

Chapter 8 Electric and Magnetic Fields

This chapter defines **electric and magnetic fields** and discusses typical field levels, what factors affect field strength, safety standards (if any), and expected average and maximum fields along the action alternatives. It also discusses potential corona-caused interference with broadcast radio or television (TV) signals and implanted medical devices.

Words in bold and acronyms are defined in Chapter 32, Glossary and Acronyms.

8.1 Affected Environment

Electric and magnetic fields (EMF) exist everywhere electricity is used. Fields vary widely throughout the project area, depending on proximity to electronic devices or electrical lines and intervening landscape or walls. In general, existing EMF levels are higher in developed areas with electrical lines and buildings with electrical wiring, electrical equipment, and appliances.

Transmission lines, like all electric devices, produce EMF. **Current**, the flow of electric charge in a wire, produces the magnetic field. Voltage, the force that drives the current, is the source of the electric field. The strength of EMF around existing lines throughout the project area depends on the design of the electrical line and distance from it.

Corona is caused by strong electric fields at the surface of conductors. Throughout the project area, corona can occur on existing transmission lines during foul weather when the conductors are wet. Corona produces audible noise (see Chapter 9, Noise) and electromagnetic interference (static) that can affect AM radio or broadcast TV signals. The level of interference depends on the distance that the radio or TV is from the transmission line and the strength of the radio or TV signal being received. Signal reception is dependent on the strength of the signal generated from the radio or TV tower, and the distance from that tower to the receiver. In general, remote rural areas are farther from tower transmitters and more likely to receive a weak signal. This does not apply to reception via cable or satellite TV or radio, or FM radio frequencies. Generally, interference from corona would be higher if the radio or TV is closer to the transmission line but less if the signal is weaker.

8.1.1 Electric Fields

Electric fields are measured in **volts** per meter (V/m) or **kilovolts** per meter (kV/m). Throughout a home, the average electric field strength from wiring and appliances can range from 5 to 20 V/m, but is often less than 10 V/m (Bracken 1990). Localized fields near a small household appliance can range from 30 to 60 V/m, but field strengths drop off sharply with distance from the source. Electric-field levels in public buildings such as shops, offices, and malls are comparable with residential levels. Outdoor electric fields in publicly accessible places can range from 1 V/m to 12 kV/m, with the higher fields present near high-voltage transmission lines of 500 kV or greater. Electric field strength is reduced by objects such as walls and vegetation.

General guidelines for both electric and magnetic field exposure have been established by several national and international organizations (see Appendices F and G). Electric field

guidelines for public exposure range from 4.2 to 5 kV/m. In one guideline, the limit on transmission line rights-of-way is 10 kV/m. Occupational exposure guidelines (i.e., for employees in the workplace) range from 8.3 to 25 kV/m. There are no national standards for electric fields from transmission lines, and the state of Washington has no electric field limit. Oregon's Energy Facility Siting Council (EFSC) has established a limit of 9 kV/m within the right-of-way (there is no edge of right-of-way limit). BPA requires new transmission lines to meet its electric field guideline of 9 kV/m maximum on the right-of-way and 2.5 kV/m maximum at the edge of the right-of-way. BPA also specifies maximum-allowable electric field strengths of 5 kV/m for road crossings, 3.5 kV/m for shopping center parking lots, and 2.5 kV/m for commercial and industrial parking lots.

8.1.2 Magnetic Fields

Magnetic fields are measured in units of **gauss** (G) or **milligauss** (mG), with 1 G being equal to 1,000 mG. Average magnetic field strength in most homes (away from electrical appliances and wiring) is typically less than 2 mG. However, appliances carrying high current or those with high-torque motors, such as microwave ovens, vacuum cleaners or hair dryers, may generate fields of tens or hundreds of milligauss directly around them (see Table 8-1). Office workers operating electric equipment and industrial workers can be exposed to similar or higher magnetic field levels. Outdoor magnetic fields in publicly accessible places can range from less than 1 mG to about 1,000 mG (i.e., about 1 G), with the highest levels localized near devices powered by large electric motors.

Table 8-1 Typical Magnetic Field Levels

Appliance ¹	Magnetic Field Range (mG) ²
Can Opener	40–300
Vacuum Cleaner	20–200
Microwave Oven	1–200
Hairdryer	0.1–70
Power Drill	20–40
Television	0–20
Computer Monitor	2–6
Notes:	
1. Applies to plug-in devices.	
2. At a distance of 1 foot.	
Source: NIEHS 2002	

Like electric fields, magnetic fields fall off with distance from the source. Unlike electric fields, however, magnetic field strength is not reduced by intervening common objects such as walls and vegetation. Consequently, though appliances can produce high localized magnetic fields, transmission lines serving neighborhoods and distribution lines serving individual homes or businesses can contribute to longer-term magnetic field exposure at much lower levels.

There are no national standards for magnetic fields, and Oregon, Washington and BPA do not have magnetic field limits for transmission lines. Guidelines created by national and international organizations range from 833 to 9,040 mG for public magnetic-field exposure and from 4,200 to 27,100 mG for occupational magnetic-field exposure (see Appendices F and G).

8.1.3 Electromagnetic Interference

If corona is present at the surface of transmission line conductors, it generates electromagnetic interference that can affect reception of broadcast radio and TV signals close to the right-of-way. This affects only conventional broadcast radio and TV receivers operating at lower frequencies (AM radio and TV channels 2 to 6). With the introduction of digital television technology, the broadcast frequencies for affected channels have been raised and corona interference with these television signals is no longer a potential problem. Satellite and cable TV systems are not affected, nor are FM radio signals.

Electromagnetic interference is generally from transmission lines operating at voltages of 345 kV or higher. However, sparks occurring in gaps between loose hardware and loose wires on distribution lines and low-voltage wood-pole transmission lines are a more common (95 percent) source of interference than corona from high-voltage electrical systems (USDOE 1980). This gap-type interference is primarily a fair-weather phenomenon and is easily remedied by line maintenance, relocation of a radio or TV antenna, or use of a directional antenna.

In the U.S., electromagnetic interference from transmission systems is governed by the Federal Communications Commission (FCC), which requires the operator of any device that causes "harmful interference" to take prompt steps to eliminate it (FCC 1988; see also Appendix F). There are no state limits for electromagnetic interference.

8.2 Environmental Consequences

General electric and magnetic field effects are discussed below, followed by specific electric and magnetic field calculations and discussion for each action alternative.

8.2.1 Impact Levels

Impacts would be **high** where project activities would cause the following:

- The electric field levels would induce a large enough current on objects on the right-of-way to exceed limits set by the National Electric Safety Code (NESC)
- Shocks would approach dangerous levels

Impacts would be **moderate** where project activities would cause the following:

- The electric field levels would violate BPA policies, but meet the NESC
- Shocks would be unpleasant, but would not be dangerous

Impacts would be **low** where project activities would cause the following:

- The electric field levels would meet BPA policies and the NESC
- Perceptible nuisance shocks may occur when touching metallic objects on the right-of-way; these shocks would not be hazardous, but may still cause discomfort

No impact would occur if shocks were not perceptible or electric field levels would not increase over existing levels.

Because studies have provided insufficient or inconclusive evidence about the potential health impacts of magnetic fields (see Section 8.2.2.2, Magnetic Fields), and because there are no national or regional standards for magnetic fields, BPA has not defined impact levels for magnetic fields.

8.2.2 Impacts Common to Action Alternatives

8.2.2.1 Electric Fields

Transmission lines, like all electrical wiring, can cause serious electric shocks if certain precautions are not taken. All BPA lines are designed and built to meet or exceed the NESC, which specifies the minimum allowable distance between conductors and the ground or other objects. These requirements determine the minimum distance to the edge of the right-of-way and the minimum height of the line, that is, the closest point that houses, other buildings, and vehicles are allowed to the line. These clearances are specified to prevent harmful shocks to workers and the public.

BPA also does not permit any uses within rights-of-way that are unsafe or might interfere with safely constructing, operating, or maintaining the transmission facilities. These restrictions are part of the legal rights BPA acquires for its transmission line easements.

However, people working or living near transmission lines must also take certain precautions. In general, when under a transmission line, a person should never put themselves or any object higher than 14 feet above ground. For example, it is important never to bring conductive materials—including TV antennas, irrigation pipes or water streams from an irrigation sprinkler—too close to the conductors as serious shocks or electrocution can occur. Also, vehicles should not be refueled under or near conductors. A free BPA booklet describes safety precautions for people who live or work near transmission lines (see *Living and Working Safely around High-Voltage Transmission Lines* available at:

<http://www.bpa.gov/news/pubs/GeneralPublications/lusi-Living-and-working-safely-around-high-voltage-power-lines.pdf>.

Besides serious shocks, transmission lines can also cause nuisance shocks when a grounded person touches an ungrounded object under or near a line, or when an ungrounded person touches a grounded object. BPA takes additional precautions to minimize nuisance shocks. Fences and other metal structures on and near the right-of-way would be grounded during construction. After construction, BPA would respond to any complaints and install or repair grounding as needed. Nuisance shocks from mobile objects that cannot be grounded permanently are minimized by conductor clearance codes and design practices, such as BPA's 5 kV/m electric field requirement for road crossings and 2.5 to 3.5 kV/m limit for parking lots.

For the action alternatives, standard minimum clearance of the conductors above ground would be 35 feet at a conductor temperature of 122°F (50°C). This standard minimum clearance would also ensure that the BPA criterion for maximum electric fields of 9 kV/m at 50°C is met.

Because of the many precautions BPA would take to minimize the risk of serious or nuisance shocks to nearby residents and passers-by, the project would create **no-to-low** impacts.

8.2.2.2 Magnetic Fields

Decades of scientific studies are inconclusive as to whether magnetic fields can potentially cause health effects. A review of these studies and their implications for health-related effects is provided in Appendices G and G1. In summary, the scientific studies and reviews of research on the potential health effects of power line electric and magnetic fields have found there is insufficient evidence to conclude exposure to either field leads to long-term health effects, such as adult cancer, neurodegenerative diseases (such as Alzheimer's or Lou Gehrig's disease), or adverse effects on reproduction, pregnancy, or growth and development of an embryo. Uncertainties do remain about possible links between childhood leukemia and childhood magnetic field exposures at levels greater than 3-4 mG. There are also suggestions that short-term exposures to magnetic fields greater than 16 mG may be related to an increased risk of miscarriage. However, animal and cellular studies provide limited support for the idea that statistical associations observed in epidemiology studies reflect a causal relationship between magnetic field exposure and an increased risk of childhood cancer or miscarriage.

An increase in public exposure to magnetic fields could occur if the project causes field level increases and if residences or other structures draw people to these areas. The predicted field levels discussed under each action alternative are only indicators of how the project would affect the overall magnetic field environment. They are not measures of risk or impacts on health. No impact levels are stated because, unlike in other resource chapters in this EIS, no basis exists for determining them (see Section 8.2.1, Impact Levels).

8.2.2.3 Implanted Medical Devices

Because EMF from various sources (including automobile ignitions, appliances and possibly transmission lines) can interfere with implanted cardiac pacemakers, manufacturers are now designing devices to be immune from such interference. However, a few models of older pacemakers still in use could be affected by EMF from transmission lines. Many pacemaker models are unaffected by fields larger than those found under transmission lines.

No government EMF limits exist to guide pacemaker wearers. However, because of the known potential for interference with some older pacemakers, EMF field limits for pacemaker wearers in occupational areas have been established by the American Conference of Governmental Industrial Hygienists (ACGIH). The ACGIH recommends that, if unsure about their pacemakers, wearers of these and similar medical-assist devices should limit their exposure to electric fields of 1 kV/m or less and to magnetic fields of 1,000 mG or less (ACGIH 2009).

Electric fields from the proposed 500-kV line would generally meet ACGIH limits beyond about 35 feet from the edge of the rights-of-way. Wearers of pacemakers and similar medical-assist devices are discouraged from unshielded right-of-way use. A driver or passenger in an automobile under the line would be shielded from the electric field. Magnetic fields would be well below ACGIH limits. For additional discussion about potential interference with implanted devices, see Appendices F, F1, G and G1.

8.2.2.4 Electromagnetic Interference

For each action alternative, potential corona-caused electromagnetic interference levels that could affect radio or TV reception were calculated for fair and foul weather conditions (see Appendices F and F1). Radio interference calculations show that levels would be at or below

acceptable limits for avoiding interference. TV interference levels would be comparable to, or less than, interference levels from other BPA 500-kV lines.

Recent conversion to digital television technology has made TV reception much less susceptible to corona-generated interference. Because of this conversion, the lower-channel stations (Channels 2 to 6), where interference could occur, now transmit at higher frequencies where corona-generated interference has not been a problem. The likelihood of TV interference due to corona is greatly reduced from just a few years ago and is anticipated to occur very rarely, if at all, along the right-of-way. The bundle of three conductors used for each phase of the proposed 500-kV transmission line would also minimize corona generation and further prevent radio and TV interference. In the event interference does occur, BPA has a mitigation program to correct it and would restore reception to the same or better quality.

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

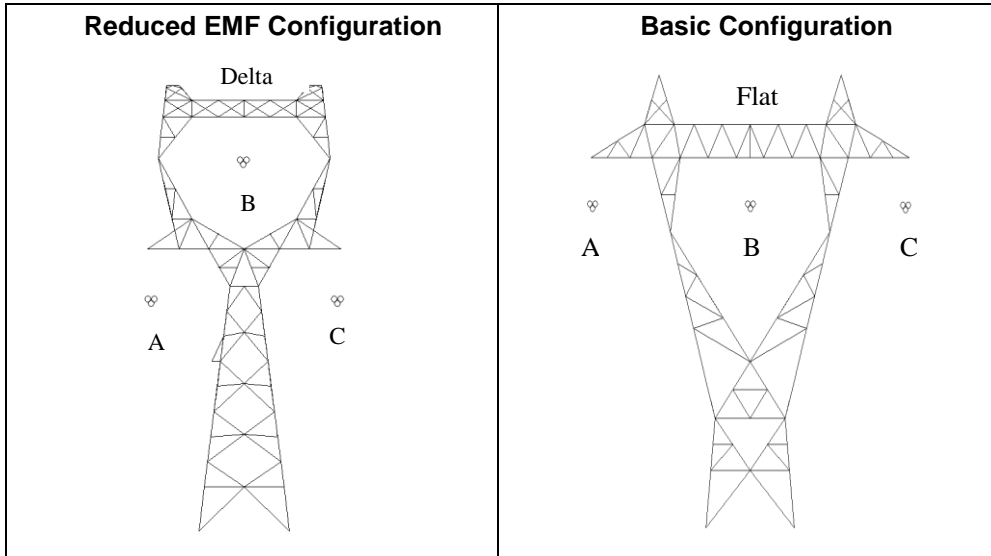
Magnetic fields can also distort images on older video display monitors with cathode ray tubes. This is unlikely to occur at magnetic field levels found very close to (within about 100 feet of) the transmission line right-of-way. If these effects occur, such interference can be remedied by moving the monitor to another location or replacing it with a contemporary flat-panel device such as a liquid-crystal or plasma display. The latter are not affected by magnetic fields.

8.2.2.5 Designing Lines to Reduce EMF

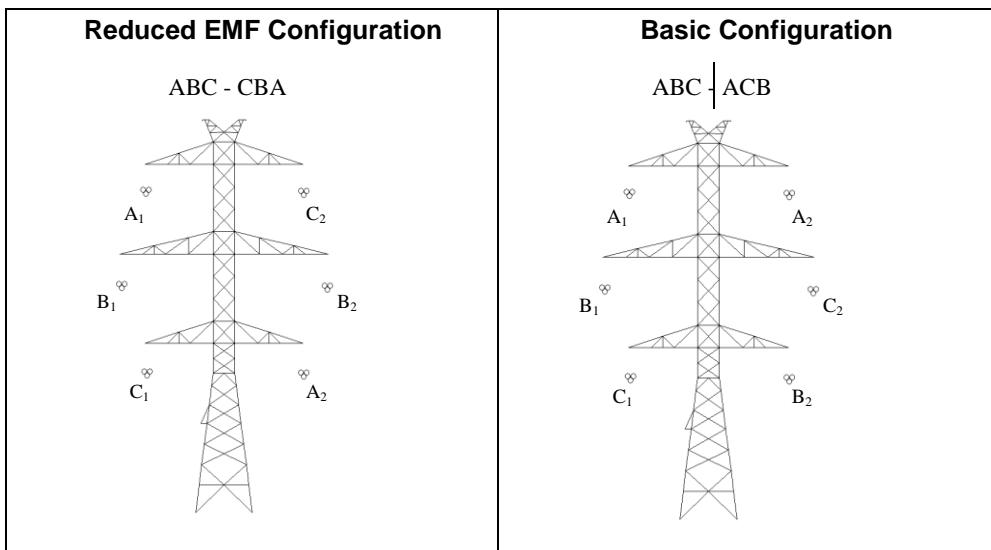
When BPA builds new high-voltage 500-kV transmission lines, the agency designs them using “EMF mitigation” techniques to keep EMF exposure as low as reasonably achievable, while maintaining system reliability.

For example, BPA uses “delta configuration” tower designs for single-circuit lines, where the three phase conductor bundles (called A, B, and C) are positioned in a triangular shape (two on the bottom, one on top) (see Figure 8-1). This configuration provides for more EMF cancellation effects than the more traditional “flat configuration,” where the three phase conductor bundles are arranged horizontally and all are at the same height above ground.

For double-circuit lines (two transmission line circuits on the same tower; six phase conductor bundles instead of three), BPA uses a “phase-optimization” approach to minimize EMF levels, when feasible. Generally, three phase conductor bundles of one line circuit are placed vertically on the left side of the tower and the three phase conductor bundles of the other circuit are placed vertically on the right side (see Figure 8-2). Such phasing arrangements for the two circuits can result in some EMF cancellation. The actual reduction of electric fields depends on the circuit voltages; the reduction of magnetic fields depends on the direction of the power flow and magnitude of the current.

Figure 8-1 Single-Circuit Tower Design to Reduce EMF

For the few short segments where triple-circuit towers would be required, each segment would be individually considered to minimize EMF.

Figure 8-2 Double-Circuit Tower Design to Reduce EMF

8.2.2.6 Substation Sites

Both electric and magnetic fields at the perimeter of the Sundial substation site and any Castle Rock substation site would reflect fields generated by the new 500-kV line, with the same magnitudes and impacts (see Section 8.2.2, Impacts Common to Action Alternatives). Within several hundred feet of the transmission line or substation fence, these fields would dissipate to ambient levels.

8.2.3 EMF Calculations

EMF levels were calculated for every line section within route segments for each alternative and option (see Appendices F and F1). The information in Appendices F and F1 can be used to pinpoint predicted EMF levels at properties along any of the action alternatives. The average of these field levels was computed across the length of the action alternatives to provide an overall measure of EMF for each alternative and option.

Impacts common to action alternatives are in Section 8.2.2. The remaining sections discuss methods used to calculate electric and magnetic fields, impacts unique to each alternative, and recommended mitigation measures.

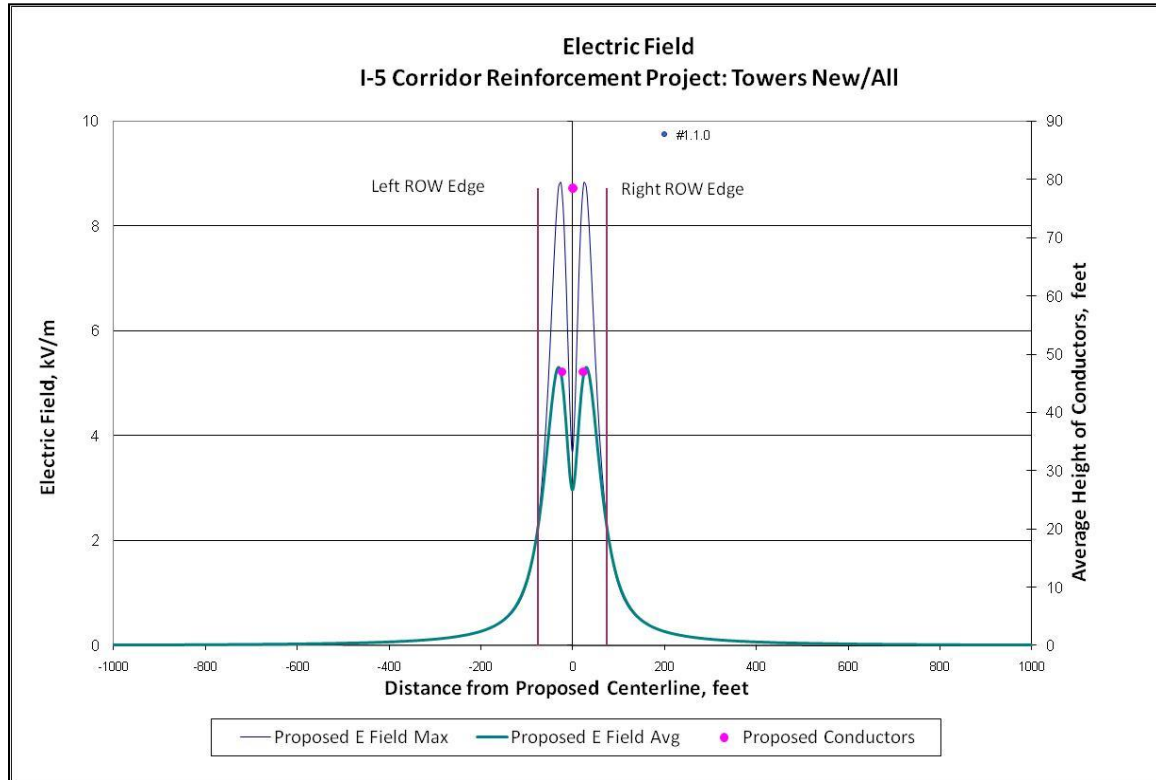
8.2.3.1 Electric Fields

Electric fields for each route segment, and for each line section within a segment, were calculated for their value on the right-of-way and their value at the edge of the right-of-way. Fields at these two locations were calculated under two operating scenarios that result in different conductor heights (and therefore different potential field strengths) above ground.

The first scenario produces the lowest allowed conductor height of 35 feet. It assumes a conductor temperature of 122°F (50°C) and that the line is operating at maximum voltage (550 kV) and carrying maximum current (1,080 Amperes [A]). Though this allows maximum electric fields to be calculated directly under the line and at the edge of right-of-way, it represents a situation that would rarely occur. Actual line height is generally above minimum clearance levels, actual voltage is generally lower than maximum, and vegetation within and near the edge of the right-of-way tends to shield electric fields at ground level. Electric fields calculated under this scenario are considered maximum levels.

The second scenario assumes an average conductor height of 47 feet (averaged along an entire span) and average current (324 A), but still assumes a maximum voltage (550 kV) to ensure conservative calculations (highest possible electric field levels under average conditions). These conditions more closely correspond to normal operating conditions with lower temperatures and average currents. Electric fields calculated under this scenario are considered average levels.

To provide summary measures of the fields for each alternative and option, the edge of right-of-way fields from all segments in alternatives and options were combined in a length-weighted average. (In the length-weighted average, the fields for the longest/shortest segments are given the most/least weight, respectively, in computing average values.) The results summarize the field levels on and at the edge of the right-of-way under extreme (maximum) and normal (average) conditions by alternative and option. (See Figure 8-3 for a visual example of maximum and average [normal] electric fields along all portions of action alternatives on new right-of-way. See figures in Appendices F and F1 for fields created in route segments on existing right-of-way.)

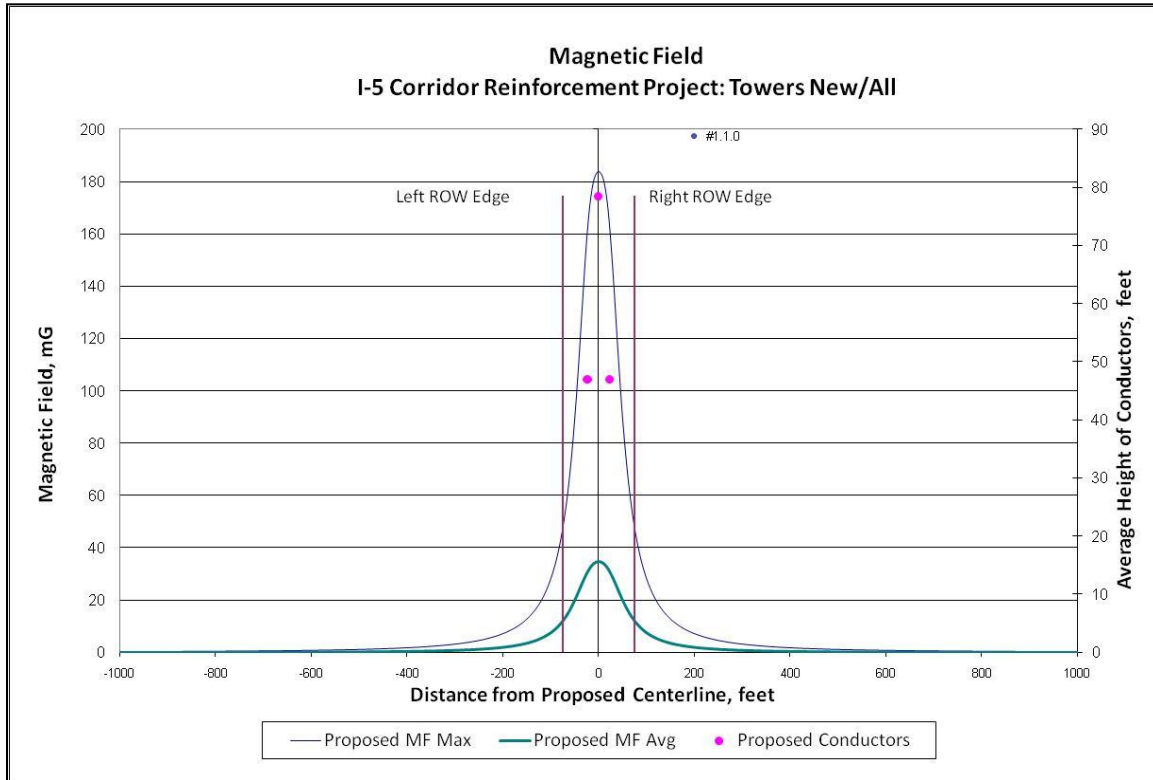
Figure 8-3 Electric Fields Surrounding the Transmission Line on New Right-of-Way¹

¹ This is identified as field calculation 1.1.0 in the tables in Appendix F, where the numeric values can be found. Source: Bracken 2011 (see Appendix F).

8.2.3.2 Magnetic Fields

Maximum and average magnetic fields were calculated using the same two operating scenarios as for electric fields. As with electric fields, the summary measures for alternatives and options represent length-weighted averages over all segments in the alternative or option. (See Figure 8-4 for a visual example of maximum and average [normal] magnetic fields along all route segments in new right-of-way. See figures in Appendices F and F1 for fields created along route segments in existing right-of-way.) These calculations take into consideration that portions of the action alternatives would share rights-of-way with existing lines, or in some cases could replace those lines. In other words, they represent the total projected magnetic fields along the rights-of-way, not net gains or losses in fields.

Figure 8-4 Magnetic Fields Surrounding the Transmission Line on New Right-of-Way¹



¹ This is identified as field calculation 1.1.0 in the tables in Appendix F, where the numeric values can be found. Source: Bracken 2011 (see Appendix F).

8.2.4 West Alternative and Options

The West Alternative and options would be mostly in (98 percent) an existing right-of-way, which crosses the highest proportion (17 percent) of populated area compared to the other action alternatives—about 7 percent urban/suburban and 10 percent rural areas. Most of the rural area is undeveloped. Beyond the right-of-way, from the right-of-way edge out to 1,000 feet on either side of the line, the West Alternative and options would be located near a greater percentage of property zoned for residential use than the other action alternatives: about 46 percent. As a result, a greater number of people would live near or pass by the West Alternative and options than the other action alternatives. (This is also substantiated by housing counts—see Table 5-1.)

Length-weighted maximum electric fields on the rights-of-way for the West Alternative and options would range from 8.8 to 8.9 kV/m (see Table 8-2).

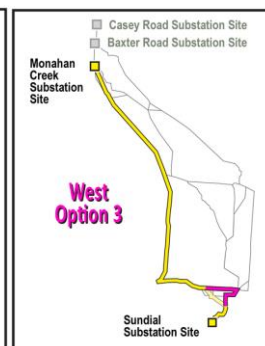
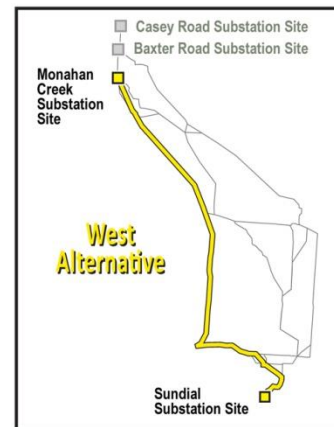


Table 8-2 West Alternative and Options—Length-Weighted Average Electric and Magnetic Field Levels

West Alternative				Electric Field (kV/m)		Magnetic Field (mG)	
Right-of-Way	Length (miles)	Field Location	Field Descriptor ¹	Proposed Action	No Action	Proposed Action	No Action
New	1.4	On right-of-way	Average	5.3	—	35	—
			Maximum	8.8		184	
		Edge of right-of-way	Average	2.3		12	
			Maximum	2.3		48	
Existing	64.2	On right-of-way	Average	5.4	2.0	36	24
			Maximum	8.8	3.8	182	134
		Edge of right-of-way	Average	1.4	0.5	10	5
			Maximum	1.4	0.5	36	21
West Option 1 ²				Electric Field (kV/m)		Magnetic Field (mG)	
Right-of-Way	Length (miles)	Field Location	Field Descriptor ¹	Proposed Action	No Action	Proposed Action	No Action
New	2.0	Same as new right-of-way values shown above for West Alternative					
Existing	1.1	On right-of-way	Average	5.6	2.3	28	19
			Maximum	8.9	4.6	139	94
		Edge of right-of-way	Average	0.6	0.6	10	4
			Maximum	0.6	0.5	35	13
West Option 2				Electric Field (kV/m)		Magnetic Field (mG)	
Right-of-Way	Length (miles)	Field Location	Field Descriptor ¹	Proposed Action	No Action	Proposed Action	No Action
New	1.7	Same as new right-of-way values shown above for West Alternative					
Existing	7.3	On right-of-way	Average	5.6	2.4	35	32
			Maximum	8.8	4.4	158	119
		Edge of right-of-way	Average	1.0	0.8	10	8
			Maximum	1.1	0.8	34	23
West Option 3				Electric Field (kV/m)		Magnetic Field (mG)	
Right-of-Way	Length (miles)	Field Location	Field Descriptor ¹	Proposed Action	No Action	Proposed Action	No Action
New	1.5	Same as new right-of-way values shown above for West Alternative					
Existing	11.5	On right-of-way	Average	5.6	2.8	41	43
			Maximum	8.8	5.2	163	136
		Edge of right-of-way	Average	1.3	0.6	12	9
			Maximum	1.3	0.5	35	21

Notes:

1. All field descriptors are segment-length-weighted means of the fields on or at the edge of the right-of-way. The values for the edge of right-of-way are computed from fields on both sides of the route. Average electric fields are computed for maximum voltages and average clearances along the route; likewise, average magnetic fields are computed for average currents and average clearances. Maximum electric fields are computed for maximum voltages and minimum clearances; maximum magnetic fields are computed for maximum currents and minimum clearances.

2. The field levels for all West options are very similar to those in the segments they would replace. The inclusion of one of these options would not significantly affect the overall mean field levels for the alternative.

Source: Bracken 2011 (see Appendix F).

These values, which occur only in small areas directly beneath conductors at the lowest clearance, meet BPA's criterion for maximum electric fields of 9 kV/m. The maximum fields for all route segments and line sections within segments would also meet the BPA criterion. Under normal (average) conditions, using length-weighted averages, the highest fields would range from 5.3 to 5.6 kV/m.

At the edge of the right-of-way, using length-weighted averages for both extreme (maximum) and normal (average) conditions, electric fields for the West Alternative and options would range from 0.6 to 1.4 kV/m on existing right-of-way and 2.3 kV/m on new right-of-way, meeting BPA's guidelines of 2.5 kV/m. (Maximum and average electric field calculations for individual route segments and line sections within segments can be found in Appendix F.) These electric field levels would be comparable to or less than those from existing 500-kV lines in the area and elsewhere, and would cause **no-to-low** impacts (see Section 8.2.2.1, Electric Fields).

Using length-weighted averages, maximum magnetic fields on the rights-of-way for the West Alternative and options would range from 139 to 182 mG on existing right-of-way (184 mG on new right-of-way). Under normal (average) conditions, the highest magnetic fields would range from 28 to 41 mG (35 mG on new right-of-way).

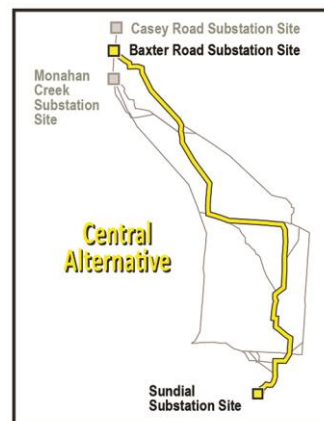
At the edge of rights-of-way, using length-weighted averages, the maximum magnetic fields for the West Alternative and options would range from 34 to 36 mG; under normal conditions, the highest fields would range from 10 to 12 mG (see Table 8-2). (Magnetic field calculations under maximum and normal conditions, for individual route segments and line sections within segments, can be found in Appendix F.) If more than one line is present in a segment, the maximum and normal fields would depend on the relative electrical phasing of the conductors and the relative direction of power flow in the lines.

Beyond the edge of rights-of-way, magnetic fields decrease quickly with distance. For example, a maximum magnetic field of 48 mG at the edge of right-of-way (75 feet from centerline) would drop to 13 mG at a distance of 150 feet from centerline, and to 3 mG at 300 feet. For the same example, the average field would drop from 12 mG at the edge of the right-of-way to 4 mG at 150 feet, and to 1 mG at 300 feet. This means that beyond a few hundred feet, transmission line magnetic fields approach common ambient levels and would be far less than those encountered near common household appliances or directly under the line.

8.2.5 Central Alternative and Options

The Central Alternative and options would mostly use new right-of-way (about 87 percent) that would cross predominantly forest land (around 90 percent of land use crossed). Only 4 percent of the land crossed by the right-of-way would be populated—2 percent urban/suburban and 2 percent rural areas (4 percent for Central Option 2). About 14 percent of the land beyond the right-of-way (out to 1,000 feet) is zoned for residential use. Fewer people would live near or pass by this action alternative than the West Alternative.

Using length-weighted averages, the maximum electric fields on the rights-of-way for the Central Alternative and options would



range from 8.8 to 9.0 kV/m (see Table 8-3), meeting BPA's criterion for maximum electric fields of 9 kV/m. The maximum fields for all route segments and line sections within segments would also meet the BPA criterion. Under normal (average) conditions, the highest fields would range from 5.3 to 5.5 kV/m.

At the edge of the right-of-way, using length-weighted averages, the maximum electric fields for the Central Alternative and options would range from 1.2 to 2.4 kV/m (2.3 kV/m on new right-of-way) under both extreme (maximum) and normal (average) conditions. Some route segments and line



sections have values that are higher than BPA's current guidelines of 2.5 kV/m at the edge of the right-of-way, however, they would not change from existing conditions. (Maximum and average electric field calculations for individual route segments and line sections within segments can be found in Appendices F and F1.) Like the West Alternative, these electric field levels would be comparable to or less than those from existing 500-kV lines in the area and elsewhere, with a similar **no-to-low** impact.

Using length-weighted averages, the maximum magnetic fields on the rights-of-way for the Central Alternative and options would range from 180 to 257 mG (184 mG on new right-of-way). Under normal (average) conditions, the highest magnetic fields would range from 34 to 62 mG (35 mG on new right-of-way).

At the edge of rights-of-way, using length-weighted averages, the maximum magnetic fields for the Central Alternative and options would range from 27 to 59 mG; under normal conditions, the highest fields would range from 7 to 15 mG (see Table 8-3). (Magnetic field calculations under maximum and normal conditions, for individual route segments and line sections within segments, can be found in Appendices F and F1.) Maximum and average fields depend on the number of transmission lines present, the relative electrical phasing of the conductors and the relative direction of power flow in the lines. Beyond the edge of rights-of-way, magnetic fields would decrease quickly with distance, approaching common ambient levels within a few hundred feet. This means that beyond a few hundred feet, transmission line magnetic fields approach common ambient levels and would be far less than those encountered near common household appliances or directly under the line.

Table 8-3 Central Alternative and Options—Length-Weighted Average Electric and Magnetic Field Levels³

Central Alternative				Electric Field, kV/m		Magnetic Field, mG	
Right-of-Way	Length (miles)	Field Location	Field Descriptor	Proposed Action	No Action	Proposed Action	No Action
New	69.7 (69.5)	On right-of-way	Average	5.3 (5.3)	—	35 (35)	—
			Maximum	8.8 (8.8)		184 (184)	
		Edge of right-of-way	Average	2.3 (2.3)		12 (12)	
			Maximum	2.3 (2.3)		48 (48)	
Existing	10.6 (6.8)	On right-of-way	Average	5.3 (5.4)	2.1 (2.1)	34 (33)	31 (31)
			Maximum	8.8 (8.9)	3.8 (3.8)	180 (175)	134 (135)
		Edge of right-of-way	Average	1.2 (1.1)	1.0 (1.0)	8 (9)	12 (11)
			Maximum	1.2 (1.1)	1.1 (1.0)	29 (32)	37 (36)
Central Option 1 ²				Electric Field, kV/m		Magnetic Field, mG	
Right-of-Way	Length (miles)	Field Location	Field Descriptor ¹	Proposed Action	No Action	Proposed Action	No Action
New	0	Same as edge of right-of-way values shown above for Central Alternative					
Existing	2.3 (0.0)	On right-of-way	Average	5.5 (5.5)	5.5 (5.5)	62 (62)	49 (49)
			Maximum	9.0 (9.0)	9.0 (9.0)	257 (257)	235 (235)
		Edge of right-of-way	Average	2.3 (2.3)	1.4 (1.4)	15 (15)	10 (10)
			Maximum	2.4 (2.4)	1.5 (1.5)	59 (59)	40 (40)
Central Option 2				Electric Field, kV/m		Magnetic Field, mG	
Right-of-Way	Length (miles)	Field Location	Field Descriptor ¹	Proposed Action	No Action	Proposed Action	No Action
New	15.0	Same as edge of right-of-way values shown above for Central Alternative					
Existing	0.4	On right-of-way	Average	5.5	2.0	34	11
			Maximum	8.8	3.7	180	78
		Edge of right-of-way	Average	1.6	0.7	7	3
			Maximum	1.7	0.8	27	15
Central Option 3				Electric Field, kV/m		Magnetic Field, mG	
Right-of-Way	Length (miles)	Field Location	Field Descriptor ¹	Proposed Action	No Action	Proposed Action	No Action
New	14.9	Same as edge of right-of-way values shown above for Central Alternative					
Existing	0	On right-of-way	Average	—	—	—	—
			Maximum				
		Edge of right-of-way	Average				
			Maximum				

Notes:

- All field descriptors are segment-length-weighted means of the fields on or at the edge of the right-of-way. The values for the edge of right-of-way are computed from fields on both sides of the route. Average electric fields are computed for maximum voltages and average clearances along the route; likewise, average magnetic fields are computed for average currents and average clearances. Maximum electric fields are computed for maximum voltages and minimum clearances; maximum magnetic fields are computed for maximum currents and minimum clearances.
- The segments in the Central options do not replace any existing segments. Using one of these options would not significantly affect average field levels for the alternative. However, there would be localized increases in magnetic fields for Central Option 1.
- Impact numbers not shown in parentheses reflect updated data, assumptions, and design refinements; impact numbers shown in parentheses are from the Draft EIS.

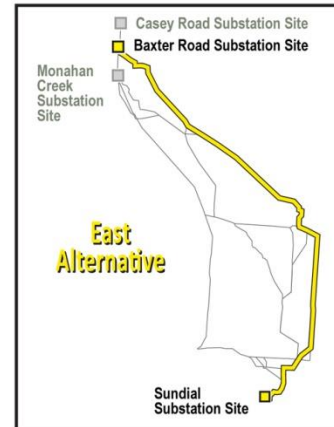
Sources: Bracken 2011, Exponent 2015a (see Appendices F and F1).

8.2.6 East Alternative and Options

Similar to the Central Alternative, the East Alternative and options would primarily use new right-of-way (about 90 percent) that would mostly cross forest land (around 90 percent of land use crossed). Only 3 percent of the land crossed by the right-of-way would be populated—about 1 percent urban/suburban and 2 percent rural areas (4 percent for East Option 1). About 7 percent of the land beyond the right-of-way (out to 1,000 feet) is zoned for residential use, the lowest of all action alternatives. Fewer people would live near or pass by this action alternative than the West Alternative.

Using length-weighted averages, maximum electric fields on the rights-of-way for the East Alternative and options would range

from 8.8 to 8.9 kV/m (see Tables 8-4), meeting BPA's criterion of 9 kV/m. The maximum fields for all route segments and line sections within segments would also meet the BPA criterion. Under normal (average) conditions, the highest fields would range from 5.3 to 5.7 kV/m.



At the edge of the right-of-way, using length-weighted averages electric fields for the East Alternative and options would range from 1.1 to 1.4 kV/m on existing right-of-way (2.3 kV/m on new right-of-way) under both extreme (maximum) and normal (average) conditions, meeting BPA's guidelines of 2.5 kV/m. (Maximum and average electric field calculations for individual route segments and line sections within segments can be found in Appendix F.) Similar to the other action alternatives, these electric field levels would be comparable to or less than those from existing 500 kV lines in the area and elsewhere, with a similar **no-to-low** impact.

Maximum magnetic fields on the rights-of-way for the East Alternative and options, using length-weighted averages, would range from 174 to 186 mG (184 mG on new right-of-way). Under normal (average) conditions, the highest magnetic fields would range from 32 to 53 mG (35 mG on new right-of-way). At the edge of rights-of-way, using length-weighted averages, the maximum magnetic fields for alternatives and options would range from 27 to 48 mG; under normal conditions, the highest fields would range from 6 to 12 mG (see Table 8-4). (Magnetic field calculations under maximum and normal conditions, for individual route segments and line sections within segments, can be found in Appendix F.) Maximum and normal fields would depend on the number of transmission lines present, their relative phasing and direction of power flow. Beyond the edge of rights-of-way, magnetic fields decrease quickly with distance, approaching common ambient levels within a few hundred feet.

This means that beyond a few hundred feet, transmission line magnetic fields approach common ambient levels and would be far less than those encountered near common household appliances or directly under the line.

Table 8-4 East Alternative and Options—Length-Weighted Average Electric and Magnetic Field Levels

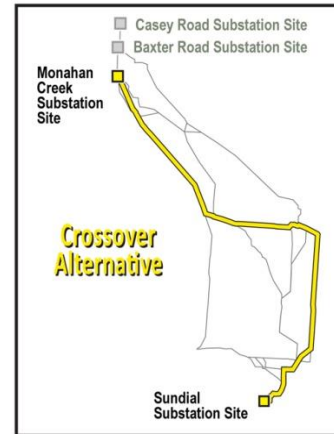
East Alternative				Electric Field (kV/m)		Magnetic Field (mG)	
Right-of-Way	Length (miles)	Field Location	Field Descriptor ¹	Proposed Action	No Action	Proposed Action	No Action
New	67.7	On right-of-way	Average	5.3	—	35	—
			Maximum	8.8		184	
		Edge of right-of-way	Average	2.3		12	
			Maximum	2.3		48	
Existing	6.8	On right-of-way	Average	5.4	2.1	32	31
			Maximum	8.9	3.8	174	135
		Edge of right-of-way	Average	1.1	1.0	9	11
			Maximum	1.1	1.0	32	36
East Option 1 ²				Electric Field (kV/m)		Magnetic Field (mG)	
Right-of-Way	Length (miles)	Field Location	Field Descriptor ¹	Proposed Action	No Action	Proposed Action	No Action
New	17.6	Same as edge of right-of-way values shown above for East Alternative					
Existing	0	On right-of-way	Average	—	—	—	—
			Maximum				
		Edge of right-of-way	Average				
			Maximum				
East Option 2				Electric Field (kV/m)		Magnetic Field (mG)	
Right-of-Way	Length (miles)	Field Location	Field Descriptor ¹	Proposed Action	No Action	Proposed Action	No Action
New	23.5	Same as edge of right-of-way values shown above for East Alternative					
Existing	0	On right-of-way	Average	—	—	—	—
			Maximum				
		Edge of right-of-way	Average				
			Maximum				
East Option 3				Electric Field (kV/m)		Magnetic Field (mG)	
Right-of-Way	Length (miles)	Field Location	Field Descriptor ¹	Proposed Action	No Action	Proposed Action	No Action
New	1.9	Same as edge of right-of-way values shown above for East Alternative					
Existing	1.8	On right-of-way	Average	5.7	2.9	53	48
			Maximum	8.8	5.3	186	133
		Edge of right-of-way	Average	1.2	0.2	6	4
			Maximum	1.4	0.2	27	8
Notes:							
1. All field descriptors are segment- length-weighted means of the fields on or at the edge of the right-of-way. The values for the edge of right-of-way are computed from fields on both sides of the route. Average electric fields are computed for maximum voltages and average clearances along the route; likewise, average magnetic fields are computed for average currents and average clearances. Maximum electric fields are computed for maximum voltages and minimum clearances; maximum magnetic fields are computed for maximum currents and minimum clearances.							
2. The segments in the East options do not replace any existing segments. Using one of these options would not significantly affect average field levels for the alternative.							
Source: Bracken 2011 (see Appendix F).							

8.2.7 Crossover Alternative and Options

The Crossover Alternative and options would require about 55 percent new right-of-way that would mostly cross forest land (about 76 percent). About 8 percent of the land crossed by right-of-way would be populated—1 percent urban/suburban and 7 percent rural areas. About 14 percent of the land beyond the right-of-way (out to 1,000 feet) is zoned for residential use, similar to the Central Alternative. Fewer people would live near or pass by this action alternative than the West Alternative.

Using length-weighted averages, maximum electric fields on the rights-of-way for the Crossover Alternative and options would range from 8.8 to 8.9 kV/m (see Table 8-5), meeting BPA's

criterion of 9 kV/m. The maximum fields for all route segments and line sections within segments would also meet the BPA criterion. Under normal (average) conditions, the highest fields would range from 5.3 to 5.8 kV/m.



At the edge of the right-of-way, using length-weighted averages, electric fields for the Crossover Alternative and options would range from 0.9 to 2.3 kV/m (2.3 kV/m on new right of way) under both extreme (maximum) and normal (average) conditions, meeting BPA's guidelines of 2.5 kV/m. (Maximum and average electric field calculations for individual route segments and line sections within segments can be found in Appendix F.) Like the other action alternatives, these electric field levels would be comparable to or less than those from existing 500-kV lines in the area and elsewhere, with a similar **no-to-low** impact.

Maximum magnetic fields on the rights-of-way for the Crossover Alternative and options, using length-weighted averages, would range from 150 to 276 mG (184 mG on new right-of-way). Under normal (average) conditions, the highest magnetic fields would range from 29 to 68 mG (35 mG on new right-of-way).

At the edge of rights-of-way using length-weighted averages, the maximum magnetic fields for alternatives and options would range from 26 to 52 mG; under normal conditions, the highest fields would range from 7 to 14 mG (see Table 8-5). (Magnetic field calculations under maximum and normal conditions, for individual route segments and line sections within segments, can be found in Appendix F.) Maximum and normal fields would depend on the number of transmission lines present, their relative phasing and direction of power flow. Beyond the edge of rights-of-way, magnetic fields decrease quickly with distance, approaching common ambient levels within a few hundred feet. This means that beyond a few hundred feet, transmission line magnetic fields approach common ambient levels and would be far less than those encountered near common household appliances or directly under the line.

Table 8-5 Crossover Alternative and Options—Length-Weighted Average Electric and Magnetic Field Levels

Crossover Alternative				Electric Field (kV/m)		Magnetic Field (mG)	
Right-of-Way	Length (miles)	Field Location	Field Descriptor ¹	Proposed Action	No Action	Proposed Action	No Action
New	42.7	On right-of-way	Average	5.3	—	35	—
			Maximum	8.8		184	
		Edge of right-of-way	Average	2.3		12	
			Maximum	2.3		48	
Existing	29.7	On right-of-way	Average	5.4	2.0	34	17
			Maximum	8.9	3.7	182	96
		Edge of right-of-way	Average	1.3	0.5	7	3
			Maximum	1.3	0.5	26	12
Crossover Option 1 ²				Electric Field (kV/m)		Magnetic Field (mG)	
Right-of-Way	Length (miles)	Field Location	Field Descriptor ¹	Proposed Action	No Action	Proposed Action	No Action
New	0.7	Same as edge of right-of-way values shown above for Crossover Alternative					
Existing	6.6	On right-of-way	Average	5.5	1.5	29	11
			Maximum	8.8	2.8	150	63
		Edge of right-of-way	Average	0.9	0.3	9	2
			Maximum	0.9	0.3	34	24
Crossover Option 2				Electric Field (kV/m)		Magnetic Field (mG)	
Right-of-Way	Length (miles)	Field Location	Field Descriptor ¹	Proposed Action	No Action	Proposed Action	No Action
New	0	Same as edge of right-of-way values shown above for Crossover Alternative					
Existing	4.1	On right-of-way	Average	5.8	5.5	68	49
			Maximum	8.8	9	270	235
		Edge of right-of-way	Average	1.9	2.1	14	16
			Maximum	2.1	2.1	51	57
Crossover Option 3				Electric Field (kV/m)		Magnetic Field (mG)	
Right-of-Way	Length (miles)	Field Location	Field Descriptor ¹	Proposed Action	No Action	Proposed Action	No Action
New	0	Same as edge of right-of-way values shown above for Crossover Alternative					
Existing	4.2	On right-of-way	Average	5.8	5.5	68	49
			Maximum	8.9	9	276	235
		Edge of right-of-way	Average	2.2	1.6	13	12
			Maximum	2.3	1.7	52	45
Notes:							
1. All field descriptors are segment-length-weighted means of the fields on or at the edge of the right-of-way. The values for the edge of right-of-way are computed from fields on both sides of the route. Average electric fields are computed for maximum voltages and average clearances along the route; likewise, average magnetic fields are computed for average currents and average clearances. Maximum electric fields are computed for maximum voltages and minimum clearances; maximum magnetic fields are computed for maximum currents and minimum clearances.							
2. The segments in the Crossover options do not replace any existing segments. Using one of these options would not significantly affect average field levels for the alternative. However, there would be localized increases in the magnetic fields for Crossover Options 2 and 3.							
Source: Bracken 2011 (see Appendix F).							

8.2.8 Recommended Mitigation Measures

Mitigation measures included as part of the project are identified in Table 3-2. More information on how BPA minimizes EMF levels through project design is provided in Section 8.2.2.5, Designing Lines to Reduce EMF. No additional mitigation measures have been identified at this time.

8.2.9 Unavoidable Impacts

Once built, the proposed line could cause accidental injury from electric shock if someone were to bring conductive material too close to the lines within the right-of-way. Electric fields on the right-of-way also have the potential to create nuisance shocks on the right-of-way. There is a theoretical possibility that electric fields could interfere with older model implanted cardiac pacemakers worn by persons walking (or otherwise not shielded) under the line or within 35 feet from the edge of the right-of-way.

EMF levels directly under the lines and in the rights-of-way could be higher than ambient levels, but would meet all applicable regulations and standards and would dissipate quickly with increasing distance beyond the transmission line right-of-way.

8.2.10 No Action Alternative

Under the No Action Alternative, no new transmission lines or substations would be constructed and the voltage on existing lines would not change. There would be no change in electric fields, shock potential, or radio and TV interference throughout the project area. However, magnetic fields near existing lines would increase as loads on these lines increase. Impacts from maintenance of existing lines and substations would continue unchanged.

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