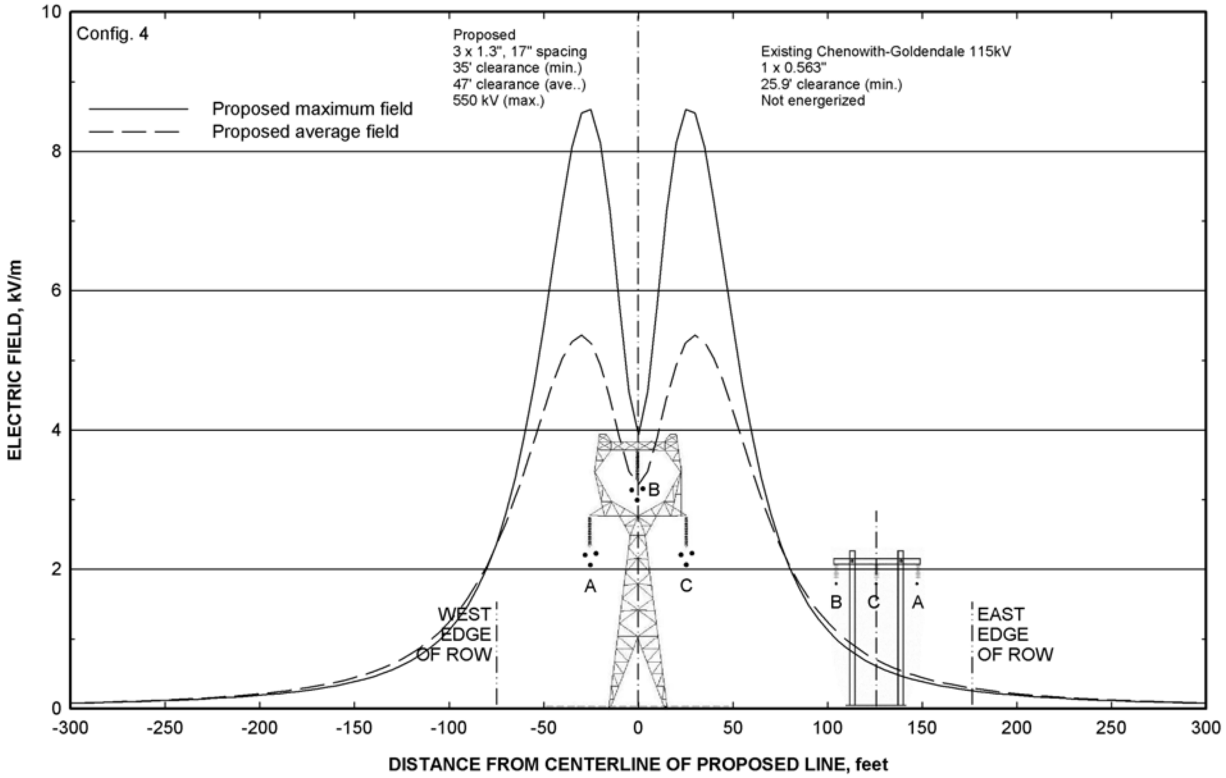


Figure 17: Electric-field profiles for single-circuit Configuration 5 of the proposed Big Eddy – Knight 500-kV line: Fields for maximum voltage with minimum and average clearances are shown. Configurations are described in Tables 1 and 2.

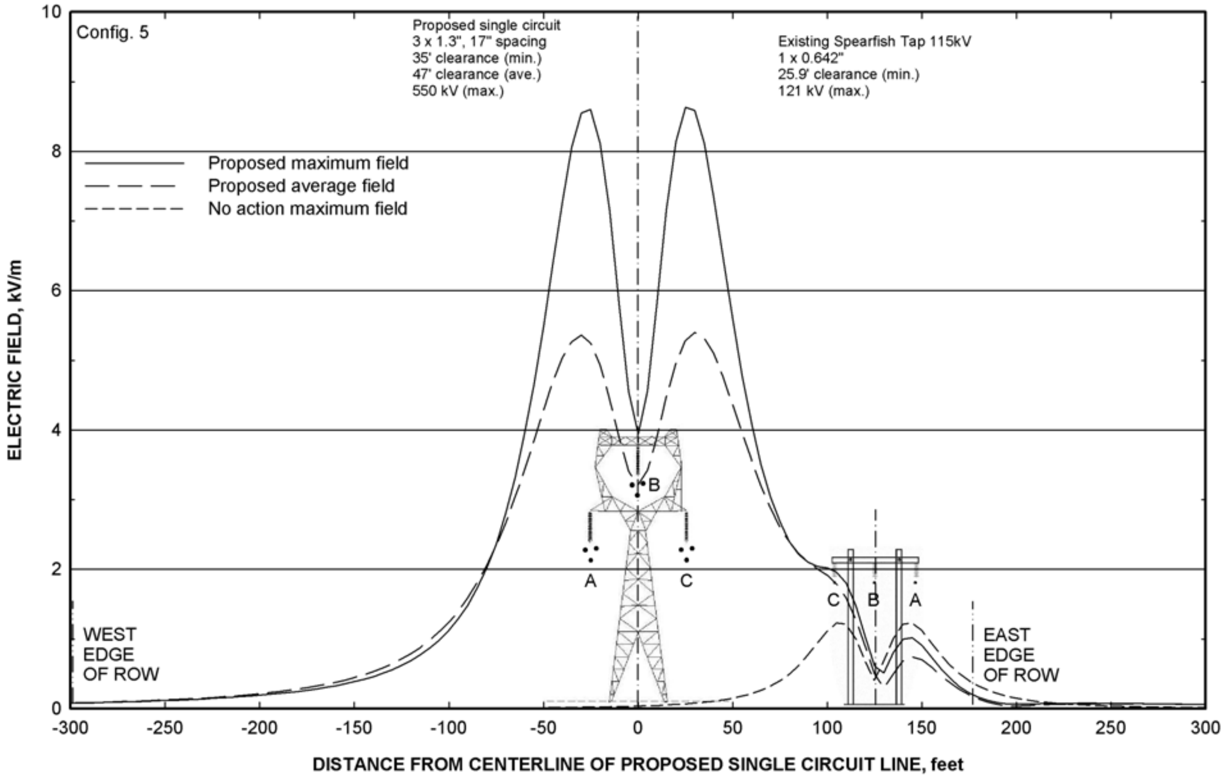


Figure 18: Electric-field profiles for single-circuit Configuration 6 of the proposed Big Eddy – Knight 500-kV line: Fields for maximum voltage with minimum and average clearances are shown. Configurations are described in Tables 1 and 2.

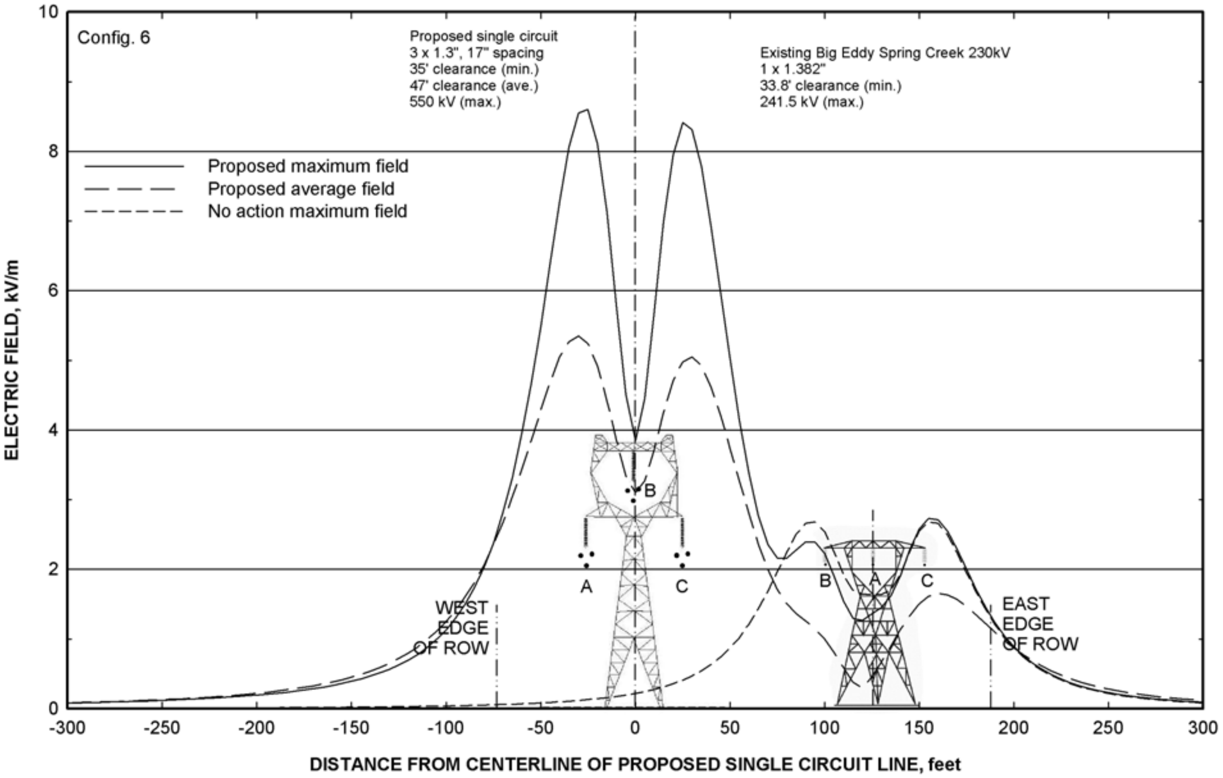


Figure 19: Electric-field profiles for double-circuit Configurations 7 and 7A of the proposed Big Eddy – Knight 500-kV line: Fields for maximum voltage with minimum and average clearances are shown. Configurations are described in Tables 1 and 2.

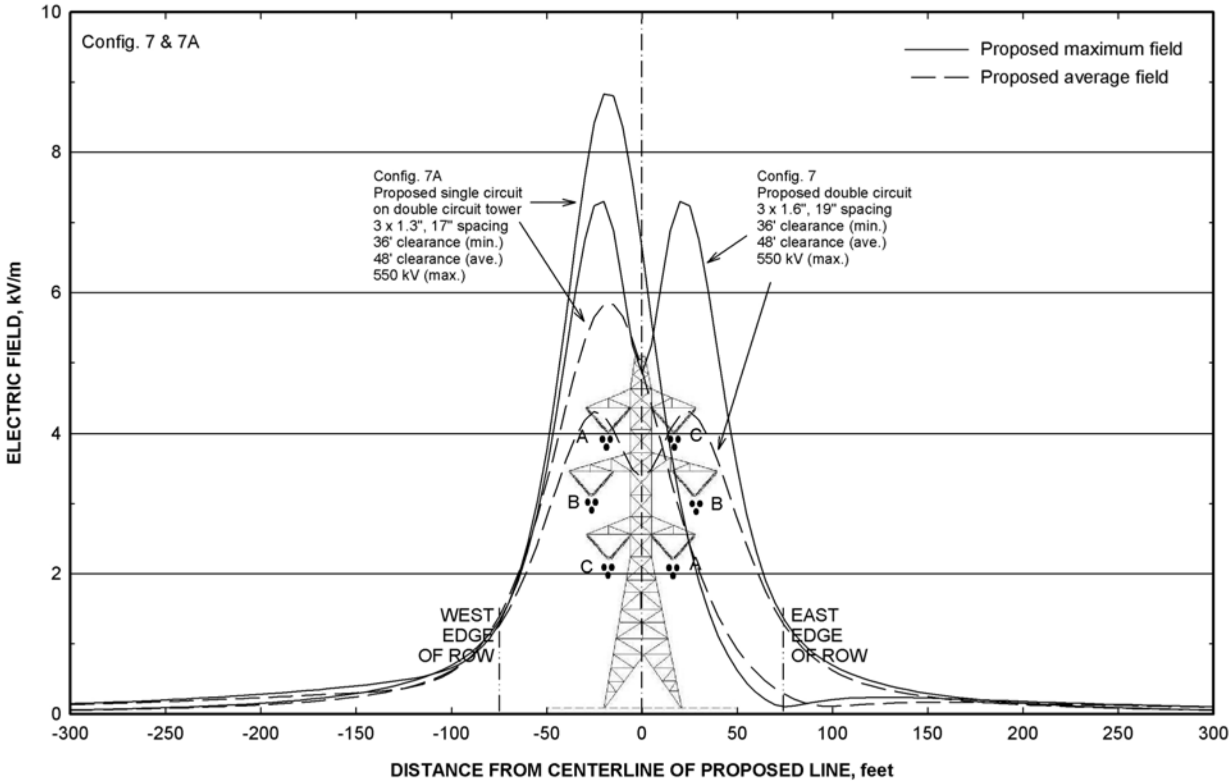


Figure 20: **Electric-field profiles for double-circuit Configuration 8 of the proposed Big Eddy – Knight 500-kV line.** Fields for maximum voltage with minimum and average clearances are shown. Configurations are described in Tables 1 and 2.

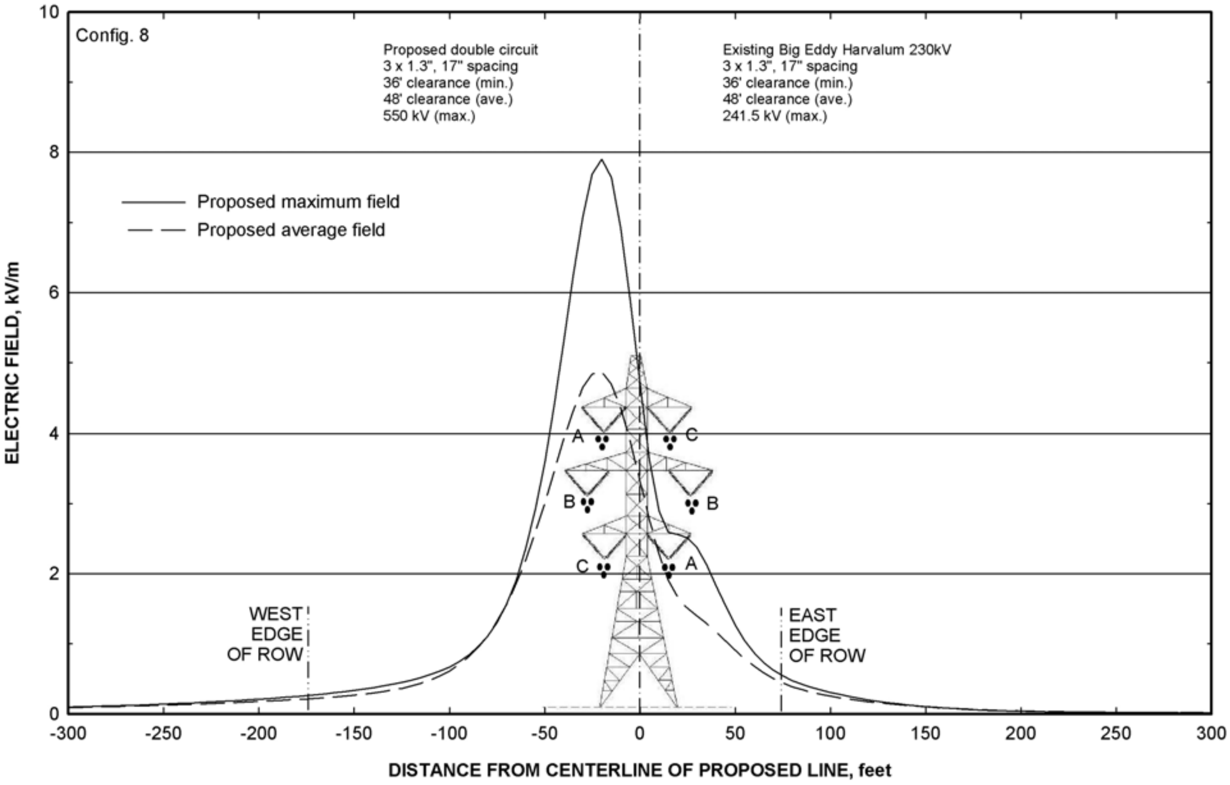


Figure 21: Electric-field profiles for double-circuit Configuration 9 of the proposed Big Eddy – Knight 500-kV line: Fields for maximum voltage with minimum and average clearances are shown. Configurations are described in Tables 1 and 2.

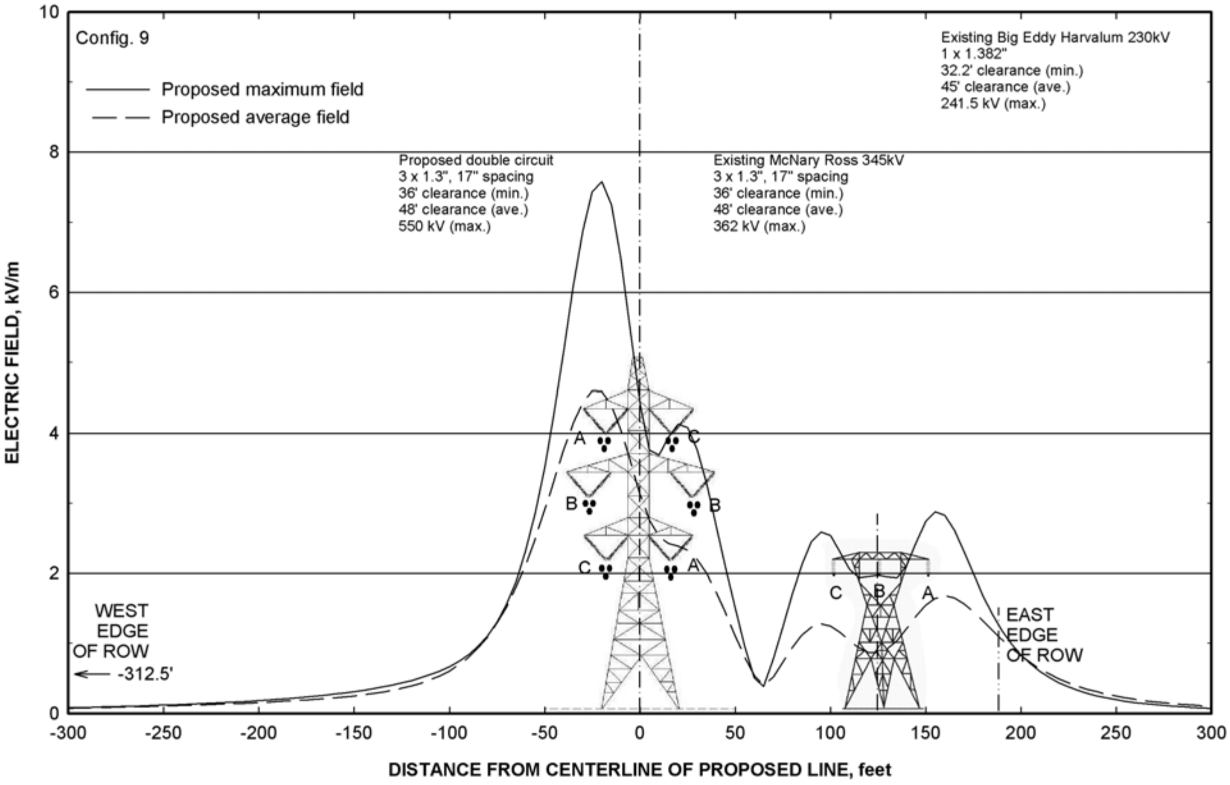


Figure 22: Electric-field profiles for double-circuit Configuration 10 of the proposed Big Eddy – Knight 500-kV line: Fields for maximum voltage with minimum and average clearances are shown. Configurations are described in Tables 1 and 2.

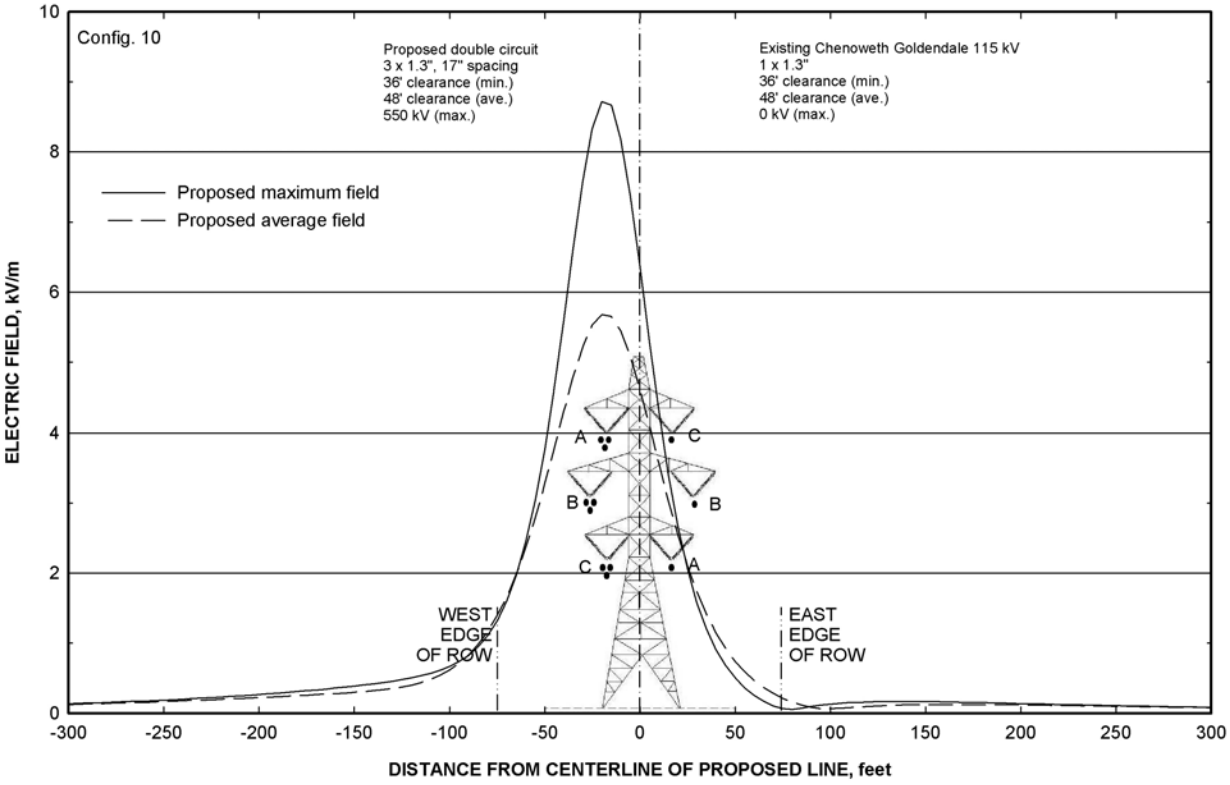


Figure 23: Electric-field profiles for double-circuit Configuration 11 of the proposed Big Eddy – Knight 500-kV line: Fields for maximum voltage with minimum and average clearances are shown. Configurations are described in Tables 1 and 2.

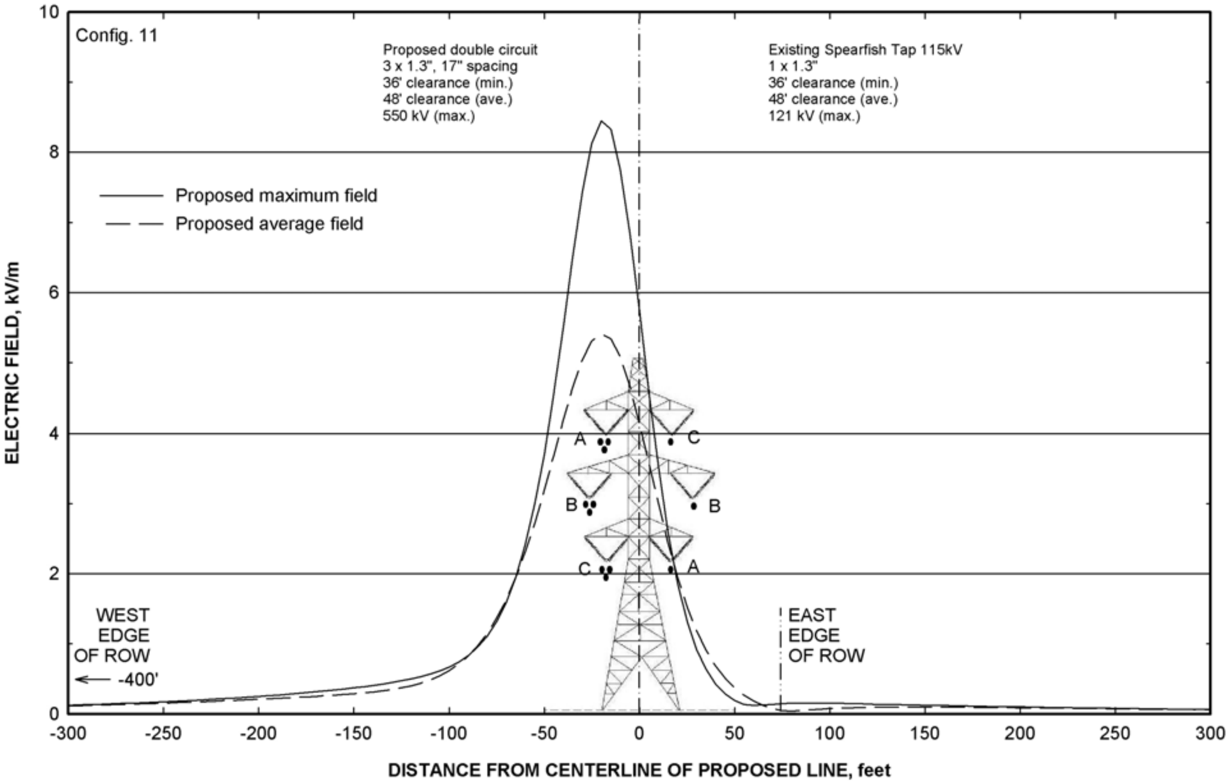


Figure 24: **Electric-field profiles for double-circuit Configuration 12 of the proposed Big Eddy – Knight 500-kV line:** Fields for maximum voltage with minimum and average clearances are shown. Configurations are described in Tables 1 and 2.

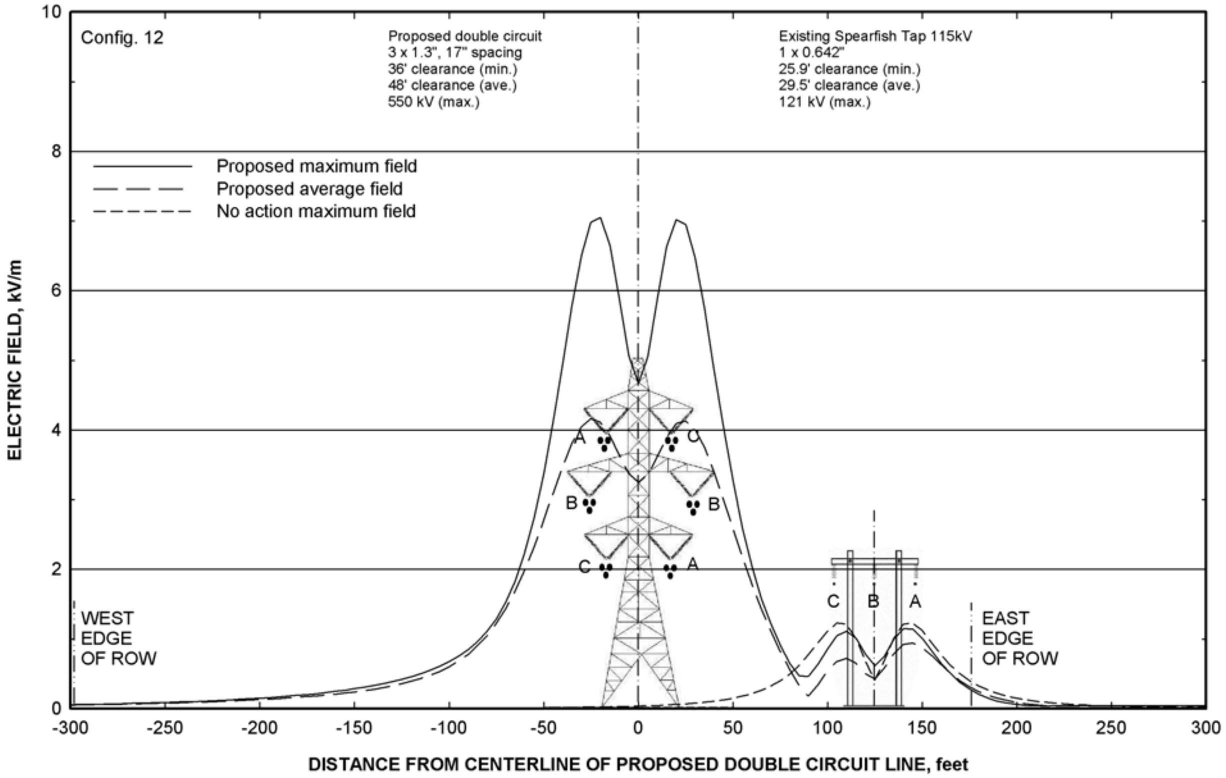


Figure 25: Magnetic-field profiles for single-circuit Configuration 1 of the proposed Big Eddy – Knight 500-kV line. Fields computed for maximum current with minimum clearance and for average current with average clearance are shown. Configurations are described in Tables 1 and 2.

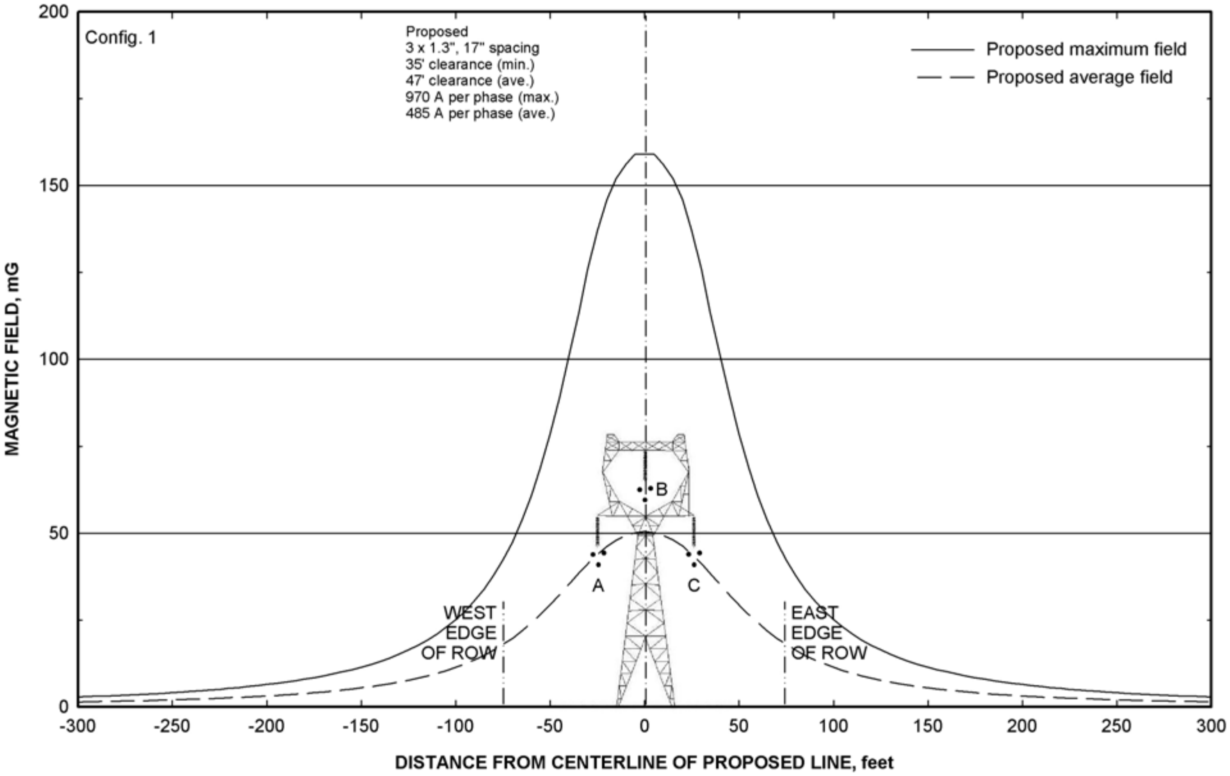


Figure 26: Magnetic-field profiles for single-circuit Configuration 2 of the proposed Big Eddy – Knight 500-kV line. Fields computed for maximum current with minimum clearance and for average current with average clearance are shown. Configurations are described in Tables 1 and 2.

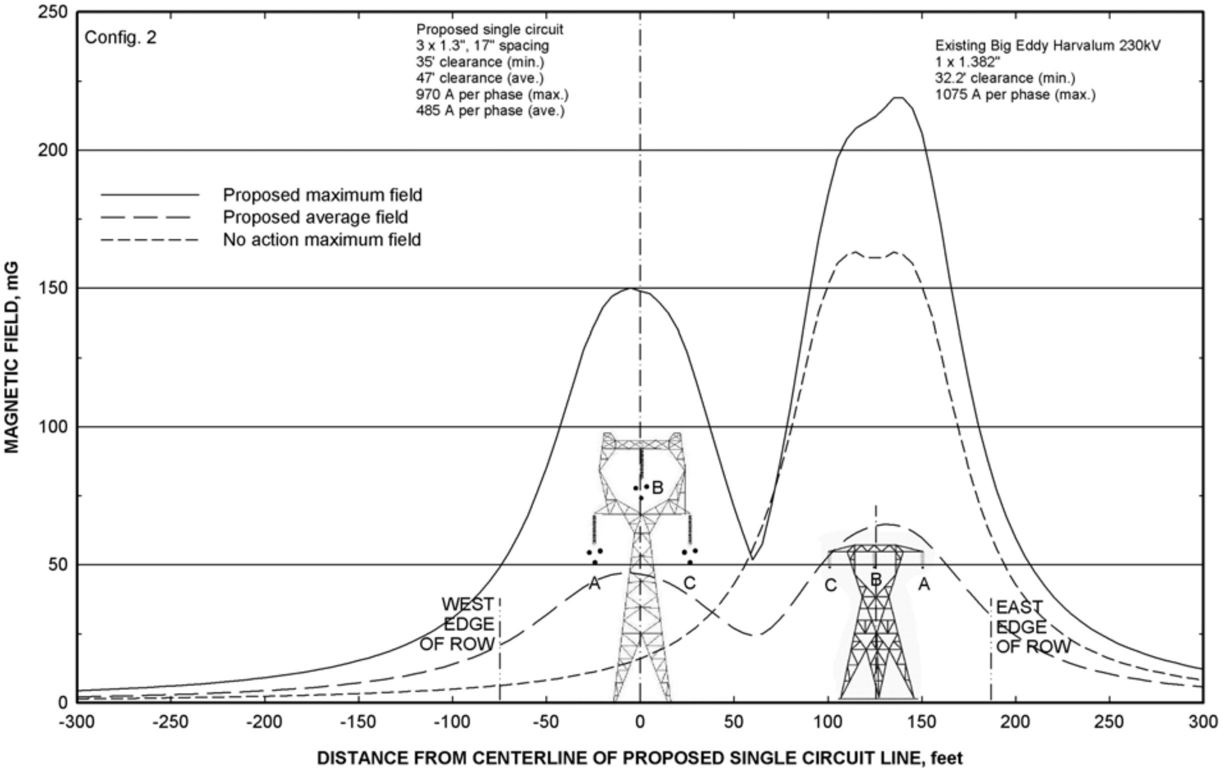


Figure 27: Magnetic-field profiles for single-circuit Configuration 3 of the proposed Big Eddy – Knight 500-kV line. Fields computed for maximum current with minimum clearance and for average current with average clearance are shown. Configurations are described in Tables 1 and 2.

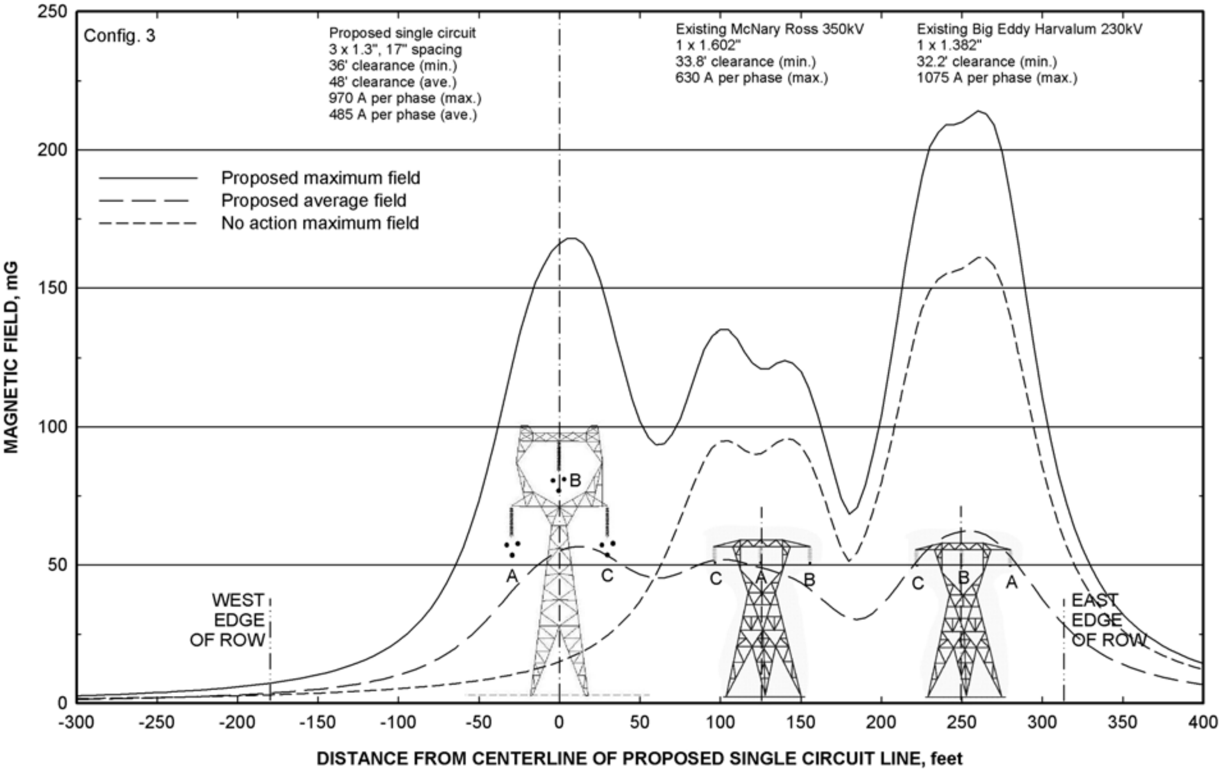


Figure 28: Magnetic-field profiles for single-circuit Configuration 4 of the proposed Big Eddy – Knight 500-kV line. Fields computed for maximum current with minimum clearance and for average current with average clearance are shown. Configurations are described in Tables 1 and 2.

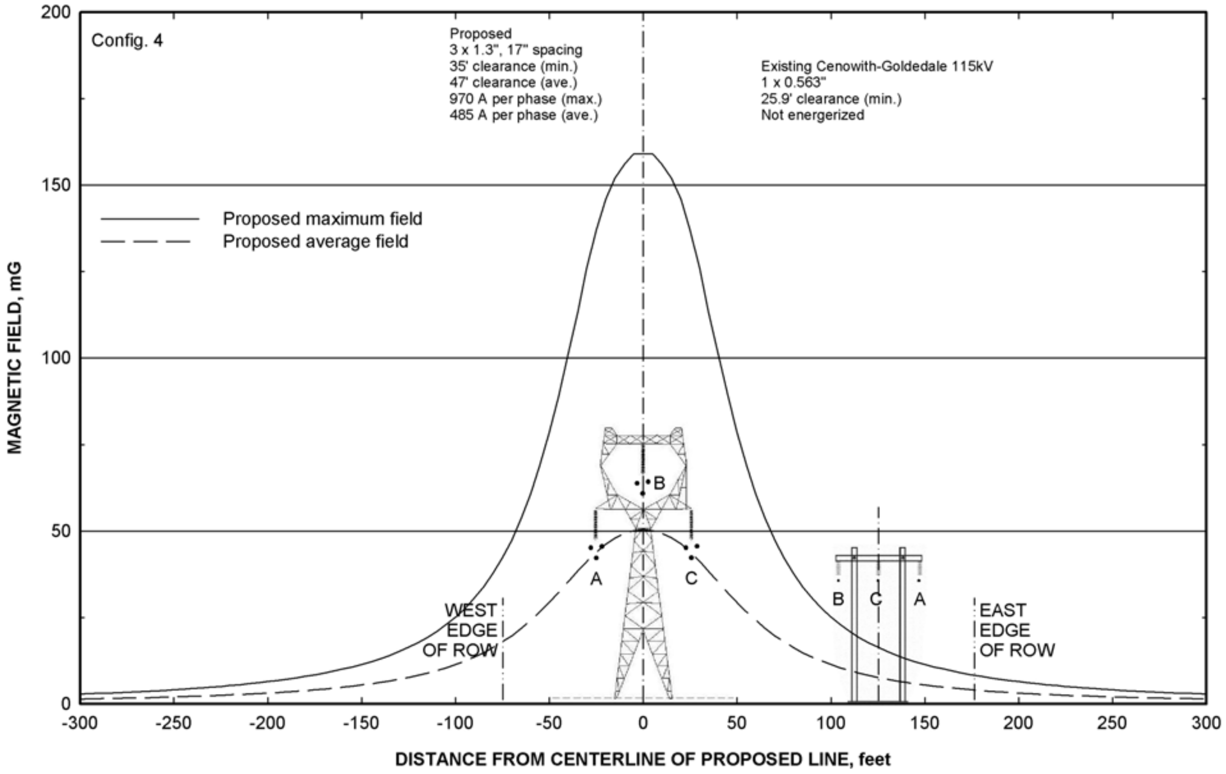


Figure 29: Magnetic-field profiles for single-circuit Configuration 5 of the proposed Big Eddy – Knight 500-kV line. Fields computed for maximum current with minimum clearance and for average current with average clearance are shown. Configurations are described in Tables 1 and 2.

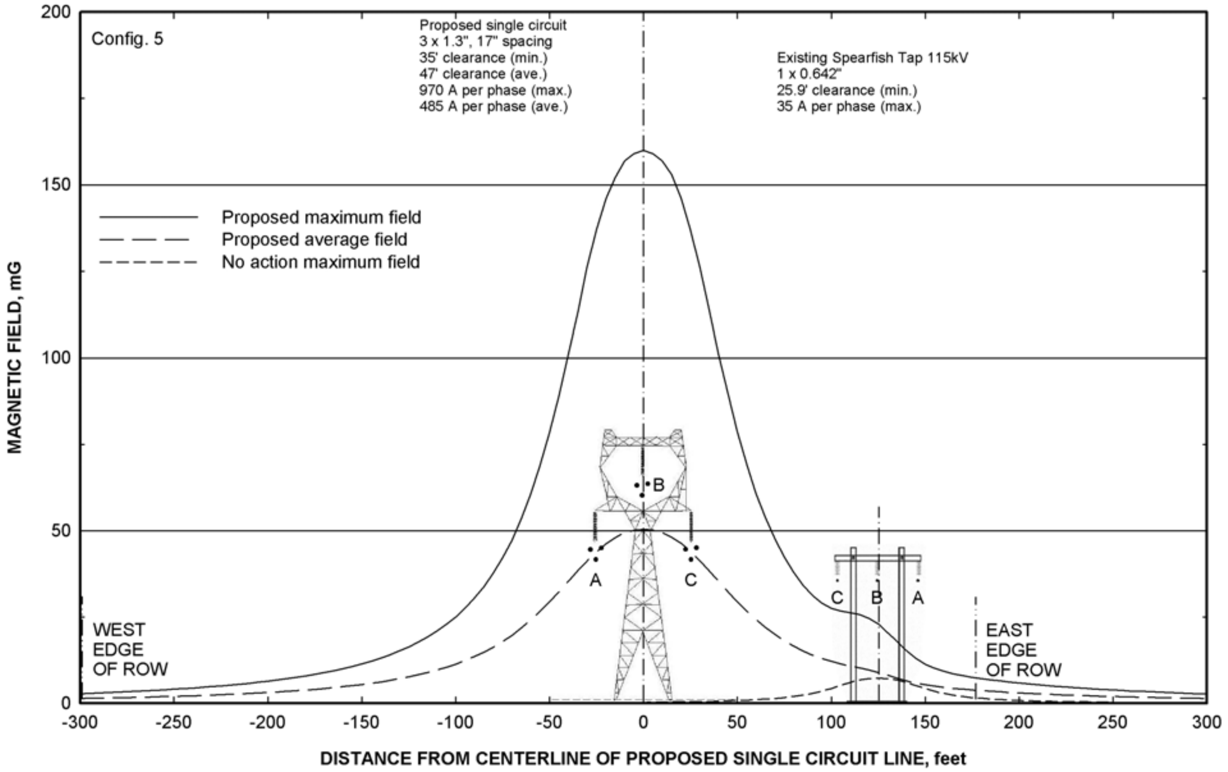


Figure 30: **Magnetic-field profiles for single-circuit Configuration 6 of the proposed Big Eddy – Knight 500-kV line.** Fields computed for maximum current with minimum clearance and for average current with average clearance are shown. Configurations are described in Tables 1 and 2.

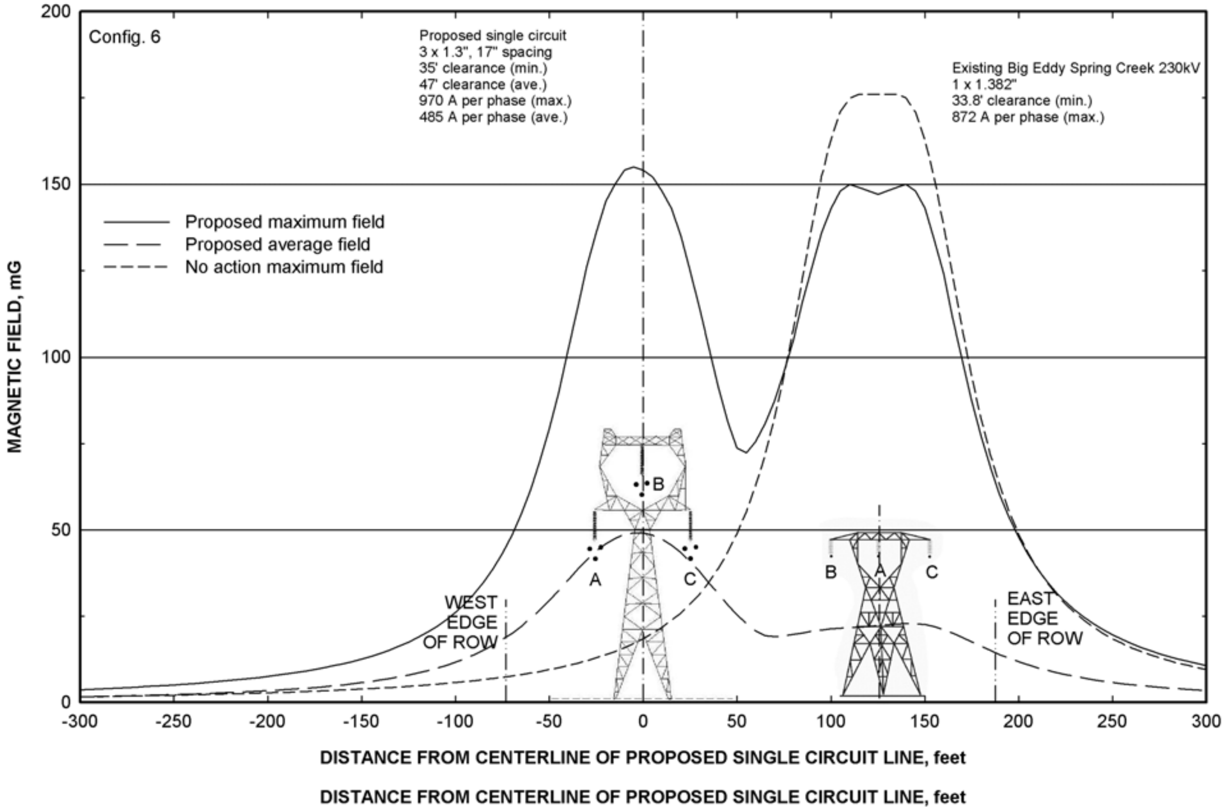


Figure 31: **Magnetic-field profiles for double-circuit Configurations 7 and 7A of the proposed Big Eddy – Knight 500-kV line.** Fields computed for maximum current with minimum clearance and for average current with average clearance are shown. Configurations are described in Tables 1 and 2.

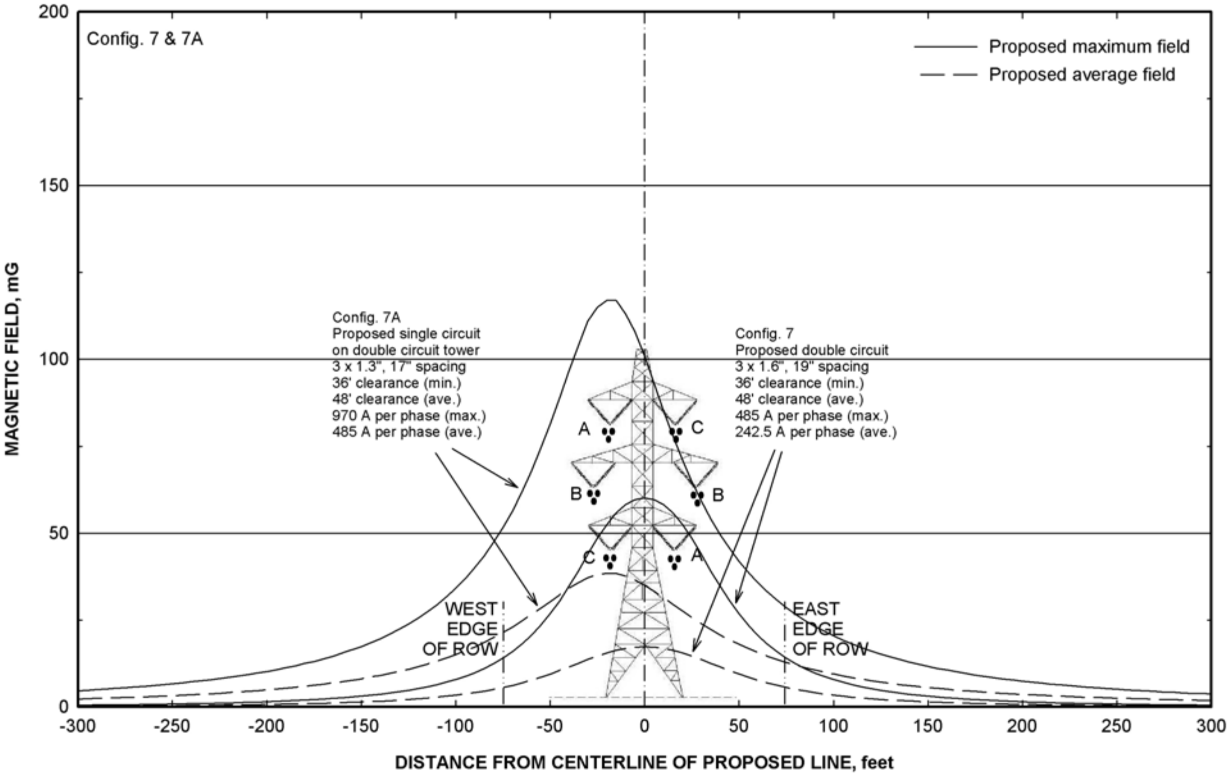


Figure 32: Magnetic-field profiles for double-circuit Configuration 8 of the proposed Big Eddy – Knight 500-kV line. Fields computed for maximum current with minimum clearance and for average current with average clearance are shown. Configurations are described in Tables 1 and 2.

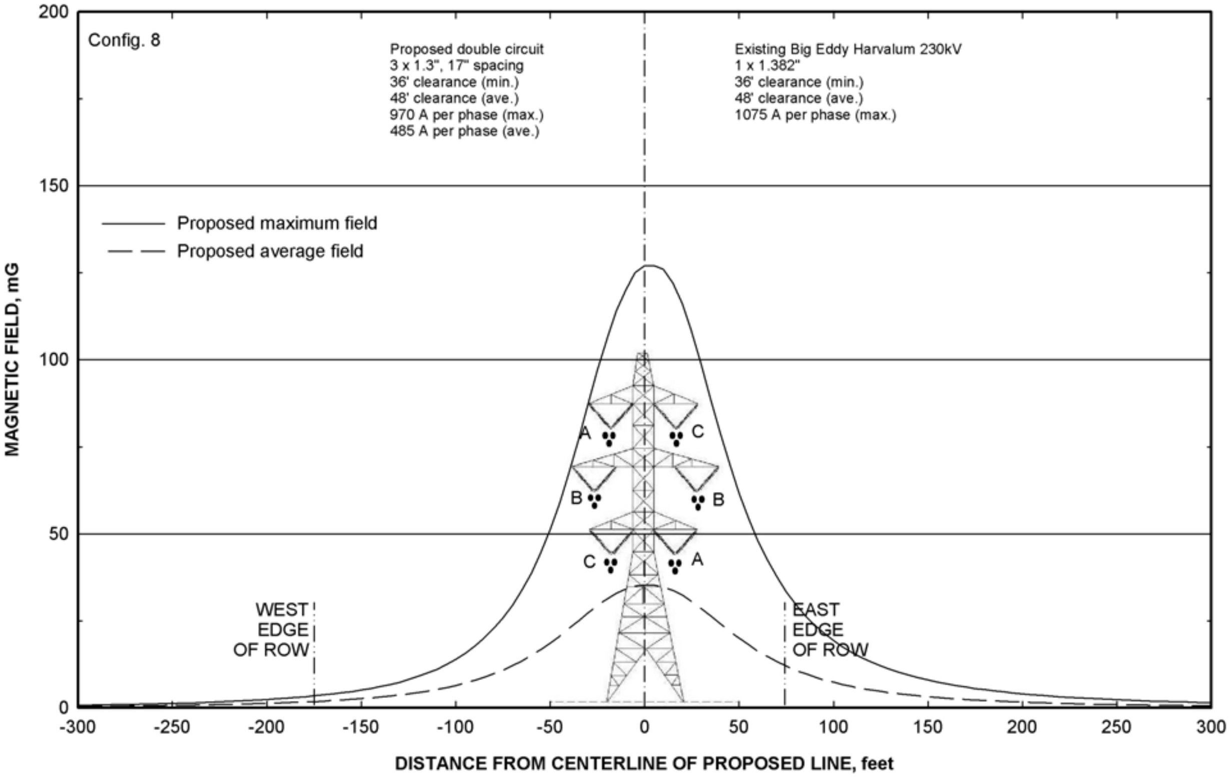


Figure 33: Magnetic-field profiles for double-circuit Configuration 9 of the proposed Big Eddy – Knight 500-kV line. Fields computed for maximum current with minimum clearance and for average current with average clearance are shown. Configurations are described in Tables 1 and 2.

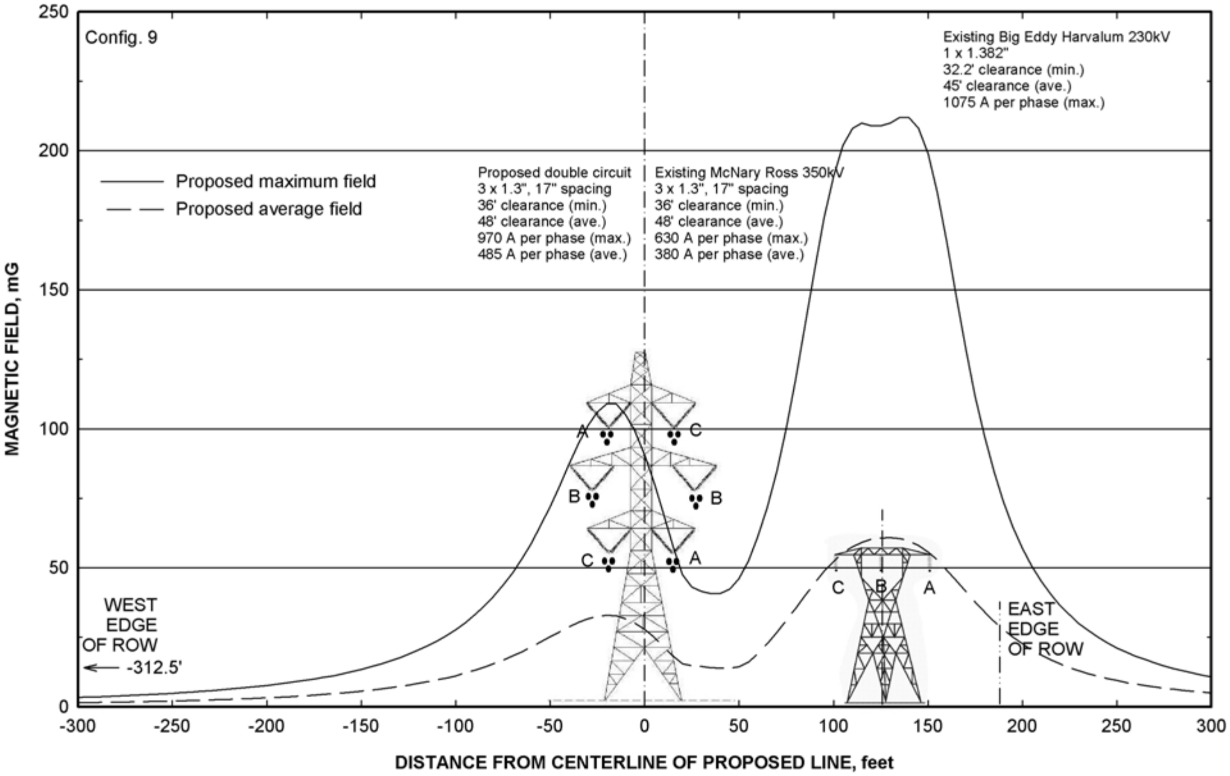


Figure 34: Magnetic-field profiles for double-circuit Configuration 10 of the proposed Big Eddy – Knight 500-kV line. Fields computed for maximum current with minimum clearance and for average current with average clearance are shown. Configurations are described in Tables 1 and 2.

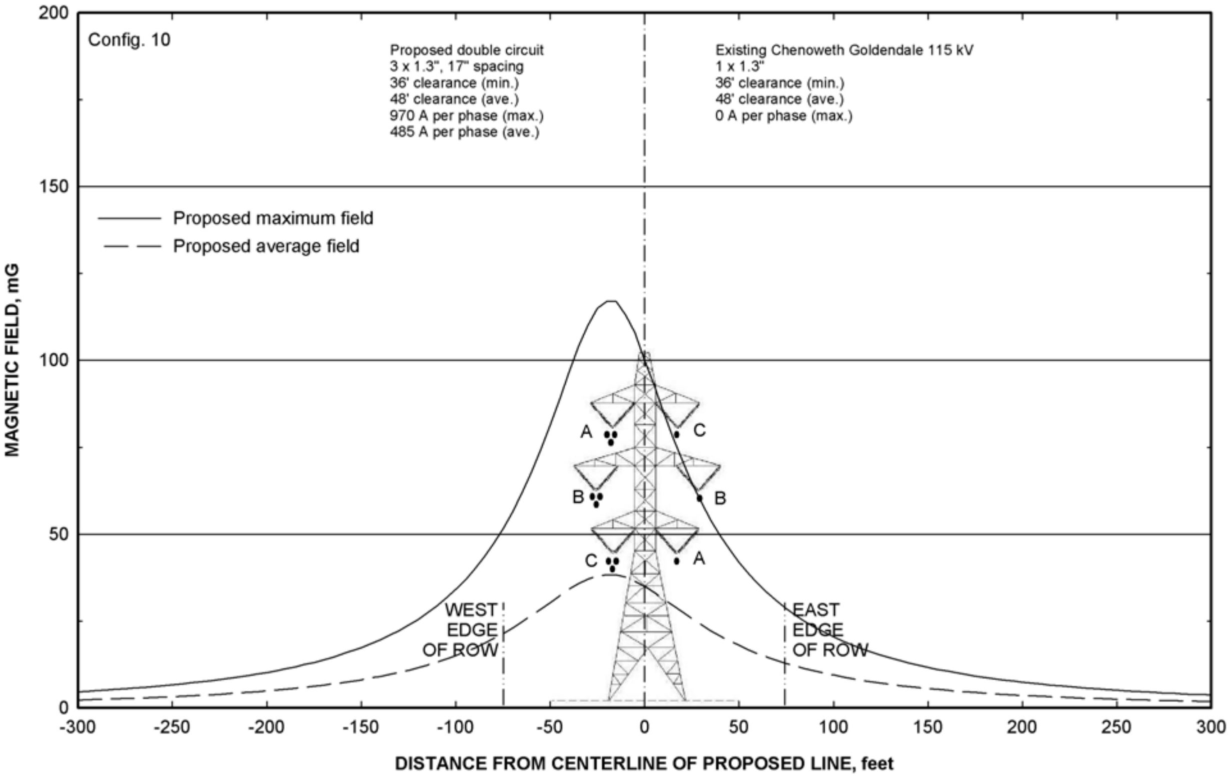


Figure 35: **Magnetic-field profiles for double-circuit Configuration 11 of the proposed Big Eddy – Knight 500-kV line.** Fields computed for maximum current with minimum clearance and for average current with average clearance are shown. Configurations are described in Tables 1 and 2.

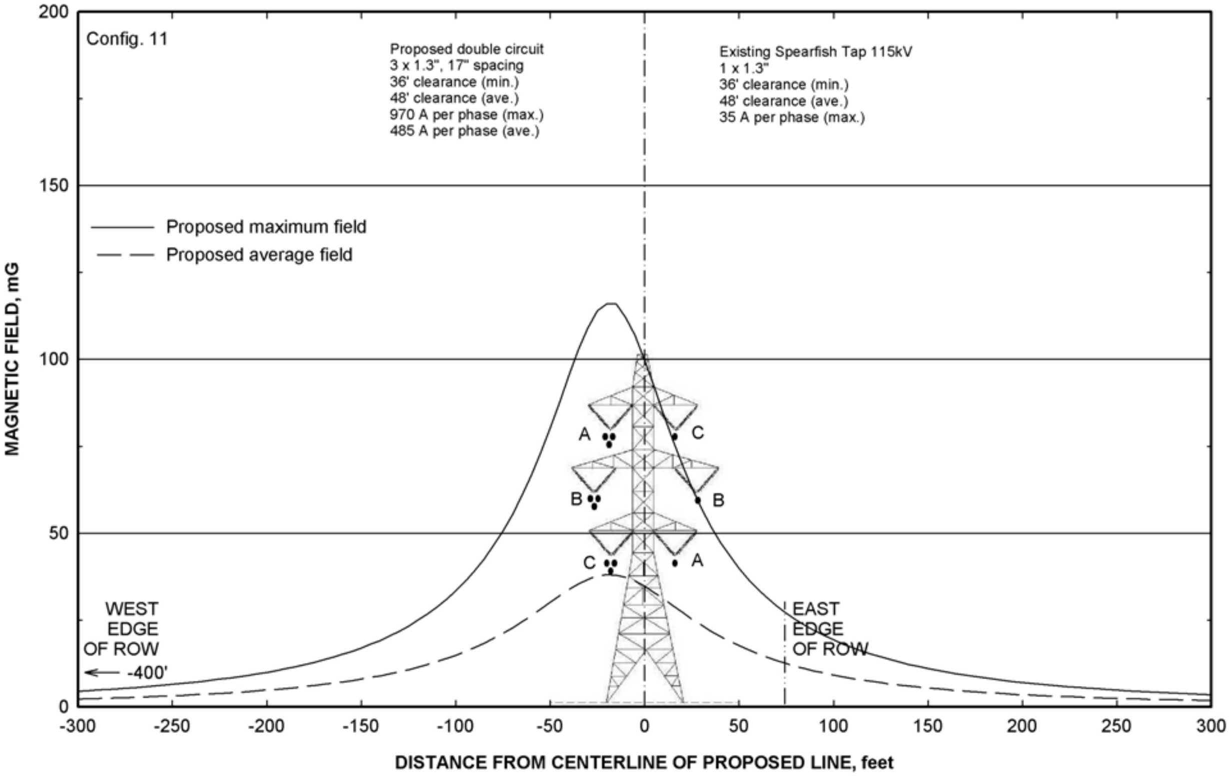


Figure 36: Magnetic-field profiles for double-circuit Configuration 12 of the proposed Big Eddy – Knight 500-kV line. Fields computed for maximum current with minimum clearance and for average current with average clearance are shown. Configurations are described in Tables 1 and 2.

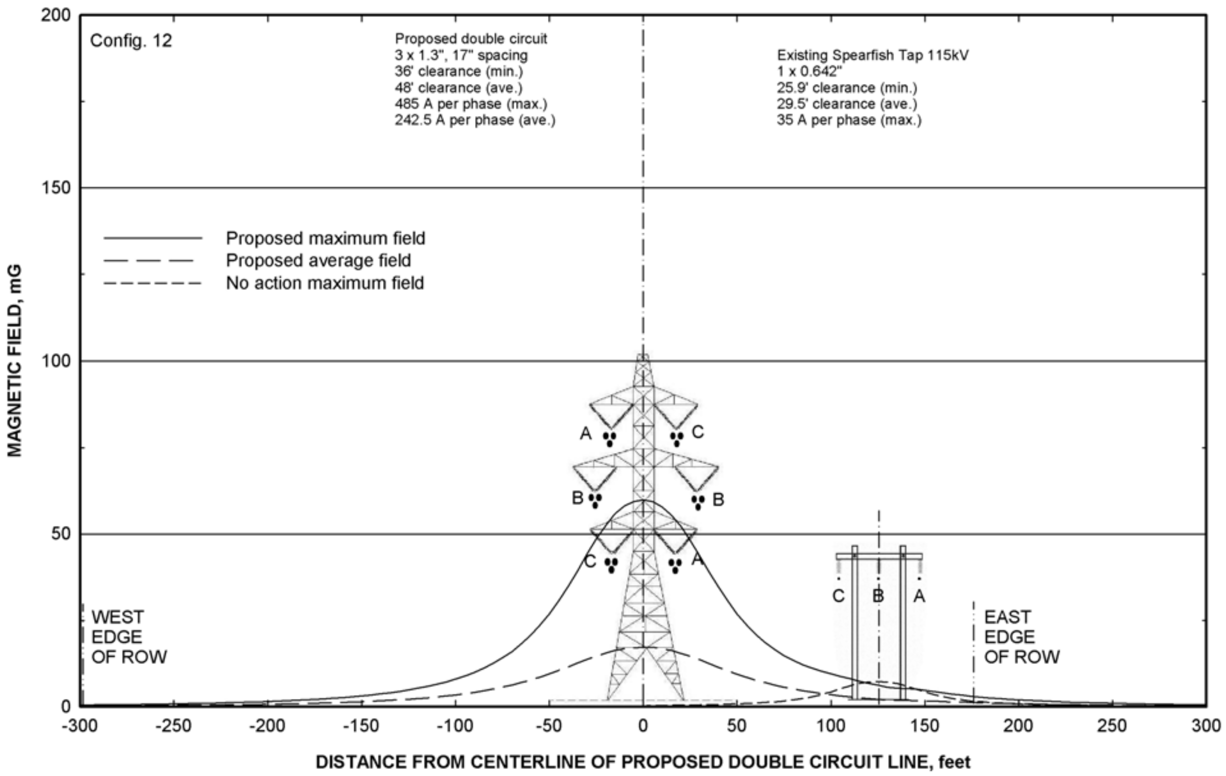
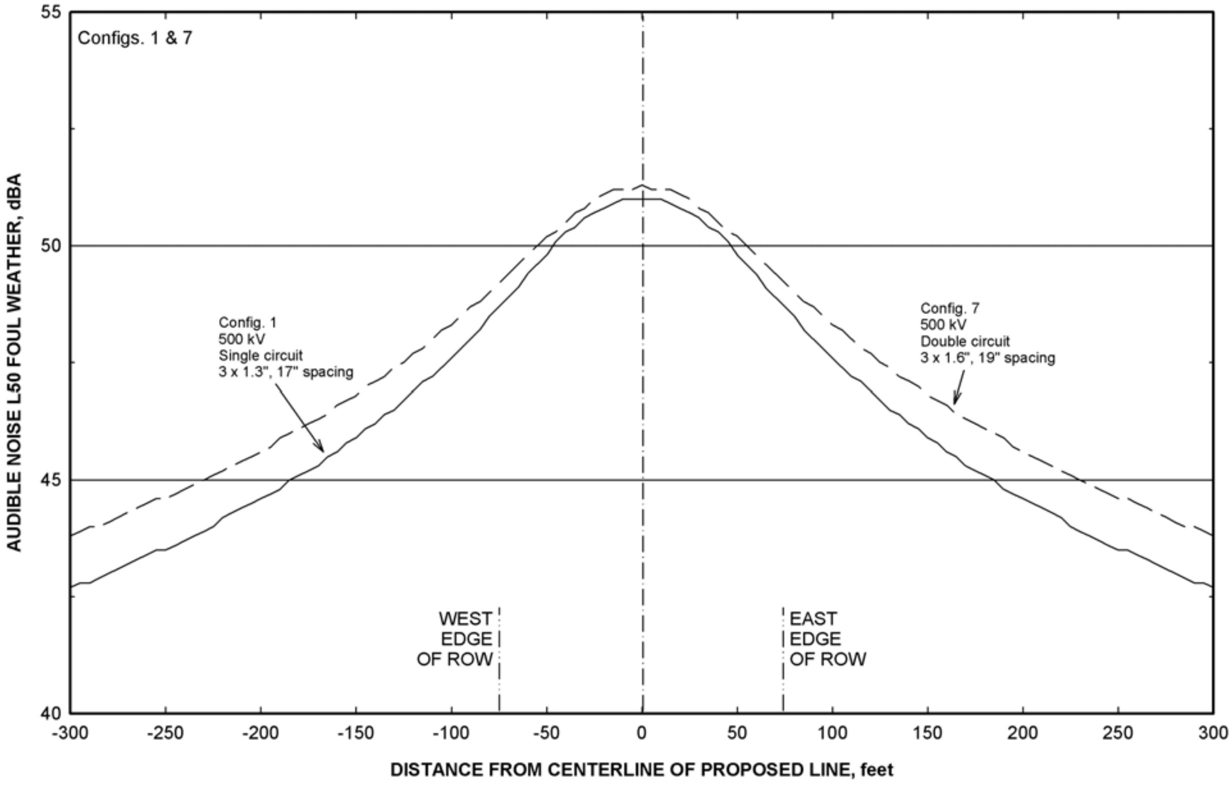


Figure 37: Audible Noise Profile for Proposed Big Eddy – Knight 500-kV Transmission Line Configurations 1 and 7 with No Adjacent Transmission Lines. Calculations performed for average voltage and average height. Configurations are described in Tables 1 and 2.



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